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World Octopus Fisheries

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World Octopus Fisheries

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ABSTRACT

Recent studies have shown that coastal and shelf cephalopod populations have increased globally over the last six decades. Although cephalopod landings are dominated by the squid fishery, which represents nearly 80% of the worldwide cephalopod catches, octopuses and cuttlefishes represent ∼10% each. Total reported global production of octopuses over the past three decades indicates a relatively steady increase in catch, almost doubling from 179,042 t in 1980 to 355,239 t in 2014. Octopus fisheries are likely to continue to grow in importance and magnitude as many finfish stocks are either fully or over-exploited. More than twenty described octopus species are harvested from some 90 countries worldwide. The current review describes the major octopus fisheries around the globe, providing an overview of species targeted, ecological and biological features of exploited stocks, catches and the key aspects of management.

KEYWORDS

Octopus; fisheries; review; global

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Color versions of one or more of the figures in the article can be found online at www.tandfonline.com/brfs.

1. Introduction

Although there are 845 living species of cephalopod described to date (Hoving et al. 2014), including nautiloids, sepioids, squids and octopods, the latter elicit a vast amount of interest and awe from the general public. Octopuses are often seen as mystical creatures, capable of escapes from captivity that Houdini could only dream of (Wood and Anderson 2004) and, to some, able to predict the winner of some matches in the FIFA World Cup football competition (as mentioned, for example, by Gleadall et al. 2018).

About 300 cephalopod species belong to the eight-armed cephalopods comprising the orders Cirroctopoda and Octopoda (Boletzky 1999; Nixon and Young 2003). The Cirroctopoda (which are not part of the octopus fishery) have fins on the body and pairs of slender cirri along the arms. Octopuses of the Order Octopoda lack these features and consist of seven families of pelagic octopuses in addition to the common benthic octopuses, which are a group of around 200 described species comprising the Family Octopodidae (Jereb et al. 2013). Almost all octopuses fished around the world belong to this family. Exceptions are the giant octopuses of genus *Enteroctopus* (Family Enteroctopodidae); and octopuses with a single column of suckers along each arm, comprising the genus *Eledone* (Family Eledonidae sensu Strugnell et al. 2014). Adult benthic octopuses (Octopodidae, Eledonidae and Enteroctopodidae), the subject of this review, are muscular animals with one or two columns of suckers along their four pairs of arms. In mature males, one arm (called the hectocotylus) of the third arm pair is modified for transferring spermatophores to the female. Subadult and adult benthic octopuses live and feed on or near the seabed. For locomotion, octopuses walk using all or some of their arms in contact with the substrate. Like many other cephalopods, they swim using jet propulsion, by contracting their muscular mantle to force water in the mantle cavity out through a tubular funnel.

Octopuses have a well-developed brain and nervous system which regulate sophisticated behavior and learning, and control elaborate, dynamic skin patterns (Hanlon and Messenger 1996; How et al. 2017). The internal shell is reduced to a pair of small rod-like stylets. These stylets have been used to estimate age by counting their daily growth increments, a technique that has been validated for some coastal species (Doubleday et al. 2006; Hermosilla et al. 2010; Rodríguez-Domínguez et al. 2013). Growth increments in beaks also have been used to estimate age in octopuses (Perales-Raya et al. 2014; Villegas-Bárcenas et al. 2014). The life span of shallow-water octopuses from tropical and subtropical areas is estimated to range between 1 and 2 years (Leporati et al. 2009; Leporati and Hart 2015; Herwig et al. 2012).

Most octopuses are semelparous, spawning only once at the end of their life cycle. Their eggs have only the chorionic membrane protecting the ovum: they lack the additional protective membranes, capsules or jelly masses found in other cephalopod groups (Boletzky 1998). Females take care of the eggs by continuously cleaning and ventilating them and protecting them from potential predators throughout the developmental period, after which the female dies. As with many other groups of marine organisms, depending on the species the life cycle may be either holobenthic, where the full life cycle takes place at the seabed, or merobenthic, where the hatchlings are planktonic until settling later as a benthic juvenile through to adulthood. Examples of holobenthic species include *Octopus maya* (Voss and Solís, 1966), *Eledone moschata* (Lamarck, 1798) and *Amphioctopus fangsiao* (d'Orbigny, 1841). Well-known merobenthic species include *Octopus vulgaris* (Cuvier, 1797), and *Enteroctopus dofleini* (Wülker, 1910). The duration of the pelagic period of merobenthic octopuses is known only for few species and ranges from 3 weeks to 6 months (Villanueva and Norman 2008). This paralarval stage (Young and Harman 1988) has a considerable potential for dispersal, with some merobenthic species reaching much broader distributional ranges in comparison with holobenthic species (Villanueva et al. 2016). Holobenthic species evolved to inhabit in cold waters at deep sea or at polar ecosystems from a merobenthic ancestor (Ibáñez et al. 2014, 2018). After settlement on the seabed, the early benthic life of young octopuses has been studied in the wild for only a few species (e.g., *Octopus bimaculatus* Verrill, 1883, by Ambrose 1988). Octopuses are primarily solitary in habit, with few exceptions (Scheel et al. 2017). Movement and activity patterns in the field have shown that shallower species with crepuscular activity are most active at dawn (e.g., *Octopus cyanea* Gray, 1849; Forsythe and Hanlon 1997), with increasing activity during the night and remaining inside a den during daylight (e.g., *E. dofleini*; Scheel and Bisson 2012).

A recent review described all substantial squid fisheries around the world, showing the main ecological and biological features of exploited stocks, interactions with the environment and their ecosystem-based fishery management (Arkhipkin et al. 2015). The present overview is the second of three such planned reviews, and follows a similar format for octopus fisheries, summarizing present knowledge of the main exploited species and stocks.

2. Octopus fisheries from ancient times to 1900

There is little information about ancient fisheries, and even for the relatively recent 18th and 19th centuries. According to Erlandson and Rick (2010), the earliest marine fisheries activities may date back as far as 160,000 years (documented for the Southern African coast). They argue that ancient communities had a considerable impact upon the ecosystems they were exploiting, periodically reducing the number of individuals by a significant amount. In contrast to documented effects on terrestrially hunted species (especially islands), however, fishing probably did not result in extinctions. Cephalopods were not specifically mentioned, but it is likely that prehistoric local coastal communities exploited littoral octopuses. In Japan, many intact earthenware octopus pots (for both *A. fangsiao* and *Octopus sinensis* d'Orbigny, 1834) from the mid-Yayoi period (100 BC to 100 AD) have been uncovered by archeological excavations, particularly around the Seto Sea; but also near Nagasaki and the Kanmon Straits (between Kyushu and Honshu); Ise Bay (near present-day Nagoya on the southern central Pacific coast of Honshu); and, on the Japan Sea coast, Miyazu Bay (northern Kyoto), Tottori and Matsue (Uchida 2009).

Little or no technical information is available concerning nets used in ancient times, nor about the methods of using them (see Arkhipkin et al. 2015, for a brief prehistorical review). Aristotle (1970 English translation) describes the morphology, anatomy, behavior and parts of the life history of *O. vulgaris* and *Eledone* sp. He did not explicitly mention fisheries but in view of all the details and observations he collated, there are strong grounds to suggest that octopuses were fairly easily accessible alive and in good condition. There is evidence in his writings that he kept close contact with fishers.

The only systematic literary source about cephalopods in ancient Roman literature is that of Pliny the Elder (1940), who merely mentions anecdotes about octopus stealing fish from fish farms. In the 2nd Century (2nd C), Oppianus of Corycus (see Oppian, Colluthus, and Tryphiodorus 1928) wrote a poem about marine fisheries in about 3,500 lines, which reveals some sophistication of ancient octopus fisheries including the following:

> Octopuses love the trees of Athena and have a passion for the grey-green foliage. It is a great marvel that they should be drawn by desire for a tree and delight in the branches of the oily plant. For wherever there is an olive of splendid fruit, which flourishes on a shoreward slope neighbouring the sea, the octopus joyfully embraces the sleek branches of the olive and seems to kiss them. But he crawls back again to the bosom of the sea, having satisfied his love and longing for the olive. The snare of this same love is his undoing, as fishermen know. For they bind together branches of the olive around a piece of lead and tow the bundle from the boat. The octopus rushes to embrace his branchy comrades and not even when he is being hauled to capture does he relax the bonds of desire, till he is within the boat, nor even while he perishes does he hate the olive.

Judging from the present-day artisanal fisheries in the Mediterranean (similar to the descriptions by Oppianus) and present day artisanal fisheries in the Far East, methods and experiences are similar. After the written records mentioned earlier, there is a gap of more than a thousand years before the next publications appear (Farrugio et al. 1993). Most important are those of Conrad Gesner (1551–1558), Guillaume Rondelet (1556), and Ulysse Aldrovandi (1606). All of them relied heavily on Aristotle (1991), and included very scant mentions of fisheries of cephalopods. Modern zoology, life history and mentions of fisheries start with Lamarck (1815–1822) and Cuvier (1817), being later continued by Verrill (1879–1882) and Tryon (1879). There are some records of cephalopod fisheries in Japan (Hitomi 1697; Terajima 1713; Anonymous 1799). Hitomi (1697) mentions fishing for octopus using nets for larger species; a small wooden structure to which are tied a cuttlebone or fish bone on one side and a hook on the other; and small octopus pots strung together for catching *A. fangsiao*. Terajima (1713; see translation by Gleadall and Naggs 1991) discusses "tako" (*O. sinensis*, and possibly also *E. dofleini*), noting the use of octopus pots tied together with line; and "iidako" (*A. fangsiao*), fished by tying together a line of empty gastropod shells (see also Anonymous 1799). All these accounts, however, right up to the beginning of the 20th C, lack details such as catch and/or landing statistics. In all countries of the world during the 19th C, fishery statistics concerning octopods were collected in a descriptive anecdotal form, or not collected at all.

3. Octopus stock exploitation

Most octopus species supporting fisheries are shallow-water species, distributed mainly on littoral reefs and

Table 1. Capture production (tonnes) of the major octopus fisheries reported by FAO (2016) from years 2005 to 2014.

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Eledone cirrhosa	339	253	572	175	187	270	152	136	855	593
Eledone sp. (*E. cirrhosa* + *E. moschata*)	8,293	8,139	9,632	7,704	8,331	7,027	6,233	5,137	5,739	6,296
Octopus maya	3,166	7,675	6,928	2,396	6,879	5,713	9,339	12,629	8,806	15,403
Octopus vulgaris[1]	34,684	43,773	34,307	33,598	40,706	41,593	40,340	40,722	42,184	43,334
Octopodidae	259,369	305,357	324,886	318,372	317,743	294,465	289,561	281,902	302,826	289,613
Total octopus	305,851	365,197	376,325	362,245	373,846	349,068	345,625	340,526	360,410	355,239
Octopus vs total cephalopod landings (%)	9	10	9	9	12	11	10	10	10	8
Total sepioid	371,353	381,574	363,420	287,772	313,380	299,894	305,982	319,524	316,331	313,877
Sepioid vs total cephalopod landings (%)	11	10	9	7	10	9	9	9	9	7
Total squid	2,744,838	3,069,167	3,231,768	3,263,230	2,428,951	2,589,118	2,725,163	2,904,677	2,925,559	3,659,078
Squid vs total cephalopod landings (%)	80	80	81	83	78	80	81	81	81	85
Total cephalopod landings	3,818,280	4,154,934	4,318,643	4,261,647	3,473,039	3,633,589	3,778,386	4,020,408	4,043,068	4,779,091

Total sepioid, squid and octopus production is also indicated and their respective percentage contribution to total cephalopod production.
[1]Statistics for "*Octopus vulgaris*" include several species in addition to *O. vulgaris* sensu stricto (Amor et al. 2017; Gleadall 2016a).

shelf areas. Few commercial species are collected deeper than 200 m: *Eledone cirrhosa* (Lamarck, 1798) is fished by trawlers usually from 50 to 300 m (Belcari et al. 2015); "*Octopus*" *conispadiceus* (Sasaki, 1917) to 530 m (Golenkevich 1998); *E. dofleini* is collected by pots down to 390 m in the NE Pacific (Barry et al. 2010), and in traps to 300 m in the NW Pacific (Golenkevich 1998); and *Enteroctopus magnificus* (Villanueva et al. 1991) is taken as a bycatch by bottom trawlers fishing down to 550 m (Villanueva 1993).

Recent studies have shown that coastal and shelf cephalopod populations have increased globally over the last six decades, a phenomenon probably partly driven by large-scale oceanic processes associated with the adaptive plasticity of this group of mollusks (Rodhouse et al. 2014; Doubleday et al. 2016), and partly due to a reduction in predator populations due to overfishing (Pauly et al. 1998). The latest world cephalopod landings reported were the highest for the 2005–2014 decade, reaching 4.8 million t in 2014 (FAO 2016). These landings are dominated by the squid fishery, which represents nearly 80% of the worldwide cephalopod catches, whereas octopuses and cuttlefishes represent only 10% each (Table 1). Octopod catches in many cases, however, represent under-quantified landings (see the Eastern Atlantic chapter here).

Total reported global production of octopuses over the past three decades indicates a relatively steady increase in catch, almost doubling from 179,042 t in 1980 to 355,239 t in 2014 (FAO 2016). Annual octopus capture production for the decade 2005–2014 published by FAO (2016) is given in Table 1. During this period, octopus captures represented 8–12% of the total cephalopod catch, a volume similar to sepioid captures (7–11%), with squid captures representing most (78–85%) of the total cephalopod catch worldwide. It is now certain, however, that octopus fisheries, especially in the African countries of the eastern Atlantic coast, have been under-reported on a massive scale (Belhabib et al. 2012).

3.1. Fishing methods

Cephalopod fishing methods have been described in detail by Boyle and Rodhouse (2005); the following sections briefly describe methods unique to octopus fishing, and gear taking octopus as bycatch.

3.1.1. Bottom trawling

Bottom-trawl gear for octopus consists of a large-mesh net dragged by cables from a vessel, essentially the same as that used for finfish. The horizontal spread of the net over the sea bottom is provided by two bottom or universal trawl doors (also known as otter boards), which settle the net on the substrate. The size of the bottom trawl net depends on the power of the vessel. Species of octopus fished by bottom trawlers are usually distributed on the continental shelf. The species *O. vulgaris* found on the Saharan Bank, NW Africa, supports one of the most important worldwide octopus bottom trawl fisheries (Balguerías et al. 2000). Examples of other octopus species mostly fished by trawlers are *E. cirrhosa* (Regueira et al. 2014) and *E. moschata* (Silva et al. 2011) in the NE Atlantic, and *Amphioctopus* spp. in the Gulf of Thailand (Chotiyaputta et al. 2002). Usually, the octopuses are a bycatch of target finfish species captured by trawlers or are part of a multispecies fishery (Quetglas et al. 1998; Noro 2013).

Table 2. Fishing methods for octopus in Japanese waters (based on Noro 2013, modified and translated by KN and IGG)

Method (Japanese name)	Method (English translation)	Depth[1]	Targeted or bycatch	Ship size*	Area	Notes
kagi-dori	angling	1–10 m	octopus-targeting	about 1 t	All areas in northern Japan	With or without a commercial fishing boat
haenawa or kara-tsuri nawa	longline (unbaited)	10–80 m	octopus-targeting	<5 t	All areas in northern Japan	—
tako-bako	octopus box (unbaited)	10–30 m	octopus-targeting	<5 t	All areas in northern Japan	—
tako-kago	octopus basket (baited)	10–50 m	octopus-targeting	<5 t	All areas in northern Japan	—
isari-biki	towed rake	10–30 m	octopus-targeting	<5 t	All areas in northern Japan	—
tako-tsubo	octopus pot (unbaited)	3–20 m	octopus-targeting	<5 t	Most of honshu, Pacific side	Mainly Kyushu & Seto Sea
tako-tsubo (with lid)	octopus pot (baited)	3–20 m	octopus-targeting	<5 t	Tokyo Bay	Crab as bait. Lid shuts when octopus enters
taru-nagashi	floating-barrel drift lines	20–100 m	octopus-targeting	<5 t	Hokkaido to Tsugaru Straits	—
sashi-ami	gill net	10–100 m	bycatch	<5 t	All areas	—
teichi-ami	fixed net	10–30 m	bycatch	5–20 t	All areas	—
sokotate-ami	bottom set-net	10–60 m	bycatch	5–10 t	Coast of Aomori Pref. only	—
kogata sokobiki-ami	small bottom trawl	60–200 m	bycatch	<15 t	Pacific coasts	—
okiai sokobiki-ami	offshore bottom trawl	100–500 m	bycatch	>15 t	Northern regions	Mostly for "*O.*" *conispadiceus*

[1]Depth data are for Aomori Pref. only.
*Gross tonnage.

This fishing method is well known to have a very negative impact on the seabed. The trawl doors, cables and net severely plow the sea bottom and cause large-scale damage to the benthic shelf (Collie et al. 2000) and slope (Clark et al. 2016) communities. As a result of the turbulence generated by the trawl, mud and sand from the bottom enter the octopus mantle and cover the gills, which may acquire an obscure color. In addition, the bottom trawl is a nonselective gear, thus, many species are collected at the same time. The impact of trawling, discards and processing of the frozen *O. vulgaris* fished in NW Africa has been discussed by Vázquez-Rowe et al. (2012).

3.1.2. Net-caught bycatch: trammel nets, gill nets, fixed nets, bottom set-nets

In addition to trawl nets, octopuses are also fished in shallow water areas as bycatch (always in minor numbers) when trammel nets are used (Tsangridis et al. 2002). This is a stationary net with three layers of netting to usually entangle demersal fishes and crustaceans, kept vertical by floats on the headrope and weights on the footrope (FAO 2001). All around Japan, octopuses are caught as bycatch of gill nets, fixed nets, and bottom set-nets (Table 2; Noro 2013).

3.1.3. Fyke nets

This net consists of cylindrical and/or cone-shaped netting bags or chambers, mounted on rings or other rigid structures and fixed to the seabed by anchors in shallow waters. In some fishing ports of the Eastern Mediterranean, fyke nets of two or three chambers are used for catching almost exclusively *O. vulgaris*, representing 30% of the total octopus production (Tsangridis et al. 2002).

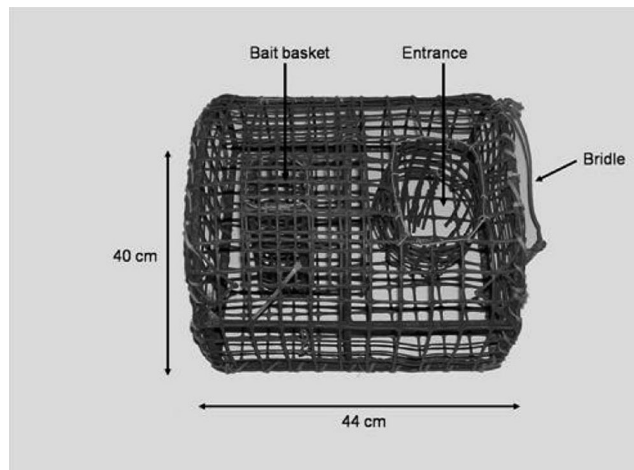

Figure 1. Typical *Octopus vulgaris* trap made from an iron frame and plastic square mesh with a size of 4 cm, and a single entrance on the top. From Erzini et al. (2008).

3.1.4. Fishing traps

Octopus fishing traps are framed traps with a single entrance partially blocked usually by plastic strips, easy to push in by an octopus but not back out (Figure 1). These traps are of different sizes and usually are baited inside with fish. Traps can be made with different local available materials, usually with a framework of wire (Hernández-García et al. 1998) and plastic mesh (Bañón et al. 2006; Bañón 2008) (Figures 2 and 3). A variant used in Japan has elastic-powered doors, closing when the octopus detaches a live crab inside the trap, preventing the octopus from escaping (Slack-Smith 2001). This kind of trap has been used also in the NE Atlantic (Carreira and Gonçalves 2009); and a kind of trigger-trap baited with a bright-orange rubber crab illuminated with a led light is

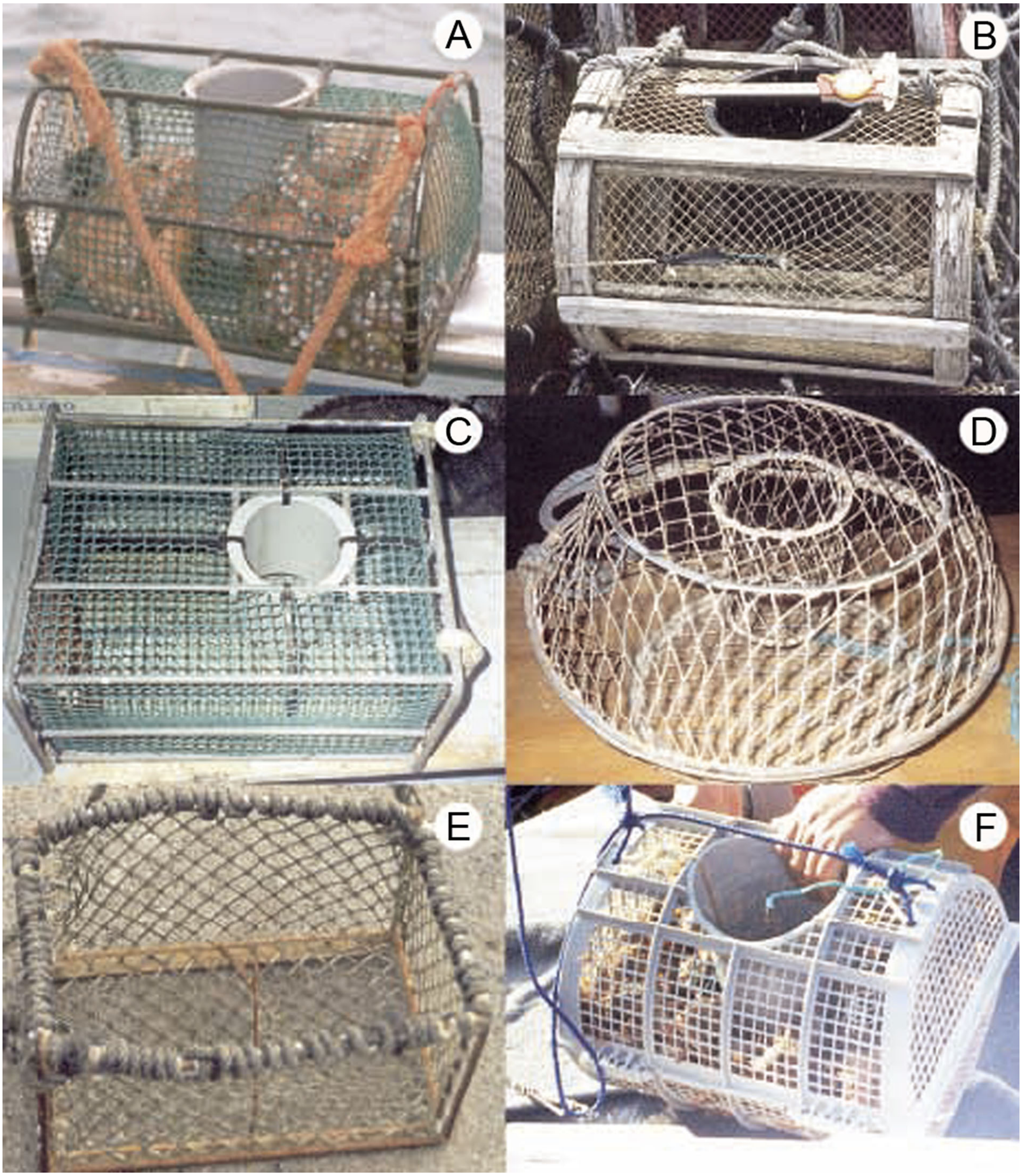

Figure 2. Types of *Octopus vulgaris* traps used in Galicia, NE Atlantic, made with different structures and materials. (A) Hemicylindrical, iron; (B) cylindrical, wood; (C) prismatic, iron; (D) toroidal, iron; (E) open, iron; and (F) cylindrical, plastic. From Bañón et al. (2006).

used for fishing *Octopus* aff. *tetricus* (Gould, 1852) (Hart el al. 2016).

Examples of octopus species fished using traps are "*Octopus*" *minor* (Sasaki 1920) in the NW Pacific (Kim et al. 2008), *O. vulgaris* in the NE Atlantic (Hernández-García et al. 1998; Bañón et al. 2006, 2018; Sonderblohm et al. 2017) (Figure 4) and several species of octopuses in the NW Pacific (Takeda 1990; Noro 2013), including *E. dofleini*. Some octopuses are fished as bycatch of other trap fisheries, as with *E. dofleini* in the Alaska cod pot (trap) fishery (Conrath and Sisson 2018).

Octopus traps usually belong to the artisanal fleet and local fishing communities, have relatively low impact on the environment and seabed (Baeta et al. 2005) and can be considered a fuel-efficient capture

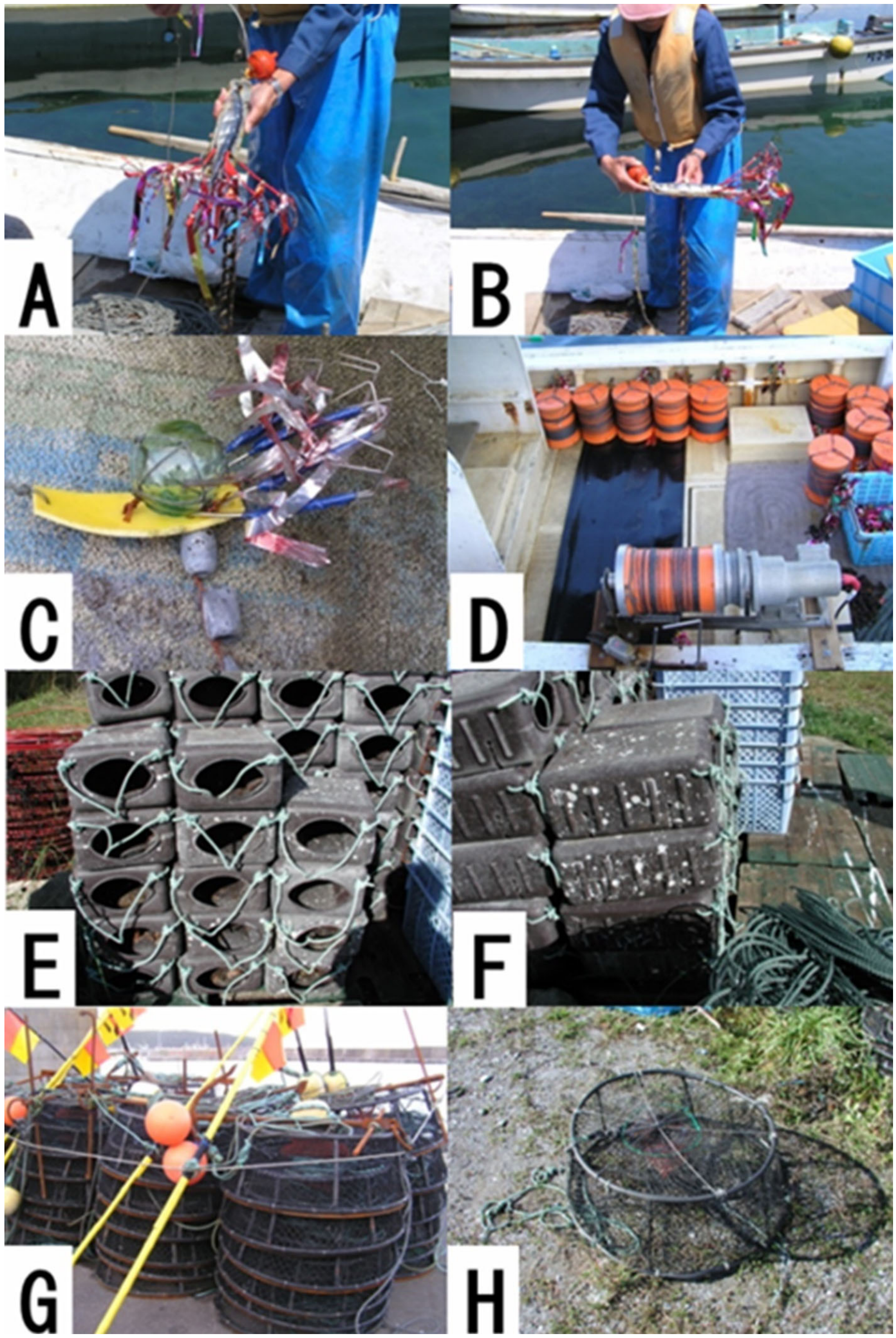

Figure 3. Japanese fishing gear for Octopus: Commercial gear used in Aomori and Hokkaido. (A–B) drag-line; (C–D) floating-barrel drift line (C: lure; D: stowed lure-barrel-line units); (E–F) octopus boxes; (G–H) octopus baskets. (Images: KN).

technique, the adoption of which can contribute towards more economical and sustainable fishery (Suuronen et al. 2012; Rangel et al. 2018). When traps are lost during fishing activities, however, the captured animal becomes the lure for the next; catching and killing multiple animals in an effect known as ghost-fishing, and reported also for octopus fishing traps (Erzini et al. 2008). Fishing traps used for "*O.*" *minor* made from biodegradable polymers may reduce ghost-fishing (Kim et al. 2014).

3.1.5. Towed rakes

In northern Japan, rakes (Figure 3A, B; Table 2) are towed at slow speeds to catch mostly *E. dofleini* (Noro 2013).

3.1.6. Floating-barrel drift-lines

Another octopus-targeting method common in northern Japan is the floating-barrel drift-line (Figure 3C, D; Table 2), where a line attaches an unbaited lure to a small barrel-shaped float, a number of which are

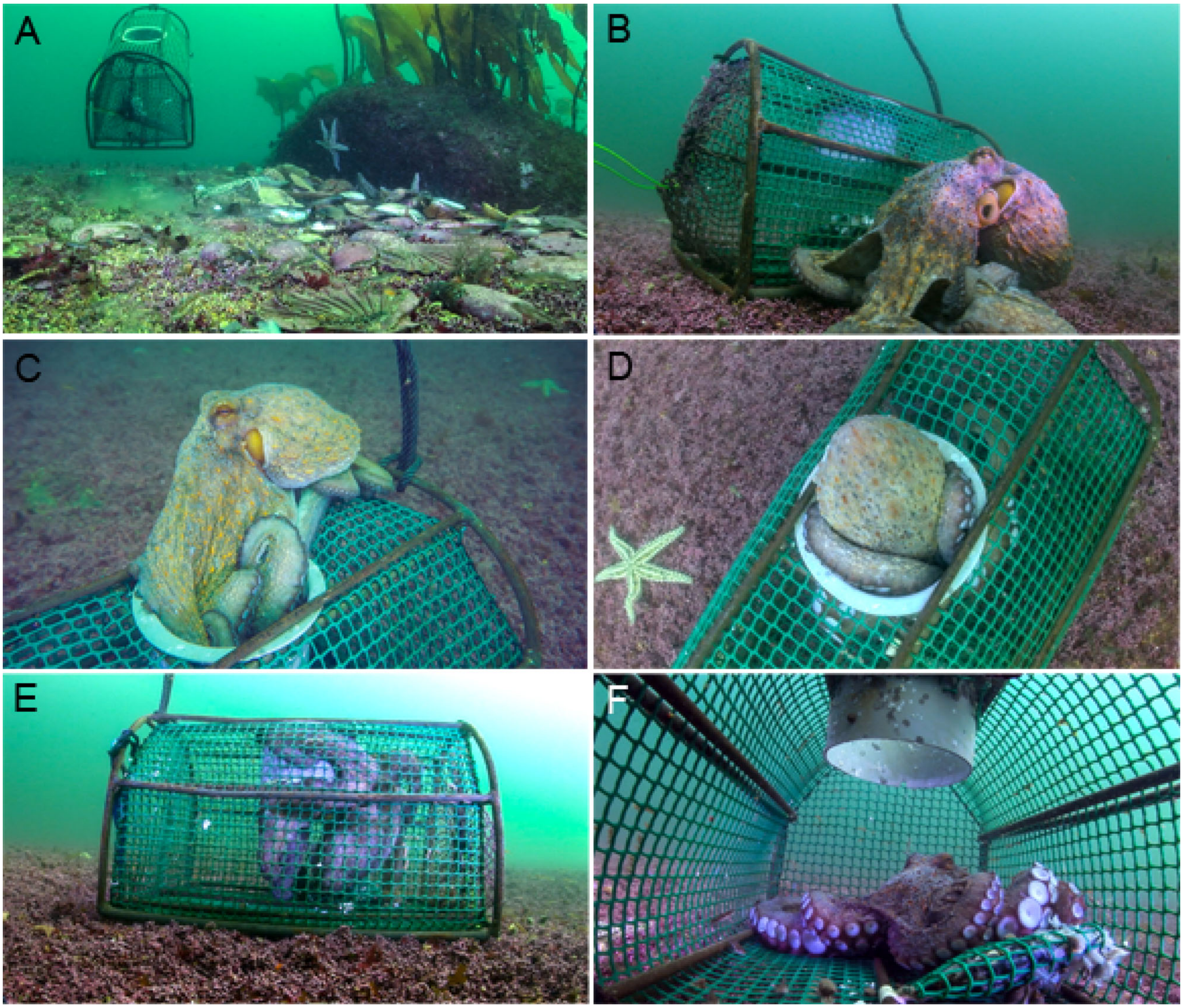

Figure 4. Octopus trap fishery for *Octopus vulgaris* on the Arousa Estuary, NE Atlantic. Images are obtained from a video recorded at around 12:00 and 8 m depth during April 2014. (A) The baited octopus trap is laid on the sea bottom, (B) the octopus detects the bait and approach to the trap, (C–D) enters the trap, (E) consumes the bait and then (F) remains trapped inside. Frames from the documentary "Esencia de las mareas," reproduced with permission of the copyright owner (©FRINSA/J.J.Candán Producciones).

then allowed to drift for several hours. This method is used for "*O.*" *conispadiceus* and *E. dofleini*.

3.1.7. Pots

This fishing gear is a device used specifically for the octopus fishery. The appeal of the pot is based on the fact that octopuses use it as a refuge in sandy/muddy bottoms where there are few natural rocky or hard shelters. The basic gear consists of a vase-like pot constructed of ceramic, wood or plastic material. PVC tubes and old tyres are, however, also used. Its design depends on the local custom and availability of materials (Figure 3 and Figures 5–8). Pots are a passive capture gear. No bait or lure is used as attractant and no net is used to retain the octopus inside, so, animals are able to freely enter and exit the pot (Figure 6).

The pots are rigged to long lines containing from 50–70 (Sobrino et al. 2011) to approximately 500 pots per line (Hart et al. 2016). The maximum number of pots per vessel is limited in accordance with the local fishing regulations, as 1,000 units (Sobrino et al. 2011) or more (Figure 7). The fishery lines are checked every 2–5 days (Sobrino et al. 2011), usually during daytime hours using small to medium size vessels. Fishing depths are usually very shallow waters (5 to 40 m), although pots for some species are set as deep as 85 m (Leporati et al. 2009).

This fishing method is highly recommended. Octopus pots are size-selective and exclusive to

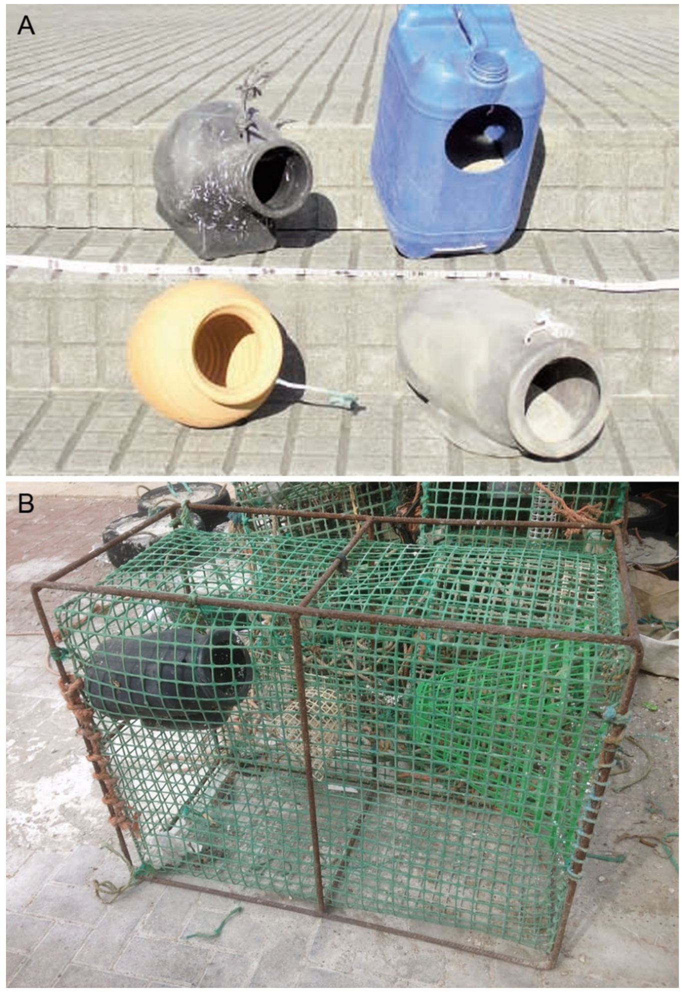

Figure 5. Pots used for octopus fishing. (A) Octopus pots of different shapes and materials used in Galicia, NE Atlantic, to fish *Octopus vulgaris* (from Bañón et al. 2006). (B) Octopus trap made with iron frame and plastic mesh, with a plastic pot inside, used for fishing *Octopus vulgaris* in Cascais, Portugal (image from R. Villanueva).

Figure 6. *Octopus vulgaris* inside a ceramic pot on sandy bottom, Western Mediterranean. From Sánchez and Obarti (1993).

octopus (no bycatch). Usually, juveniles do not enter them because of their relatively large size, targeting mostly subadult and adult individuals. There is little or no physical impact of the pots on the seabed and it is a fuel-efficient capture technique. Ghost-fishing mortality does not occur (cf. with basket traps or trammel nets) as octopuses can enter and leave the pot freely. For these reasons, octopus pot fishing is a low-impact, environmentally-friendly fishery. Lost plastic pots may, however, contribute to substantial plastic pollution: of the total marine debris collected in the *O. vulgaris* fishing area off Morocco, 50% of items were made of plastic, and 94% of these were plastic from lost plastic octopus pots (Loulad et al. 2017).

To avoid mature females spawning inside the pots, with the subsequent destruction of the egg mass at harvesting, the egg string length of the species should

Figure 7. Plastic pots stored on the port of Santa Pola, Spain, Western Mediterranean, for *Octopus vulgaris* fishing (image from F.A. Fernández-Álvarez).

be considered. An internal pot diameter equal to or less than the mean egg string length of the species will discourage most females from using the pot as a refuge to spawn because of the lack of space to properly attach, handle and ventilate the egg mass inside the pot. Females will therefore select instead another wider, natural, suitable refuge to spawn, and are thereby excluded from the fishery.

Pot fishing is also highly recommended for collecting living octopuses for laboratory experimentation. Octopuses collected by pots have very few or no skin abrasions, exhibit less post-capture stress and have higher survival rates in captivity in comparison with other fishing methods such as bottom trawling, where high post-capture mortality is observed.

Octopus species fished by pots are *O. vulgaris* in the Mediterranean (Sánchez and Obarti 1993), NE Atlantic (Jouffre et al. 2002; Sobrino et al. 2011; Sonderblohm et al. 2017), Eastern Atlantic (Ávila-Da-Silva et al. 2014) and South Africa (Oosthuizen 2004); *Octopus insularis* (Leite and Haimovici, 2008) in the SE Atlantic (Haimovici et al. 2014); *Octopus pallidus* (Hoyle, 1885) in Tasmania (Leporati et al. 2009); *O. sinensis*, and *A. fangsiao* in Japan (Gleadall and Noro, pers. obs.); *O.* aff. *tetricus* in Western Australia (Leporati et al. 2015); "*O.*" *minor* in Korea (Kim et al. 2015); and *E. dofleini* in Alaska (Barry et al. 2010).

3.1.8. Fishing lines

Fishing lines with one or several hooks at the end and using different kinds of bait near the hook are used by jigging the line at the shore or from small vessels in shallow water. Markaida et al. (2015) reviewed and illustrated different models of hooks used for diverse octopus species. A variety of baits are used, such as live or dead crabs, bivalve shells, colored stones, white plastic bags or rubber imitation prey. The different kinds of bait and tackle are known by many local community names. A drift fishing line is used in coastal waters of Hokkaido (Japan) for the fishery of *E. dofleini* (Taka and Wada 2018) and a particular system of multiple fishing lines from a vessel is the *al*

Figure 8. Upper two figures: Commercial pots used in Shikoku for *Octopus sinensis*. These are a modification of traditional earthenware octopus pots, made from a sturdy plastic material with a side extension to form a flattened side, which has a heavy concrete filling to ensure the pots lie stably on the seabed with the opening horizontal. Middle two figures: Left, commercial earthenware octopus pots as used commonly in Western Kyushu (note the circular opening visible at the "closed" end of the pot standing on the left; the pot on the right is lying in the normal horizontal position used for catching octopus); Right, flat reel of sturdy twine with lure attached (used mostly for recreational fishing). Lower figures: Octopus lures for recreational rod-and-line fishing. (A) Lures typically used for *Amphioctopus fangsiao*; (B) lure for small octopus species; (C–D) lures typically used for *O. sinensis*. At right are lateral views of A and B. The scarlet attachments in A, C and D are painted lead weights to which the line is attached. With the lure resting on the seabed, or being dragged by a slowly drifting boat, the weight is periodically lifted and dropped, an action which is said to attract an attack by an octopus. The dominant pink and red hues belie Japanese fishermen's belief that octopuses are attracted to these hues. Scale bars 20 mm. (Images: IGG).

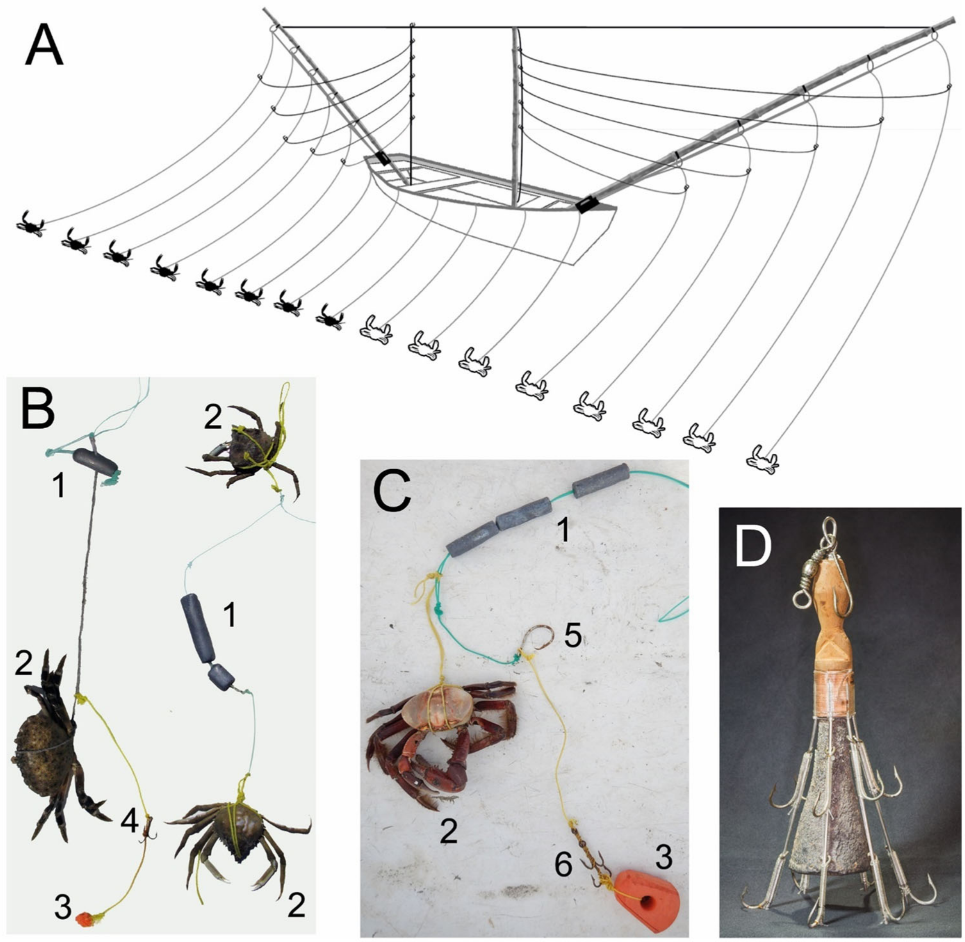

Figure 9. A) Simplified model of an open boat showing fishing lines for *Octopus maya* (modified from Markaida et al., 2019). (B) Two terminal tackles of the fishing gear for *Octopus maya* in Campeche showing (1) sinkers, (2) bait, (3) float and (4) treble hook (modified from Markaida et al., 2019). (C) Terminal tackle for octopus in the major fleet: (1–3) as before, (5) hook to hold bait fish for *O. vulgaris* and (6) jig. (D) Octopus jig called *pata 'e gallina* from Margarita Island, Venezuela (Courtesy of Juan Carlos Mendialdúa).

garete fishing style, using fresh crabs to attract *O. maya* (Markaida et al. 2015; Figures 9 and 10). This style of fishing consists of the use of three small boats: a larger one of 5–8 m in length equipped with an outboard motor, carrying in its interior one or two smaller *alijos*, each of 2.5 m length. Once at the fishing location, the three vessels are manned separately by taking advantage of marine currents and the wind using a small sail called *garete* (Markaida et al. 2015).

3.1.9. Fishing by hand

Fishermen operate on foot, by snorkeling or from small boats, predominantly around the low tide period using harpoons, iron rods, hooks, spears and a variety of sharp pointed instruments to capture octopuses. Examples of octopus species fished by these methods are *O. cyanea* in the SW Indian Ocean (Guard and Mgaya 2002; Nair et al. 2018; Sauer et al. 2011); *Octopus hubbsorum* (Berry, 1953) in the NE Pacific (Alejo-Plata et al. 2009); *O. insularis* in the SE Atlantic (Haimovici et al. 2014), *O. maya* (Markaida et al. 2015) in the Western Central Atlantic; *Octopus mimus* (Gould, 1852) in the SE Pacific (Rocha and Vega 2003); *Callistoctopus nocturnus* (Norman and Sweeney 1997) (*Octopus nocturnus*) in the SW Pacific (Norman and Sweeney 1997); and *Octopus tehuelchus* (d'Orbigny, 1834) in the SE Atlantic (Navarte et al. 2006). Some fishermen flush octopuses from their den using one of a variety of irritants such as certain plant saps (Norman and Sweeney 1997), copper sulfate crystals (Herwig et al. 2012), or chlorine bleach (Wright and Esmonde 2001; Haimovici et al. 2014). In Canada, the use of irritants for the extraction and fishing of *E. dofleini* is regulated, because of their harmful effects on the environment, so it is recommended that chlorine bleach be replaced with hydrogen peroxide (H_2O_2) as an irritant less harmful to the

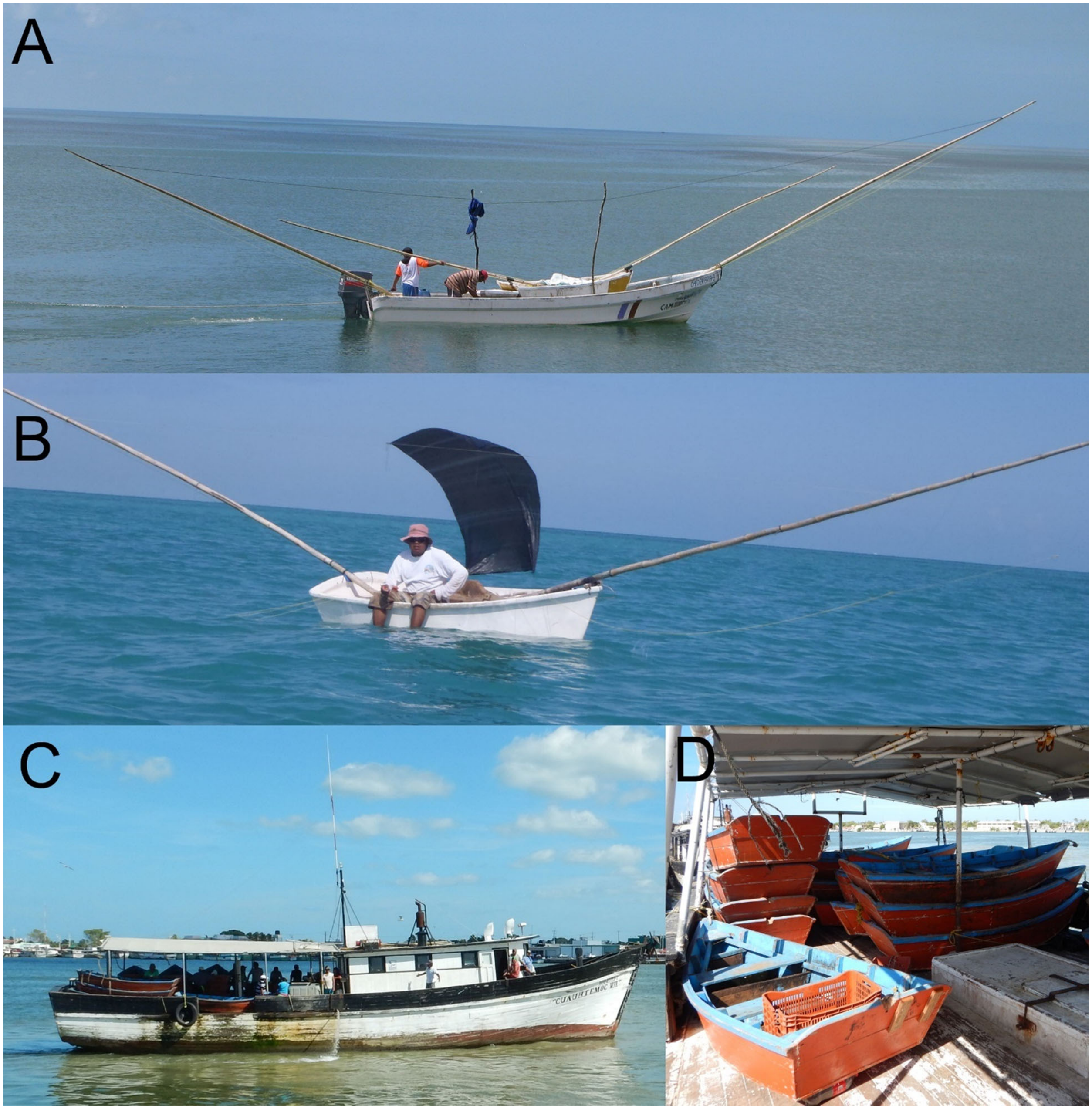

Figure 10. *Al garete* fishing style used for the *Octopus maya* fishery. (A) A motor boat with fishing lines carrying inside a small boat called "alijo." (B) The "alijo" with the small sail called "garete" extended, used to drift downwind. (C) A vessel from the large fleet equipped for fishing octopus. (D) Dories (alijos) piled up in the stern of a vessel. From Markaida et al. (2015).

environment (Wright and Esmonde 2001; Fisheries and Oceans Canada 2011–2012).

A particular method of fishing known as hookah diving requires the fisherman to breathe using an air supply hose from a compressor placed on the deck of the vessel. It is widespread in the eastern Pacific for *O. mimus* and *O. hubbsorum* from Mexico, Ecuador, Peru and Chile (Defeo and Castilla 1998; Armendáriz-Villegas et al. 2014; Markaida et al. 2018). Fisheries devoted to ornamental octopus species for the aquarium trade also use hand fishing. Examples of octopus species collected for the global aquarium market are *Wunderpus photogenicus* (Hochberg, Norman and Finn 2006) (Hochberg et al. 2006) from the Central West Pacific, the Blue-ringed octopus *Hapalochlaena lunulata* (Quoy and Gaimard, 1832) from the Southern West Pacific (Williams et al. 2011) and the undescribed Larger Pacific Striped Octopus (Caldwell et al. 2015) from the Central East Pacific.

3.1.10. Recreational octopus fisheries

In many countries, recreational fishermen catch octopuses by different methods, which mainly depend on the particular octopus species or the traditions of the

Figure 11. Recreational fishing. (A) Two hook designs and a baited stick (with sardine and squid) used for recreational *Octopus vulgaris* fishing in the intertidal zone during low tides in northern Spain, NE Atlantic. (B) Fisherman trying to attract an octopus placing the lure under a rock. (C) After the lure is grabbed by the octopus, it is caught with the hook. (Images from F.A. Fernández-Álvarez).

area. The bathymetric range of coastal octopuses makes them suitable for fishing from the shore, from a boat or by scuba diving (Morales-Nin et al. 2005; Venturini et al. 2017). From both the shore and boats, octopuses are fished by a hand line or a fishing rod using octopus jigs, which might be baited (Bañón et al. 2006), unbaited (Bañón 2014) or with an artificial vinyl crab attached (Figure 8; Noro 2013; Markaida et al. 2015). Frequently used baits include sardine, crabs, and chicken legs (Bañón et al. 2006; Markaida et al. 2015). In Japan, some species of octopus are fished using an irritant such as ash, salt or strong saline solution; and in Thailand the fluids ejected by living sea cucumbers in response to handling are used to entice octopuses from their lair at low tide on beaches of coral rubble (Gleadall, pers. obs.).

The most primitive artificial bait designs are white rocks, gastropod shells or even wheat spikes (Chenaut 1985; Solís-Ramírez 1998; Bañón 2014). Some of these fishing methods were used for commercial or subsistence fisheries in the past (Biagi 1997; Bañón 2014; Markaida et al. 2015). Now, other than for a few small fisheries, these devices are used only for recreational fishing (Pierce et al. 2010). In some countries, octopuses are fished regularly off reefs by recreational fishermen for use as bait for other kinds of sea organisms such as fishes or crabs (Herwig et al. 2012).

In some areas, octopuses are fished from the shore by hand, with spears or hooks (Bañón 2014). In Northern Spain, a traditional fishing method combines a baited stick and a hook mounted at the end of a stick and is used in the intertidal zone at low tide. Farmers living close to the seashore traditionally fished octopus this way in the intertidal zone, to supplement their diet with proteins (Manterola-Izpizua et al. 2012). Usually, these sticks measure ~1.5 m and are baited with fish (commonly sardine or anchovy) and/or squid flesh. The baited stick is placed inside the octopus den and the fisherman waits until it grasps the lure. Then, the octopus is slowly taken outside its den with the baited stick and extracted with the hook (Figure 11). One of the few invertebrates fished by scuba spear fishermen is the octopus, sometimes representing a high percentage of spear captures (Morales-Nin et al. 2005).

Figure 12. Drying *Octopus vulgaris* in the port of Santa Pola, Western Mediterranean (image from F.A. Fernández-Álvarez).

The use of octopus traps is forbidden to recreational fishermen in many countries and reserved for professionals. Recently, however, the Fisheries Department of Western Australia has opened a trigger trap trial and allows recreational fishermen to use up to six of these devices (Fish Resources Management Act 1994 Section 7(2) (a) Exemption Number 2927).

3.2. Processing

Since the arrival of modern refrigerator and transport systems in the last part of the 20th C, many octopuses from small traditional fisheries are sold fresh both locally or in inland territories, especially for domestic markets. This type of product is usually sold without any further processing except cleaning. Before the widespread use of refrigerators, in some European countries the major fraction of the product was dried for storage and exportation to inland territories (e.g., Bañón et al. 2006; Manterola-Izpizua, et al. 2012). As a product of this prolonged tradition, in some areas the tradition of drying octopuses and/or the ovaries for local consumption still persists (Figure 12). Drying of octopuses is still widely practised in Japan, particularly Kyushu and SW Honshu (Gleadall, pers. obs.).

Much of the modern octopus catch is sold frozen, usually whole or with the arms separated from the head and body. After frozen storage, lipid composition seems more affected than protein degradation. Effects of frozen storage at $-18\,^{\circ}$C on *O. maya* showed no remarkable protein denaturation at the third month of storage and 20% at the firth month, and polyunsaturated fatty acids decreased 6% and 9% at the third and fifth month, respectively (Gullian-Klanian et al. 2017). Recently, some concerns have been raised about the dubious practice by some producers of soaking octopus (*O. vulgaris,* "*O.*" *minor*) in fresh water before freezing to increase their weight (Mendes et al. 2017a, 2017b, 2018; Lee et al. 2019).

Cooked octopus has a very firm, tough texture, due to the content, structure and stability of octopus collagen (Morales et al. 2000). Traditionally, before cooking and selling, octopus meat was tenderized by repeatedly beating the octopus against hard surfaces, or with wood or metal sticks, but also prolonged heating in boiling water has been applied. These tenderizing procedures have been abandoned with the popularization of freezers, since a freeze-thaw cycle has an equivalent effect (Gleadall et al. 2010; Mendes et al. 2017a). Such methods were always too time-consuming and energy-demanding for the canning industry, which developed alternative systems such as the addition of small amounts of acid (e.g., vinegar) during the boiling process (Katsanidis 2006; Katsanidis and Agrafioti 2009). Tumbling has been also found to be an effective method for tenderizing octopus before cooking (Gokoglu et al. 2017). Some food treatments such as high hydrostatic pressure inactivates microorganisms and enzymes, improving quality during storage and distribution. When used with octopus, pressure reduces the proteolysis of myofibrillar proteins, which implies that this technology may be effective in controlling the softening of octopus muscle (Hurtado et al. 2002).

Critical control points (Cato 1998) during octopus processing have been identified to ensure quality of the final product, from catching, chilled and frozen storage, packaging, labeling, controlled thawing, splitting, gutting and washing according to the International Organization for Standardization (ISO) series of standards (Arvanitoyannis and Varzakas 2009a, 2009b). In recent years, interest in biologically active substances in cephalopods has increased (Besednova et al. 2017). In particular, Karthigayan et al. (2006) have successfully extracted promising anticancer drugs from posterior salivary gland extracts of *Amphioctopus aegina* (Gray, 1849). The properties of octopus ink have been tested successfully for antimicrobial and potential anticancer, antiulcerogenic and antioxidant activities (Mohanraju et al. 2013; Derby 2014).

3.3. Climatic change and octopus fisheries

3.3.1. Warming

Climate change, a function of anthropogenic greenhouse gas emissions, is altering the physical and chemical properties of the ocean. Approximately 90% of the additional heat trapped in the atmosphere by anthropogenic gas emissions has been absorbed by the oceans (IPCC 2013). This has led to a 1°C increase in mean global sea surface temperature (SST) since the beginning of the twentieth century, and by 2100, in a "business-as-usual" scenario, global SST is expected to rise by another 4.8°C (IPCC 2013). Marine organisms can respond by adapting to the new conditions within their existing distributional range or by moving their ecological niches through space (distribution shifts) and/or time (phenological shifts) (Beaugrand et al. 2002; Parmesan and Yohe 2003; Perry et al. 2005; Bates et al. 2013; Pinsky et al. 2013; Poloczanska et al. 2013; Lenoir and Svenning 2015; Molinos et al. 2015; Poloczanska et al. 2016; Pecl et al. 2017).

Regarding octopod populations, there are already cases of poleward shifts in species' distributions associated with climate forcing, namely *Octopus hubbsorum* off the Pacific coast of Mexico (Domínguez-Contreras et al. 2013) and *Octopus tetricus* (Gould, 1852) off South-Eastern Australia (Ramos et al. 2014, 2015, 2018). The latter studies showed that even at the extended zone (Tasmanian waters) of its common distribution, *O. tetricus* displays fast growth rates and short life span, i.e., 11 months, which allows a high rate of population turnover (Ramos et al. 2014). The presence of mature individuals, high fecundity, and viable embryos suggest that *O. tetricus* has the potential to be a self-sustaining population (Ramos et al. 2015). Moreover, persistent gene flow from throughout the historical zone towards the range extension zone, and moderate genetic diversity; may favor the establishment and long-term persistence of the population in the range extension zone (Ramos et al. 2018). Climate-driven expansion has also been described in other cephalopod groups, namely in: i) squids - *Dosidicus gigas* (d'Orbigny, 1835) (Zeidberg and Robison 2007; Rosa et al. 2013a), *Todarodes sagittatus* (Lamarck, 1798), *Todaropsis eblanae* (Ball, 1841) and *Teuthowenia megalops* (Prosch, 1849) (Golikov et al. 2013); and ii) sepiolids - *Sepietta oweniana* (d'Orbigny, 1841) (Golikov et al. 2014) and *Stoloteuthis leucoptera* (Verrill, 1878) (Quetglas et al. 2013a). There is also some evidence of changes in octopod fauna in the Mediterranean region associated with climate-driven range invasions, namely the presence of lessepsian migrants *O. cyanea* and *A. aegina* in the Levantine Sea (Galil 2007; Osman et al. 2014). Most of these distributional shifts are occurring at higher latitudes, and other regions where the marine ecosystems are warming the fastest (Hoegh-Guldberg and Bruno 2010; Fossheim et al. 2015), and, therefore, increased borealization of cephalopod communities in the Arctic is also expected during this century (e.g., Xavier et al. 2016).

Doubleday et al. (2016) recently showed that the abundance of cephalopod populations has been increasing globally for the last six decades and suggest that cephalopods are likely benefiting from a changing ocean environment. It is generally argued that the high plasticity of life history traits associated with short life spans and opportunistic feeding regimes are the key determinants allowing octopod and squid populations to respond quickly to changes in climate regimes (e.g., Pecl and Jackson 2008; Tian 2009; Caballero-Alfonso et al. 2010; Quetglas et al. 2013b; Rodhouse 2013; Rodhouse et al. 2014). The fact that they "live fast and die young" and act like "weeds of the sea" may allow them to more quickly adapt to future global warming than their fish competitors and predators Additionally, adaptation in cephalopods may be supported by the higher probability of occurrence of mutations and/or establishment of novel gene complexes in these short-lived organisms (Berteaux et al. 2004; Rosenheim and Tabashnik 1991; Parmesan 2006).

At first glance it would seem that climate change may be beneficial to coastal octopod fisheries due to enhanced growth rates, shorter life spans and greater population turnover. For example, a recent study in Madagascar, found the day octopus (*O. cyanea*) to be one of the species most potentially capable of adapting to climate change of 40 commercially exploited marine species examined for that region (pers. comm. G. Pecl). Of course, it would be expected that in general tropical species (and respective fishing stocks) may be more affected by warming than the temperate ones, due to the fact that the former evolving in a relatively stable thermal environment but nearer their thermal maxima (Tewksbury et al. 2008). That is, their ability to increase their upper thermal tolerance limits is much reduced compared to temperate species (Stillman and Somero 2000, 2001; Rosa et al. 2014a; Rosa et al. 2014c; Rosa et al. 2016). Moreover, any tropical species living on coral reefs, e.g., *O. cyanea* in Madagascar, will be negatively affected by any habitat loss resulting from coral bleaching. As such, there is increasing evidence that the response of octopod populations to future warming will not be straightforward, both in tropical and temperate regions.

Potential impacts of climate change have been documented via various experimental approaches. For instance, Repolho et al. (2014) showed, in a temperate and highly-seasonal region of the western Portuguese coast, that +3 °C above summer mean sea surface temperatures shortened embryonic developmental time of the common octopus (*O. vulgaris*) by 13 days, but also decreased survival by approximately 30% and increased drastically the percentage of smaller premature paralarvae (from 0 up to 20%). Moreover, the metabolic costs of the transition from an encapsulated embryo to a free planktonic form also increased significantly. Thus, the octopus planktonic paralarvae will require more food per unit body size to counterbalance the enhanced energy expenditure rates associated with pulse jet dynamics (i.e., the energy cost of swimming predominantly by jet propulsion). They will also have a reduced capacity to endure starvation under the future warming conditions. In the Patagonian red octopus *Enteroctopus megalocyathus* (Gould, 1852), a temperate sub-polar octopus species, the optimum range of temperatures for embryo development is between 12 and 15 °C, yet an increase of just +1 °C outside such range was enough to drop embryo survival by 15% (Uriarte et al. 2016). Juárez et al. (2016) and Caamal-Monsreal et al. (2016) also observed, in the holobenthic species *O. maya* off the Yucatan Peninsula that present-day bottom summer temperatures (around 30 °C) have already drastically inhibited female spawning and significantly reduced embryo survival (by ~70%) (Caamal-Monsreal et al. 2016). An additional increase of 1 °C was enough to elicit 100% embryo mortality after two weeks of ontogenetic development (Juárez et al. 2016). The early ontogenetic development of *O. mimus* in Chilean waters (Warnke 1999) under simulated medium and strong El Niño Southern Oscillation (ENSO) events (20 °C and 24 °C, respectively) took 35% and 62% less time than normal conditions. There were no abnormalities visible in the embryos developed under strong ENSO conditions, and there was also no adverse effect on the viability of the hatchlings. A more recent and comprehensive study on the thermal ecology of *O. mimus*, however, showed that the optimum range of temperatures for embryos was around 15 to 18°C, and that 21 °C is already outside the optimal thermal window based on the excessively high metabolic rates, with Q_{10} values reaching above 5 (Uriarte et al. 2012). Moreover, using a combination of individual-based bioenergetics and stage-structured population models, André et al. (2010) showed that the biological responses of *O. pallidus* to future warming may not be linear. In fact, future warming may lead to a significant shift from an exponential population growth to an exponential decline in just a few decades.

3.3.2. Acidification

Basic information concerning biological responses to different temperature conditions have been more or less well documented within octopod fauna, but significant gaps in knowledge include responses to ocean acidification (OA). Besides heat accumulation, the global ocean has also taken up ~30% of anthropogenic carbon dioxide (CO_2) released into the atmosphere. In fact, atmospheric CO_2 levels have risen for the first time above 40 Pa, in at least the last 800,000 years (NOAA 2017), and are expected to exceed 90 Pa by 2100 (IPCC 2013). Concomitantly, ocean surface pH is projected to decrease by 0.13–0.42 units by the end of this century, depending on the emission scenarios (IPCC 2013). Besides the pH changes, there is also a subsequent alteration in the relative proportion of dissolved inorganic carbon (DIC) species, namely a shift in inorganic carbon equilibria towards higher CO_2 and lower carbonate ion (CO_3^{2-}) concentrations. Collectively these chemical changes are known as the "OA problem" (Caldeira and Wickett 2003; Doney et al. 2009; Gattuso et al. 2015). Carbonate ions are one of the building blocks of calcium carbonate ($CaCO_3$) and thus OA may affect the ability of calcifying organisms to precipitate $CaCO_3$ (Gazeau et al. 2007; Hoegh-Guldberg et al. 2007). Moreover, OA also lead to acid–base balance disturbances, metabolic depression, growth reduction, behavioral impairments and increased skeletal deformities in non-calcifying groups (e.g., Seibel and Walsh 2001; Fabry et al. 2008; Munday et al. 2009a; Munday et al. 2009b; Munday et al. 2011; Nilsson et al. 2012; Pimentel et al. 2014; Pimentel et al. 2016; Rosa et al. 2017).

To the best of our knowledge, there is no information about the potential effects of OA on octopod fauna. Nonetheless, elevated CO_2 has been shown to elicit negative effects on the survival, growth, calcification and physiology of other cephalopod groups. For instance, Rosa and Seibel (2008) showed in juvenile jumbo squid (*D. gigas*) that OA substantially decreased metabolic rates (31%) and activity levels (45%), and that the effects were significantly exacerbated by warming conditions. The authors also argued that reduced aerobic and locomotory scope in warm, high-CO_2 surface waters would impair predator–prey interactions with cascading consequences for growth, reproduction, and survival. OA-driven changes in defensive behaviors, namely increased jet escape responses and ink jetting instead of defensive arm postures, were also observed in the adult pygmy squid *Idiosepius pygmaeus* (Steenstrup, 1881) (Spady et al. 2014).

Regarding OA and cephalopod early life stages, Rosa et al. (2014b) found that the combination of OA and warming led to a significant drop (~50%) in the survival rates of summer egg clutches of a coastal squid (*Loligo vulgaris* Lamarck, 1798). Moreover, increased premature hatching and a larger percentage of abnormalities were also found under such conditions. OA-driven impairments in calcification processes have also been described in the coastal squid *Doryteuthis pealeii* (Lesueur, 1821) (Kaplan et al. 2013). Additionally, besides increased time to hatching and shorter mantle lengths, squid statoliths (paired aragonite concretions critical for balance and detecting movement) were reduced and abnormally shaped (with increased porosity) under OA. Similar statolith-related findings were obtained in *Doryteuthis opalescens* (Berry, 1911) under combined conditions of OA and hypoxia (Navarro et al. 2016). More recently, Zakroff et al. (2018) developed a new 3D tracking system, which revealed that *D. pealeii* paralarval activity and horizontal velocity decreased linearly with increasing CO_2 levels (yet, the overall energetic impacts were subtle).

Interestingly, cuttlefish *Sepia officinalis* (Linnaeus, 1758) exhibit a certain level of pre-adaptation to long-term OA exposure, where depending on cuttlefish size, cuttlebones could accrete between 20 to 55% more $CaCO_3$ under OA (Gutowska et al. 2008; Gutowska et al. 2010). Yet, such findings were obtained using CO_2 levels (between ~400 and ~600 Pa) beyond those expected for the end of this century. Hu et al. (2011) also showed that cuttlefish embryos display a downregulation of ion regulatory and metabolic genes under OA, which along with a general decrease in their somatic growth, seemed to indicate that the early life stages were more vulnerable to OA than the adult. Along with the rise of pCO_2 inside the egg capsule (as well as a drop in pH and pO_2) during cuttlefish embryonic development, oxygen tension below critical pO_2 levels suggests that the already harsh abiotic conditions inside the capsule may be magnified under future ocean conditions (Rosa et al. 2013b). Such a tendency will ultimately promote premature hatching and smaller post-hatching body sizes, thus challenging survival and fitness. Similar severe abiotic conditions inside capsules, with differential levels of hypoxia and acidification throughout embryonic development, have also been described in squids (Navarro et al. 2014; Long et al. 2016).

Based on these collective findings, we argue that negative OA-driven effects on the early development, physiology and behavior of octopods cannot be ruled out, especially at the early stages of ontogeny, with cascading impacts on their population dynamics and associated fishery stocks.

3.3.3. Coastal hypoxia

Episodes of low dissolved oxygen (DO; <2 mg/l), or hypoxia, have also become a major ecological concern over the last decades, because they are increasing in frequency, duration and severity in coastal areas worldwide due to anthropogenic forcing (Diaz and Rosenberg 2008; Altieri et al. 2017). DO levels are dependent on a number of physical and biological processes (e.g., circulation, ventilation, air-sea exchange, production and decomposition), and they naturally occur in certain areas, such as mesopelagic oxygen minimum zones (Stramma et al. 2008), upwelling areas, estuaries and fjords (Levin 2003; Levin et al. 2009; Rabalais et al. 2010).

Such hypoxic events in coastal areas constitute acute perturbations at species and community levels, with great impacts on fisheries, especially those located in the highly productive upwelling areas of eastern boundary currents (Grantham et al. 2004; Chan et al. 2008). Sub-lethal effects of hypoxia include decreased feeding and growth rates, and changes in activity level and predator avoidance (Bell and Eggleston 2005; Goodman and Campbell 2007). It is thought that benthic fauna is particularly vulnerable to coastal hypoxia because the sediments usually tend to be depleted in oxygen relative to the water column (Gray et al. 2002; Wu 2002). Yet, because the physiological and behavioral thresholds are so species-specific (Vaquer-Sunyer and Duarte 2008, 2011), the consequent community structure shifts and changes in species interactions are difficult to predict (Essington and Paulsen 2010). For instance, benthic shallow-living octopods (namely *O. vulgaris*, *Octopus briareus* (Robson, 1929), *O. cyanea*, *Octopus californicus* (Berry, 1911) and *O. bimaculoides*) are known to be quite resilient to hypoxia as they are able to regulate their metabolism down to less than 15% oxygen saturation (Maginniss and Wells 1969; Borer and Lane 1971; Wells and Wells 1983; Wells 1990; Seibel and Childress 2000). Such tolerance is associated with their ability to slow down the ventilatory stream and possibly suppress their metabolism, although this is not yet confirmed. This allows them to occupy tide pool environments where oxygen saturation can reach anoxia. For instance, *O. californicus* and *O. bimaculoides* are able to endure 8 or 4 h of complete anoxia at 6 and 10 °C, respectively (Seibel and Childress 2000). Such short-term physiological capability, however, will not allow octopods to thrive under the enduring hypoxic events predicted for the future. Nonetheless, indirect effects through changes in predator-prey interactions may also occur. That is, octopods may not be affected by hypoxia, but their prey or predators may. Consequently, the overall result of hypoxia-driven effects on octopod communities and related fisheries could be either positive or negative (e.g., see examples in Eby et al. 2005; Altieri 2008).

It is important to note that although many explorations of climate change have considered only one, or at most, two drivers of climate change (e.g., one or two of temperature, OA or hypoxia), in natural systems these drivers are occurring and changing in concert (Boyd et al. 2015). Wholistic considerations or explorations of climate change thus need to consider multiple drivers of climate change. Here, we have also not considered all of the potential drivers of climate change. For example, changes in productivity, stratification, and the strength and direction of ocean currents. Already, strong changes in the intensity and position of western boundary currents have been observed (van Gennip et al. 2017, and this will have consequences for larval retention and dispersal for example. Changes in current intensity and direction may potentially magnify or dampen any disruptions to population structure and population connectivity arising from reduced larval durations occurring as a function of warming waters. Finally, the flow-on effects of climate-driven changes in octopus populations may have substantial implications for the broader ecosystem. For example, modeling suggests the range extension of *O. tetricus* into Tasmanian temperate reef areas may potentially have negative impacts for the reef-associated abalone and rock lobster populations and associated fisheries (Marzloff et al. 2016).

4. North-Western Atlantic

The FAO Statistical Area 21 (Northwest Atlantic) extends off eastern America from latitude 35°N (∼Cape Hatteras) to 78°10′N, and includes the Labrador Sea. There is no directed fishery for octopus in the entire area. Although *O. vulgaris* is distributed as far north as Connecticut (Vecchione et al. 1989), catches indicate octopus abundances are low in this area, occurring primarily south of Cape Hatteras. Virginia historical bycatch data since 1950 only account for 9.9 t, while Maryland, New York and Rhode Island combined reported just 0.6 t.

5. Central-Western Atlantic

The coastline of FAO Statistical Area 31 (Central-Western Atlantic) extends off eastern America from latitude 5°N (French Guiana) to 35° N (∼Cape Hatteras, North Carolina); and includes the Caribbean

Sea and the Gulf of Mexico, as well as 25 sovereign states and a dozen insular dependent territories. The high diversity of octopods in this region has been widely acknowledged (Voss and Toll 1998; Norman et al. 2014). Voss (1960, 1971, 1986) was the first to assess the octopus fishery potential in the area, identifying six prospective fishery species in the Caribbean (Voss 1960), four of which attain appropriate sizes: *O. vulgaris*, *O. briareus*, *Callistoctopus macropus* (Risso, 1826) (*Octopus macropus*) and *O. maya* (Voss, 1971). Only six countries in this region report octopus landings on a regular basis (FAO 2016). Yearly landings averaged 24×10^3 t (ranging $10–38 \times 10^3$ t) in this century (FAO 2016), with the majority of these landing corresponding to Mexico (96%) and Venezuela (3%), where the only targeted and regulated octopus fisheries occur. In the remaining countries, the octopus fisheries are not officially acknowledged.

5.1. *Octopus vulgaris* (common octopus)

This is a large octopus that has been reported from tropical to temperate waters of the Atlantic. Its cosmopolitan distribution has been questioned (e.g., Mangold 1997; 1998). Genetically, *O. vulgaris* is one of the most widely studied cephalopod species (Carlini and Graves 1999, Guzik et al. 2005) which is a result of a combination of its cosmopolitan (wide) distribution and the difficulties of identifying the species based on morphological criteria. Norman and Hochberg (2005) referred to this taxon as a "species complex" and argued that a number of distinct taxa are classified incorrectly as *O. vulgaris* in different parts of the world. In fact, a number of genetic and morphological studies, principally in the western hemisphere, have resulted in the description of a number of new species, including *O. maya* (Voss and Solís Ramírez 1966), *O. mimus* (Guerra et al. 1999), and *O. insularis* (Leite et al. 2008a; Flores-Valle et al. 2018; González-Gómez et al. 2018).

The wide distribution of *O. vulgaris* in the Atlantic, however, has been confirmed by the molecular genetic analysis of specimens from coastal waters of the Southwestern Atlantic along Brazil, (Warnke et al. 2004; Leite et al. 2008a; Moreira et al. 2011; Sales et al. 2013), and South Africa (Oosthuizen et al. 2004). *Octopus* "*vulgaris*" type I is a geographically disjunct form of *O. vulgaris* corresponding to the Tropical Central-Western Atlantic Ocean, distributed from the US to Venezuela (Norman et al. 2014; Roper et al. 2015). According to Warnke et al. (2004) specimens from Isla Margarita, Venezuela, are not distinguishable from those from the Eastern Atlantic. Recent genetic studies, however, have revealed that individuals from Venezuela and Yucatan (Type I) and Brazil (Type II) belong to the same Western Atlantic subgroup, differing from the subgroups from the Eastern Atlantic and Asia (Sales et al. 2013; Lima et al. 2017).

This species is presumably caught along the coastline of the whole region, with main fisheries occurring in northeastern Yucatan (Mexico) and eastern Venezuela. Productivity in both areas is driven by seasonal coastal upwellings (Kämpf and Chapman 2016). Knowledge on its biology in the region is very fragmentary. Off South Carolina the largest octopus are caught in late fall and early winter at water depths of 12–25 m. As water temperature decreases in December and January, catch rates also drop sharply. Although brooding females are found in other seasons, most spawning activity occurs during spring. They feed mainly on brachyuran crabs and fish (Whitaker et al. 1991). Studies on *O. vulgaris* from Yucatan are under way.

Off eastern Venezuela the fishing season is during the warmer months, July to December, when octopus migrate to shallow sandy and shelly bottoms 25–50 m depth to mature. Mature individuals of both sexes dominate catches. Female size at maturity is 153 mm mantle length (ML) and 844 g body weight (BW). The presence of 8% of spent females in catches raise some concern on the sustainability of this resource. From January to June (closed season) the more productive waters ensure sufficient food for octopus hatchlings. Growth estimates using size distribution analysis suggest a life span of 15.6 months for males and 19 months for females (Arocha and Urosa 1982; González et al. 2015). Similarly, in the Gulf of Cariaco *O. vulgaris* are abundant between July and September, with a predominance of mature individuals. Females spawn in September and October. No octopus are found from December to March (Arocha and Urosa 1982).

A number of studies have been undertaken on the food and feeding behavior of *O. vulgaris* in the shallow waters of Bermuda, Bahamas and Bonaire (Anderson et al. 2008; Kuhlmann and McCabe 2014; Mather 1988, 1991; Mather and O'Dor 1991; Mather and Nixon 1995). Captive female *O. vulgaris* from the Bahamas copulate and spawn throughout the year (Wodinsky 1972).

5.2. *Octopus maya* (Mayan octopus)

This species is endemic to the Campeche Bank, off the western and northern shores of the Yucatan peninsula. Octopus from Campeche grow and mature during the fishing season, from August to December, spawning in November and December. A small proportion of mature individuals are, however, found throughout the year. Both sexes reach sexual maturity within a wide range of BW. Size at 50% maturity varies among seasons and localities, but averages at 124 mm ML and 1,024 g BW for females and 91 mm ML and 484 g BW for males. In cultured animals, the life span is 300 days. Estimations from modal length analysis ranging 10–26 months (DOF 2016a) are probably overestimated. *O. maya* attain over 4 kg BW in captivity, although individuals rarely exceed 2.5 kg in catches (Solís-Ramírez 1998; Van Heukelem 1983a; Markaida et al. 2017).

The recruitment process varies annually (Arreguín-Sánchez 1992). Two recruitment peaks have been observed in the fishery from ML modal analysis; one in April–May and another in September–October. Only the second recruitment peak is observed during the fishing season (Arreguín-Sánchez et al. 2000).

Females lay 300–5,000 large eggs (11–17 mm) on shallow bottoms 2–7 m depth. Eggs develop over a period of 45–65 days. Hatchlings are benthic, weighing around 0.1 g and behave like adults (Solís-Ramírez 1998; Van Heukelem 1983a). These large hatchlings make *O. maya* a preferred candidate for rearing studies, and as a result the majority of knowledge on its biology comes from cultured animals (Van Heukelem 1983a; Rosas et al. 2014; Vidal et al. 2014).

5.3. *Octopus insularis*

Recent genetic research from Veracruz shallow reefs (south western Gulf of Mexico) confirms the presence of *O. insularis* in that fishery (Flores-Valle et al. 2018; González-Gómez et al. 2018), and largely supposed to be *O. vulgaris*. The main reproductive season occurs between January and March (Hernández-Tabares and Bravo-Gamboa 2002). Males mature at a smaller size (590 g BW; 90mm ML) than females (870 g BW; 108 mm ML) (González-Gómez et al., 2020). The discovery of *O. insularis* in Puerto Rico, Guadalupe and Dominica islands widely extends the geographical range of this species, and raises concerns about previous *O. vulgaris* ecological studies as they were carried out in similar habitats to those occupied by *O. insularis* in Brazil (Lima et al. 2017).

5.4. Other species

A small number of *C. macropus* contribute to octopus catches off Veracruz (Hernández-Tabares 1993; Hernández-Tabares and Bravo-Gamboa 2002). This species can attain sizes just less than 1 kg BW, but is of lower economic value than *O. vulgaris* (Díaz-Álvarez et al. 2009). It was occasionally caught north of Los Frailes Island, NE Margarita Island, Venezuela, being landed mixed with *O. vulgaris* (Arocha 1989). It might be caught in other regions as well. Little is known about its biology in the area (Voss 1957) and its taxonomy in the western Atlantic is still unresolved (Norman et al. 2014).

The species *O. briareus* is soft and is not a preferred species for consumption. In Puerto Rico it has no commercial value and in Cuba is considered somewhat toxic (Voss 1960). As for *C. macropus*, this species does not seem to be abundant enough to support a fishery (Voss 1986). Females spawn 100–500 eggs (10–14 mm long) from January through April in shallow waters. It grows to 1 kg BW. This species has been experimentally cultivated and it is popular in the aquarium trade in the US (Aronson 1986; Hanlon 1983; Norman et al. 2014).

Other species from the Western Central Atlantic such as *Octopus hummelincki* (Adam, 1936) (*Octopus filosus*), *Amphioctopus burryi* (Voss, 1950) (*Octopus burryi*), *Octopus joubini* (Robson, 1929) and *Octopus zonatus* (Voss, 1968) are too small to promote any commercial interest (Voss 1960; Arocha and Urosa 1982). The species *A. burryi* and *O. zonatus* are mixed with the octopus landings from the northeastern coast of Venezuela, particularly from the area around Margarita Island (Arocha 1989). A recently described species, *Octopus tayrona* (Guerrero-Kommritz and Camelo-Guarin 2016), is taken in shallow waters (<6 m depth) of Colombia.

5.5. Stock Identification

Although no studies on stock identification have been conducted, *O. vulgaris* is fished in several separate regions of the central western Atlantic: US, Yucatan peninsula (Mexico) and Venezuela.

Isozyme studies did not find evidence of distinct intraspecific stock units of *O. maya* (Tello et al. 2007, 2012). Microsatellite analysis suggests that *O. maya* constitutes a single population, with most genetic variability located at the center of the species distribution (Sisal) and genetic variation thinning towards the periphery of the distribution (Seybaplaya and El Cuyo (Juárez et al. 2010).

5.6. Catches/landings

5.6.1. Eastern U.S

No octopus directed fishery has ever occurred in the eastern United States. Bycatch of *O. vulgaris* from a

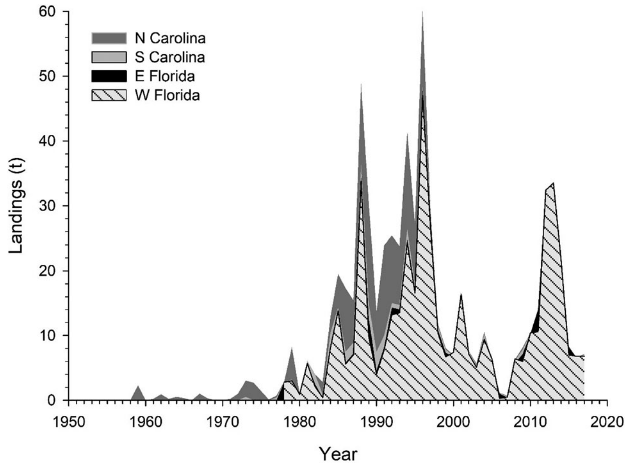

Figure 13. Historical octopus landings in the southeastern US. Data from Annual Commercial Landing Statistics at http://www.st.nmfs.noaa.gov/commercial-fisheries/index.

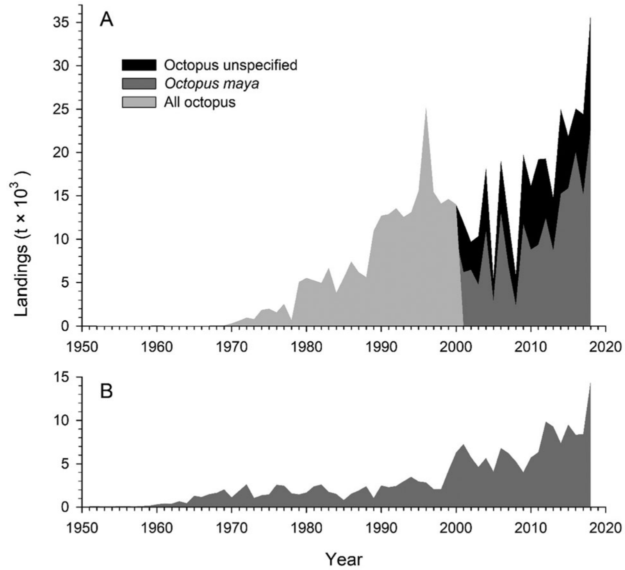

Figure 14. Historical cumulative octopus landings for (A) Yucatan and (B) Campeche states. Catches from Quintana Roo are not shown. Since 2000 catches from Yucatan state are segregated in *Octopus maya* and unspecified octopus items (accumulated). Data from Solís-Ramírez (1988), CONAPESCA (2016, 2018).

variety of gears, however, accounts for several dozen tonnes caught annually in the Carolinas and Florida (Figure 13). In western Florida (Gulf coast) bycatch is done during the stone crab (*Menippe mercenaria*) fishing season, from November to March (NMFS 2007). Octopus bycatch has increased in recent years due to the very low stone crab landings which may have encouraged fishermen to develop better markets for octopus (Ryan Gandy, Florida Fisheries and Wildlife Research Institute, pers. comm. 2/9/2016).

Expanded regulations on many offshore finfish fisheries and a rising price for octopus is causing some interest. Experimental fishing with pots suggests the potential for a seasonal fishery targeting relatively large octopus off South Carolina (Whitaker et al. 1991). With catches of several thousand pounds, a small-scale fishery could be supported off South Carolina and Georgia (Whitaker, pers. com. 4/2/2016). However, trials in North Carolina suggest that octopus abundance would not support a directed commercial operation (Rudershausen 2013). Voss (1985) found that octopus bycatches in the Florida stone crab and blackfish traps could be profitable if properly handled. Experimental fishery results suggest that there are sufficient octopus stocks in Florida to support a directed fishery using unbaited pots (Roper 1997).

5.6.2. Mexico

Octopus may have been fished by the ancient Maya from Yucatan peninsula, since it is mentioned in the very first colonial chronicles from Campeche (Landa 1986). The first statistical records date from 1947 and by the 1950s yearly catches averaged around 100 t in Campeche. By 1965 landings attained 1,300 t year^{-1}. Intensive promotion during the 1970s expanded the fishery to the neighboring state of Yucatan (Solís-Ramírez 1988). In 1982 the large fleet began targeting octopus in more distant waters, incrementing landings to 8,000 t year^{-1}. The fishery expanded in 1996, when exportation to the European Union raised prices (Josupeit 2008). In this century, *O. maya* mean yearly landings accounted for 7×10^3 t at Campeche. Yucatan accounted for at least 10.4×10^3 t year^{-1}, although sharp decreases in catches below 3×10^3 t occurred in 2005 and 2008 (Figure 14; CONAPESCA 2016). Record landings occurred in 2018 with 13.6×10^3 t in Campeche and 22.8×10^3 t in Yucatan. The fishery expanded to Holbox, in the eastern state of Quintana Roo, by 1989 where some 200 t year^{-1} have been landed in this century. Currently the fishery extends in shallow waters of the Campeche Bank, from Sabancuy to Holbox (Figure 15B).

Catch per unit effort (CPUE) for *O. maya* in 1980 averaged 46 kg/small boat/day; with a CPUE of approximately 33 kg/boat/day at Dzilam del Bravo and 31 kg at Champoton (Solís-Ramírez and Chávez 1986). In 2002–2008, small boat catches from the states of Yucatan and Campeche ranged 6–60 kg/day (DOF 2014; Salas et al. 2012). Alijos (small dories) carried by a variety of boat sizes caught 13–28 kg/day (Salas et al. 2009, 2012). The monthly CPUE of large vessels also varied greatly, landing 1.2–5.5 t per trip (11–14 days) (DOF 2014; Galindo-Cortes et al. 2014).

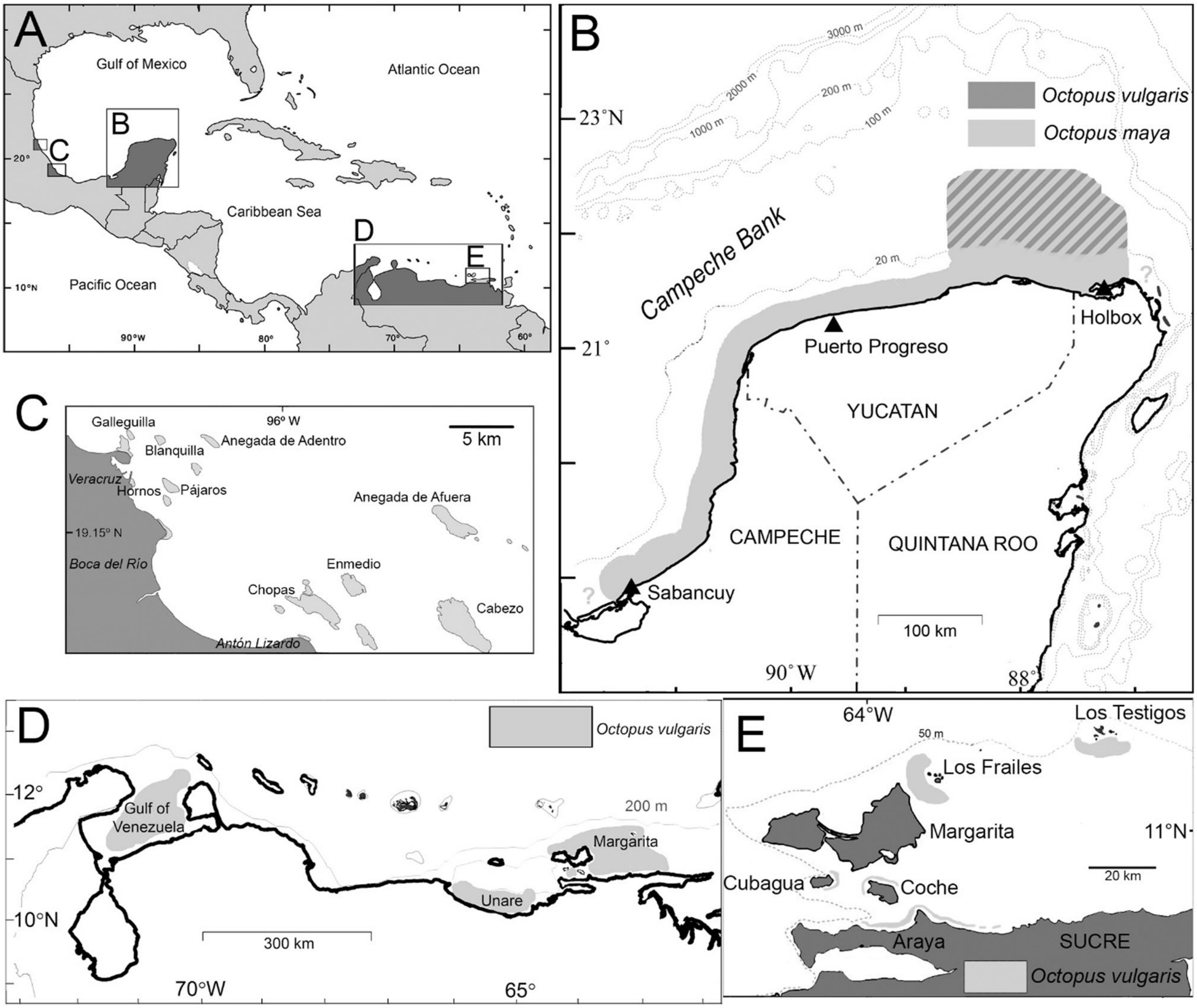

Figure 15. (A) Octopus fishing grounds in the north western Atlantic. (B) Yucatan Peninsula (modified from Galindo-Cortes et al. 2014; Avendaño et al. 2019). (C) Veracruz reef system showing the most visited reefs (modified from González-Gómez et al. 2018), Tuxpan reef system is not shown. (D) Industrial fishery fishing grounds in Venezuela (modified from Arocha 1989). (E) Octopus fishing grounds for the artisanal fishery in eastern Venezuela.

The catchability of octopus using baited lines differs by area, fleet and species (Velázquez-Abunader et al. 2013; Gamboa-Álvarez et al. 2015). CPUE analysis and visual surveys revealed significant changes in the spatial and temporal distribution of *O. maya* abundance on the Yucatan shelf (DOF 2014; Gamboa-Álvarez et al. 2015; Galindo-Cortes et al. 2014).

Fishing for *O. vulgaris* on the Yucatan shelf began in 1982, when large, mechanized vessels from the red grouper and snapper fishery targeting *O. maya* ventured in deeper waters of the northeast peninsula (Solís-Ramírez 1988; Figure 15B). Landing statistics from Yucatan state started segregating catch by species in 2000: *O. maya* and "Unspecified octopus" as a generic name. The latter accounts for 38% of all catches since then, averaging 6×10^3 t year^{-1} and is thought to mainly represent *O. vulgaris* (Figure 14A; CONAPESCA 2016). This distinction is far from accurate, however, as *O. maya* could easily have been misidentified as *O. vulgaris* in landings (Lima et al. 2017). FAO (2016) statistics for the Mexican Atlantic report common octopus since 1958 with consistently larger catches than *O. maya*, which are reported just since 2005. This discrepancy can only be explained because data for both species were switched.

The octopus fishery located on the Veracruz and Tuxpan reef systems in the western Gulf of Mexico targets mainly *O. insularis* (formerly thought to be *O. vulgaris*), with less than 10% of the catch being *C. macropus*, although no differentiation is made in catch statistics (Hernández-Tabares 1993; Hernández-Tabares and Bravo-Gamboa 2002; Tunnel et al. 2007;

Jiménez-Badillo 2010; 2013). In Tuxpan octopus fishery occur mainly at El Tuxpan, Tanhuijo and Isla Lobos reefs, while in the Veracruz system most reefs contribute to the fishery (Hernández-Tabares and Bravo-Gamboa 2002; Figure 15C). At Veracruz octopus catches average 80 t year^{-1}, while at Tuxpan only 3 t have been landed since 2006 (Figure 16). Individual catches average 3–11 kg per fisherman per day at the Veracruz reef system, where octopus densities range 10–155 individuals/km^2 (Jiménez-Badillo 2010).

5.6.3. Venezuela

Over 90% of the cephalopod catch from Venezuela was taken as bycatch from double-rigged trawlers of the shrimp fleet until mid-90s. Three regions have been described in this fishery; namely the Gulf of Venezuela in the west, and two areas in the east, the Unare shelf and around Margarita Island (Nueva Esparta and Sucre states) (Figure 15D). The *O. vulgaris* bycatch from the Gulf of Venezuela decreased to its lowest level in 1979. Since 1982 landings began to improve, with 85% of the octopus landed in the northeast, mainly around Margarita Island from May to October (Arocha 1989). Octopus catches by shrimp trawlers abruptly decreased from the mid-1990s, until this fishery was terminated in March 2009 (Figure 17A). This fishery produced an average octopus bycatch of 500 t year^{-1}.

The remainder of the octopus catch was taken by artisanal fishermen, mainly along the northeastern and, to a lesser extent, central coasts (Arocha 1989). Since 1995, artisanal octopus catches rapidly increased. Most catches are done in the insular dependencies of Los Frailes and Los Testigos archipelagos (Figure 15E). Additional fishing grounds are located in Margarita, Coche and Cubagua islands (Nueva Esparta) and in the Araya peninsula and to the east (Sucre state). Over 90% is landed in Nueva Esparta state and the rest in Sucre. Landings averaged 700 t year^{-1}, although in recent years they have decreased (Figure 17B).

Octopus are targeted using lines with jigs off eastern Margarita Island from July to December (González et al. 2001). Catch per fisherman ranged between 4–11 kg per hour of fishing during 1996–1999, with a peak usually found to occur in September (González et al. 2001). Catch rates per fishermen appear to have increased since then, being estimated at 20 kg day^{-1} in 2015.

5.6.4. Other countries

The majority of the catch in Puerto Rico is comprised by *O. vulgaris*, taken mostly in November and December with spears and hooks (Voss 1971, 1975). Today almost all the catch is taken by scuba divers who collect queen conchs on the south coast, where some 19% of fishermen target octopus amongst other resources. Some octopus is caught in lobster traps. Annual catches range from 4–22 t and are distributed along the year (Figure 18A). Estimates for mis- and/or

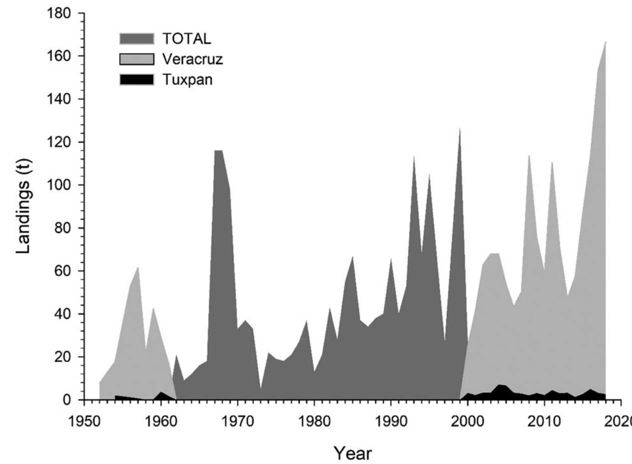

Figure 16. Historical octopus landings in the Veracruz and Tuxpan reef systems, state of Veracruz, Mexico. Data from Solís-Ramírez (1988), CONAPESCA (2016, 2018).

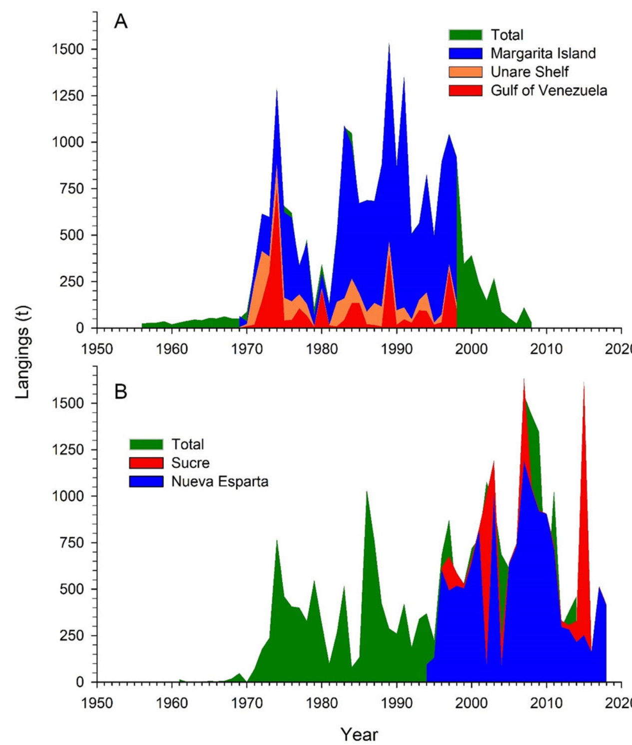

Figure 17. Historical cumulative octopus landings from Venezuela for (A) bycatch in shrimp trawlers and (B) artisanal fishery. Reported data from Arocha (1989), Marcano et al. (2001), INFOPESCA and Pauly and Zeller (2015).

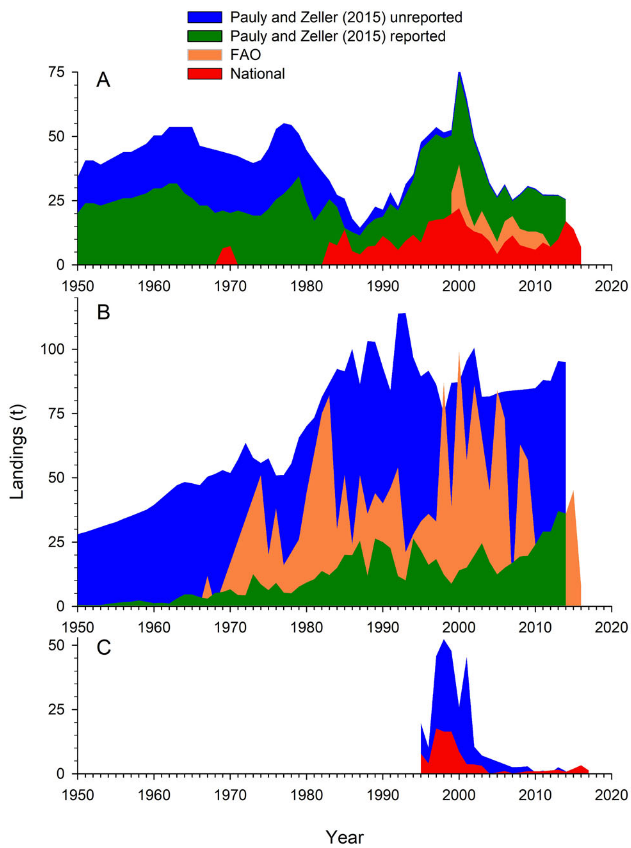

Figure 18. Historical non cumulative octopus landings reported from FAO (2016), Pauly and Zeller (2015) and national agencies from (A) Puerto Rico (SEDAR 2009; Matos-Caraballo 2012), (B) Dominican Republic and (C) Colombia. Unreported estimates from Pauly and Zeller (2015) are accumulated.

non-reported landings represent 0.22–0.5 times these reported values (SEDAR 2009; Matos-Caraballo 2012).

In the Dominican Republic, catches for 2010–2014 averaged 30 t year^{-1} (Figure 18B; FAO 2016). The catch is directed to tourism and does not meet the local demand, which must be imported. Unreported catches, mostly subsistence fishing, more than double those of reported landings (Pauly and Zeller 2015). Most octopus are caught in the northeast of the island as bycatch in a variety of fisheries: free and scuba diving, traps "nasas," lines and beach seines (Voss 1971, 1975; Estanislao Balbuena, CODOPESCA; pers. com., 7 March 2016).

Octopus landings off the Atlantic coast of Colombia from 1995 to 2009 ranged from 0–17 t (Figure 18C; FAO 2016). Octopus are caught by artisanal fishermen, although no fishing method is mentioned (Díaz et al. 2000). Most of the artisanal catch from shallow waters (<6 m depth) seems to be comprised by the newly described species *O. tayrona*.

In Cuba, octopus production for 1958 was estimated at roughly 10 t (Voss 1960), although currently

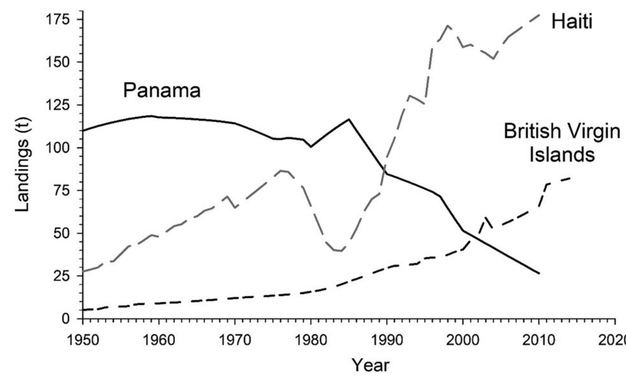

Figure 19. Reconstructed octopus catches for Haiti, Panama and British Virgin Islands (Pauly and Zeller 2015).

no directed fishery nor catch records exist (Rafael Tizol, Centro de Investigaciones Pesqueras, pers. com. 2/12/2016). Octopus were taken in fish traps or with hooks using water glass (Voss 1973, 1975). In Jamaica the octopus catch was insignificant, being used only for bait (Voss 1973). Octopus catches are not reported for the rest of the Caribbean. Catches, if any, should be negligible, and most probably taken as bycatch in a variety of gears (Voss 1971, 1986). Octopus catches have been reconstructed for several countries (Pauly and Zeller 2015). Haiti, Panama and British Virgin Islands catch several dozen tonnes in their artisanal and subsistence fisheries (Figure 19).

5.7. Fisheries/fishing methods/fleet

5.7.1. Eastern U.S

The species *O. vulgaris* is caught as bycatch in the South Atlantic Bight and the adjacent Gulf of Mexico by a variety of fishing gears such as hook and line, fish potters, blue crab potters and trawlers fishing for penaeid shrimps (Whitaker et al. 1991). Off Northern Carolina, the highest catches occur in wire mesh traps used for Black Sea Bass, *Centropristis striata* (Rudershausen 2013). In Florida, the largest octopus bycatches occur in the stone crab trap fishery, particularly from September to December (Voss 1985).

The experimental fisheries conducted in the Carolinas and Florida used pots constructed of plastic pipe and sections of automobile tires set in a longline fashion, as well as wire mesh traps (Whitaker et al. 1991; Roper 1997; Rudershausen 2013; Voss 1985).

5.7.2. Mexico

In the 1950s, *O. maya* was first caught with hooks (Carranza 1959). Fishermen used water-searchers – also called "look-boxes" or "water-glasses" – to look for octopus from small vessels operating in shallow waters <3 m depth. This method was still in practice in the sixties (Solís-Ramírez 1998). Fishing with baited lines, commonly known as "garete" (drifting), was also already established in the sixties, although when this method was first introduced remains unclear. Each open boat carries two long rods from which 2–4 lines baited with crabs are set. One side of the boat bears additional baited lines. The boat drifts over the fishing ground, while the crabs are carried over the sea bottom, attracting any active octopus (Figure 9A). As it takes the crab, the fisherman hauls the line in, retrieving the octopus (Markaida et al., 2015, 2019). Lines were generally baited with crabs, although baiting with *Strombus* shells was also popular. Lines are weighted with lead sinkers. The use of a treble hook at the end of the line to hold the octopus is optional, as the octopus will rarely leave the bait when pulled out from shallow waters (Figure 9B).

The boats were originally wooden, propelled with a sail, the lines were made of henequen and the rods made of mangrove (Solís-Ramírez 1998; Voss 1985). Substantial changes modified the fishing effort in the 80s as boats become fiberglass and equipped with outboard engines, and nylon lines and bamboo rods were introduced (Solís-Ramírez 1988). Today this method is the most sophisticated among the line methods used to catch octopus worldwide, as each fisherman handles over a dozen baited lines set together.

This fishing gear is considered sustainable for octopus exploitation as mature or spent females cease feeding and do not attack the bait (Van Heukelem 1983a). Bycatch is also non-existent, as no hooks are needed on the line when pulling the octopus up in shallow waters. It does, however, demand a vast quantity of crabs of different species, compromising their availability and increasing fishing costs (Solís-Ramírez 1998; Markaida et al. 2015, 2019). Traditionally local decapods such as blue crab (*Callinectes* spp.), stone crab (*Menippe mercenaria*) and spider crab (*Libinia dubia*) have been used as bait (Solís-Ramírez 1997). In recent years crabs from neighboring states such as the mangrove crab (*Ucides cordatus*) from Tabasco and blue crab (*Callinectes* spp.) from Chiapas have been imported. Experiments substituting these baits with artificial lures have not been successful (Markaida et al., 2019).

The major fleet uses crabs as bait when targeting *O. maya*, and fish when targeting *O. vulgaris*. Sandperch *Diplectrum* or grunt *Haemulon* are fished on the spot and used fresh. They are tied onto a hook on the line. Because fishing is performed over deeper waters, a rudimentary jig made with hooks at the end of the line is used to snare the octopus when it tries to grab the bait (Figure 9C; Botello et al. 2010; DOF 2014).

Three different fleets operate in the octopus fishery on the Yucatan peninsula (Salas et al. 2009; 2012). Small fiberglass open boats of 5–9 m in length and with overboard engines (50–95 hp) are widespread over the entire range of this fishery (Figure 10A). They fish for a whole morning, typically 6 am to 15 pm, targeting *O. maya* in shallow waters (5–8 m depth in Campeche) 10–24 km offshore. They may spend an additional day at sea if properly supplied. Each boat can carry 1–3 small (2–3 m in length) dories (alijos) to the fishing grounds (Figure 10A and B), multiplying the effort while saving fuel cost. Alijos always operate fewer baited lines than boats. Both the boat and the alijos drift while fishing with a single fisherman on board. A rudimentary sail (which can work as an anchor as well) favors drifting (Figure 10B). Currently around 3,500 small boats in the state of Yucatan and another 1,700 in Campeche, target octopus with their alijos (Salas et al. 2009, 2012; DOF 2014).

The medium fleet is a heterogenous group of larger boats, 9 to 12 m long, with larger capacity. They carry four fishermen and 3–4 alijos, undertaking trips of 3–4 days. The *O. maya* occurring ~40 km offshore are the target of this fishery. Some authors consider them as part of the small fleet (DOF 2014; Galindo-Cortes et al. 2014).

The larger fleet targets both *O. vulgaris* and *O. maya* in deeper (20–30 to 60 m depth), distant waters of the NE corner of the Yucatan peninsula (Galindo-Cortes et al., 2014; Avendaño et al., 2019). These are mechanized vessels (12–22 m in length) from the red grouper and snapper fishery serving as mother vessels carrying 12–15 alijos (Figure 10C and D). Fishing trip duration is 11–15 days. Alijos fish octopus in two daily sessions, returning to the mother vessel for food and to spend the night. Catch is preserved with ice. Currently around 400 such vessels, based mainly at Puerto Progreso, Yucatan, operate in the octopus fishery (Salas et al. 2012, Figure 15B). Out of octopus season (January to July) all fleets target other marine resources.

Other fishing methods commonly used in Yucatan include skin diving with hooks, traps and pots, although they are considered illegal (Botello et al. 2010). In Campeche state, PVC pipes and commercial plastic jars are used as octopus pots set in a longline fashion, and they have raised great concern (Botello et al. 2010). Organized divers invest in concrete blocks to set artificial reefs that attract octopus. They are GPS-located and regularly visited by a team of eight divers in a single boat. This is a widespread practice of a major concern. Catches are substantially larger than those made with baited lines and are believed to comprise a major share in landings in Campeche. While diving for octopus they also spear a variety of finfish, and collect conchs and stone crabs as well. Octopus bycatch in traps targeting other species such as stone crab are of lesser importance.

According to Voss (1960; 1973), in the fifties, octopus were caught off the coast of Veracruz city using pots named "nummarelas" by two Italians. Today octopus fishing in Veracruz state is done by free divers (with hooks) in the shallow waters (0–5 m) of reef lagoons. Small open boats with outboard motors (18–25 feet long) are used to reach the offshore reefs. Most fishermen target other finfish while diving (Hernández-Tabares and Bravo-Gamboa 2002; Beaver and Chavez 2007; Jiménez-Badillo 2010, 2013).

5.7.3. Venezuela

In Venezuela most octopus were taken as bycatch from double-rigged trawlers of the shrimp fleet until the mid-90s. This fishery ended in March 2009. Tire traps made with sections of automobile tires called "longanizos" were invented in the 1960s (see illustrations in Whitaker et al. 1991; Markano and Lodeiros 1987). Successful experiments (37% efficacy) conducted in 1981 led to the adoption of this gear by fisher communities of the northern shore of Cariaco Gulf (Sucre) (Marcano and Lodeiros 1987). These traps were eventually replaced by jigs and a variety of pots. Longlines of plastic jars (4 liter capacity, 8 cm wide) and PVC pipe pots (30 cm long, 10 cm wide open) are commonly used. Pots are weighted with concrete. These longlines are 200 m long and contain 30 pots at 6 m intervals. The longline is left to soak for 15 days. Pots are mainly baited with hen feet, or fish such as grunts, catfish or toadfish (Eslava et al. 2017). Pots are used mainly in Sucre. Only 20 boats (15% of all) at El Tirano (Margarita Island) use these gears, each employing 10 longlines, and with an average catch of 20 kg per longline.

Octopus is also taken as bycatch in fisheries using wired unbaited traps called "nasa antillana" which target a variety of species from finfish to lobster (illustrated in Eslava et al. 2003). They are set in groups of two to ten traps at intervals of 15–20 m at depths of 20–50 m. Octopus bycatch increases during the octopus season (González et al. 2015).

Currently the artisanal fishery for *O. vulgaris* on Margarita Island uses lines with elaborated jigs, introduced from the mainland. Two jig types were redesigned: *Araña* (spider, in 1996) and *pata e gallina* (hen foot, in 1997) which was derived from the later and is currently used. They are made with a metal pipe which holds several hooks (Figure 2 in González et al. 2001; Figure 9D). Another type of commercial jig is available in the market, made with a conic lead and two rows of six hooks each. Pieces of fish (*Bagre marinus* or *Lycodontis moringa*) or a red rag are attached as bait. Each fisherman handles one or two lines of 18–25 m length, drifting over the bottom for 10–20 min (González et al. 2001, 2015). Two to five fishermen go fishing in small open boats 6–9 m length with 40–75 hp outboard motors.

Use of chemical compounds to catch octopus, such as copper sulfate, have been reported at Morrocoy, Falcon state, in the western shore (Montañez 2012). As mentioned above, in the whole Caribbean octopus is commonly taken as bycatch by a variety of gears: diving, traps, pots, nets.

5.8. Fishery management and stock assessment

5.8.1. Mexico

The *O. maya* fishery has been regulated for many decades. In 1972, a first experimental closure was established from November 16 to July 31 to protect juveniles and spawning females (Solís-Ramírez, M. 1996). Different assessments for the period 1979–1982 and 1985 estimated an annual maximum sustainable yield (MSY) of $7{,}7\text{–}10 \times 10^3$ t and indicated that the *O. maya* fishery was risking overfishing. Some of these studies recommended the establishment of a minimum legal size (MLS) and reduction of the fishing season (Walter 1986; Solís-Ramírez and Chávez 1986; Seijo et al. 1987; see Table 4 in Solís-Ramírez 1997). In 1984 two official agreements established the current fishing regulations: a closure from December 16 to July 31, a MLS of 110 mm ML and the prohibition of fishing with hooks (DOF 1993, 1994). Updated normative (DOF 2016a) explicitly forbid any other gear except the use of baited lines.

Violation of regulations is a cause of major concern in this fishery. Most catches from the small fleet are under the MLS (Salas et al. 2009, 2012; Markaida et al. 2017). Use of forbidden fishing methods is widespread at Campeche, such as pot longlines and free diving with hooks (Botello et al. 2010). This is evident in catches with some incidence of spent females (Markaida et al. 2017). The legal fishing gears, however, employ vast quantities of decapods as bait, which usually lack any management. Recently, regulations aimed at preventing detrimental impacts to crab populations of some species have been implemented, explicitly forbidding the use of stone crab and land crabs as bait (DOF 2016a), although these practices are still widespread.

Assessments for the period 1993–1999 suggested intense exploitation. It was recommended that fishing effort should not be increased and no more fishing licenses granted (Arreguín-Sánchez et al. 2000; González-de la Rosa et al. 1997; Hernández-Flores et al. 2001). Further assessments using commercial catch data from 1995–2008 suggest that the current level of exploitation might be unsustainable (Jurado-Molina 2010). Research undertaken at Holbox, however, suggests sustainable exploitation in this locality (Hernández-Sánchez and De Jesús-Navarrete 2010).

Since 2001 the Fisheries Institute has established yearly total allowable catch (TAC) quotas for the Yucatan peninsula fishery. These are based on preseason abundance estimates of *O. maya* conducted by visual surveys along submarine transects and a relative abundance (fishing availability) assessment using baited lines (Wakida-Kusunoki et al. 2004; Botello et al. 2010; Galindo-Cortes et al. 2014). Quotas, however, have never been implemented and in most years the TAC has been exceeded. The *O. maya* annual abundance estimates for the 2001–2011 period varied greatly from 16,219–27,019 t (DOF 2014; Salas et al. 2009; Vidal-Martínez and Olvera-Novoa 2016; Galindo-Cortes et al. 2014).

Fishing effort is regulated through permits to fish octopus. In the state of Yucatan in 2016 there were 52 permits issued for 342 large vessels and 554 permits for 2,269 small boats (Vidal-Martínez and Olvera-Novoa 2016). In Campeche 792 permits covered 1,472 small boats for 2016. In Quintana Roo, 18 permit holders operate 323 small boats (DOF 2014).

The *O. vulgaris* fishery on Yucatan shelf is managed by the same regulations as for *O. maya*, sharing the same MLS, seasonal closure and gear limitation (DOF 1994, DOF 2016a). As this species is much less available for study, however, no assessment has been done. It is thought that exploitation levels are still low and the potential exists to expand the fishery (Botello et al. 2010; Galindo-Cortes et al. 2014).

The Veracruz reef system is a protected area established as a National Park in 1992. The *O. insularis* fishery in this region has been controlled with the same regulations applied to octopus from Yucatan (DOF 1993, 1994), with notorious contradictions. Recently, however, a close collaboration between local fishermen, authorities and academia (Jiménez-Badillo 2013), established an official agreement considering definite closures for the fishery in this National Park in 2011 (1 January to 28 February and the whole of August) (DOF 2012a). The number of licenses to fish for octopus range 15 to 22, corresponding to 227 fishermen in 70 boats. A single permit was issued for Tuxpan reefs (Jiménez-Badillo 2013; Galindo-Cortes et al. 2014; DOF 2018). A recently established regulation (DOF 2016a) replaces that established by DOF (1993), recognizing explicit MLS and fishing gears for Veracruz: a MLS of 140 mm ML for females, 110 mm ML for males and the use of hooks during free diving over bottoms <5 m depth. A management plan has been recently published for octopus from the Mexican Gulf and Caribbean that includes both Veracruz reefs and Yucatan peninsula fisheries, while acknowledging their peculiarities (DOF 2014).

5.8.2. Venezuela

Regulation for the octopus fishery of northeast Venezuela began in 2008. A seasonal closure from January 1st to June 30th and MLS of 400 g BW are considered (GO 2008). Fishing gears are not mentioned in this document. Catches have to be reported monthly. Currently a new proposal is being worked out to formally allow only jigs, lines, free diving and "nasas" as legal fishing gears for octopus fishing. The use of pots, "longanizos" or chemicals to catch octopus should be considered prohibited.

Fishing effort is controlled through annually establishing the number of permits and vessels allowed in the octopus fishery (GO 2008). Permits for jigging are individuals, yearly and they cost around 3 US dollars. Permit numbers at Nueva Esparta increased from 635 in 2009 to 3,452 by 2017 while catches did not increase. A possible explanation to this discrepancy is that a significant part of catches is not being landed in the country but sold offshore to foreign vessels (Eslava et al. 2017). No assessment is performed in this fishery although high annual exploitation rates of 0.6 estimated from Margarita Island led to the conclusion that the fishery is overexploited (González et al. 2015; Eslava et al. 2017).

In Puerto Rico the only regulatory measure considers illegal to fish and/or capture octopus using a gaff with a grappling hook diameter of less than one inch (Departamento de Recursos Naturales y Ambientales 2010). To our knowledge, no other country in the region employ management measures for octopus.

5.9. Economic importance

5.9.1. Mexico

The Yucatan peninsula octopus fishery is the main fishery in the region (peninsula) and the third marine fishery resource by value and the seventh by volume in Mexico (CONAPESCA 2016). It is also the largest octopus fishery in the Americas and the third largest worldwide (FAO 2016). The value of this fishery is estimated at over 1,000 million Mexican pesos annually (ranging 40–100 US million dollars year^{-1}; CONAPESCA 2018; Vidal-Martínez and Olvera-Novoa 2016). This figure increased threefold during 2018 due to record catches and prices. It employs about 90% of local fishermen, some 15,000 in the state of Yucatan and around 5,000 at Campeche. Octopus is exported to Europe through 23 certified facilities in Yucatan and three in Campeche. A third of the landings have been exported since 1995, with a yearly exported volume ranging from $1.6–16 \times 10^3$ t and a value of 4.6–107 US million dollars (Balanza comercial de mercancías de México, Anuario estadístico; Vidal-Martínez and Olvera-Novoa 2016). In both states, Yucatan and Campeche, Octopus Product Systems have been established aiming to improve the quality of the octopus from the boat to the facilities through training programs, fishery management, design of facilities and so through close cooperation with federal and local institutions (DOF 2014; Galindo-Cortes et al. 2014).

Some 162 fishers target octopus in the Veracruz reef system, 30% of them full time. At least 1,000 families depend directly on the octopus fishery in these reefs, while others depend indirectly on supporting services such as marketing, processing, boat building and transportation (Jiménez-Badillo 2010, 2013). The fishery was valued at almost one million dollars in 2017 (CONAPESCA 2018). Efforts to culture *O. insularis* at the University of Veracruz are underway (Méndez-Aguilar et al. 2007).

5.9.2. Venezuela

In El Tirano at Isla Margarita the octopus fishing season employs 75% of the 300 fishermen and 131 small open boats. Cephalopod exports are negligible (FAO 2016), although some quantity is exported to Trinidad and Tobago, Martinique and Europe and the majority of the catch is consumed locally.

The status of the octopus fishery has changed little in the remaining region of the central western Atlantic since surveys by Voss. There is no proper fishery nor catch records. Negligible volumes are taken in a variety of gears. Octopus might be used as bait. In touristic areas, most octopus have to be imported (Voss 1960, 1973).

6. South-Western Atlantic

The South-western Atlantic, or FAO statistical area 41, encompasses the east coast of the South American continent. Throughout this region, cephalopods are a major contributor to the landings of the fisheries, reaching an average of 654,489 t annually between 1989 and 2013. The majority of the catch is made up of squid, in particular *Illex argentinus* in Patagonian waters (Haimovici et al. 1998, Crespi-Abril and Baron 2012). Octopus landings during the same period were on average 1,396 t annually, or 0.21% of the catch.

At least 14 species of the family Octopodidae are known to occur in the neritic region of the Southern West Atlantic, namely *A. burryi*, *Macrotritopus* cf. *defilippi* (Verany, 1851), *O. hummelincki*, *O. insularis*, *Paroctopus* cf. *joubini* (Robson, 1929), *C. macropus*, *Scaeurgus unicirrhus* (Orbigny, 1840), *Pteroctopus tetracirrhus* (delle Chiaje, 1830), *O. vulgaris* in the warmer waters; and *O. tehuelchus*, *Eledone gaucha* (Haimovici, 1988), *Eledone massyae* (Voss, 1964), *E. megalocyathus* and *Robsonella fontaniana* (*R. fontanianus* being the currently accepted name) (d'Orbigny, 1834) (Haimovici and Perez 1991, Haimovici et al. 2009, Ré 1998a, 2009; Jereb et al. 2013) in the colder waters. Only a few species are fished, however.

In southern Brazil *O. vulgaris* is the target of a pot longline fishery and *E. massyae* is part of the bycatch of the shrimp fishery. In central and northeastern Brazil *O. insularis* is the target of both pot longliners and small scale fisheries in which occasionally *C. macropus* is also caught (Costa and Haimovici 1990; Ávila-Da-Silva et al. 2014; Haimovici et al. 2014). Along the Patagonian coast there are two small scale fisheries for *O. tehuelchus* and *E. megalocyathus* (Ré 1998a; Ré and Ortiz 2008; Ortiz 2009; Storero 2010).

6.1. Octopus vulgaris (common octopus)

A phylogeographic analysis based on the mitochondrial genes 16S rDNA and Cytochrome Oxidase subunit I (COI) confirmed the monophyletic status of specimens of *O. vulgaris* from the Southwestern Atlantic relative to those of other areas around the world, although three distinct haplogroups were clearly differentiated, corresponding to the Americas, Europe and Africa, and Asia (Sales et al. 2013). In the Southwestern Atlantic, *O. vulgaris* is most abundant along the southern and south-eastern Brazil coast (0–100 m depth) on soft bottoms with biodetritic patches (Haimovici et al. 2009). Larger concentrations occur in the Southeastern Brazil Bight from Cabo Frio (23°S) to Santa Marta Grande Cape 29°S) (Tomás and

Petrere 2005; Ávila-Da-Silva et al. 2014), but *O. vulgaris* is fished as far south as the border between Brazil and Uruguay (lat 34°S).

In Brazil adult specimens frequently attain sizes up to 2,000 g and occasionally over 4,000 g (Tomas and Petrere 2005). Sexually mature and spawning females have been found year round along southeastern Brazil, with reproduction occurring throughout the year with no evidence of seasonal spawning peaks (Tomas 2003). Tomas (2003) found 50% of females and males were in advanced stages of maturity at 110 mm dorsal ML, and by 150 mm ML, over 90% were mature. These ML converted to total weights (TW) with the relationship $TW = 0.0019{*}ML^{2.66}$ (Tomas and Petrere 2005) correspond to 511 g and 1.167 g respectively. Along Southern Brazil, mature females with their deposited eggs were observed year round in the catches of the pot longline fishery (Haimovici pers. comm.). This species lays small eggs and has high fecundity. Paralarvae of pelagic octopod larvae identified as pertaining to *O. vulgaris* were caught using ichthyoplankton bongo nets in a series of pelagic surveys along the outer shelf and slope of Southeastern Brazil and Southern Brazil in autumn and winter, but not in spring (Santos and Haimovici 2007).

Castanhari and Tomás (2012) investigated the growth of *O. vulgaris* by counting the microincrements on the lateral wall of the upper beaks of 120 specimens and observed the microincrement pattern was similar to the one validated experimentally for *O. vulgaris* in the Mediterranean Sea by Canali et al. (2011). The number of microincrements varied from 162 to 356 (ML 50 to 1633 mm, 55 to 1498 g). Growth was fitted to potential relationships ($ML = 0.876a^{0.876;}$ WT: $0.001\ a^{2,424}$) and no differences were observed between males and females.

The diet of *O. vulgaris* along Southern Brazil was investigated by examining stomach contents (n:117) and by collecting prey items carried into longline fishery pots by octopus. Crustaceans (62%), followed by fish (29%) and cephalopods (9%) were the most frequently consumed prey. Within the longline pots, partly eaten fresh remains of 11 species of crustaceans (Brachuiura, Scylaridae, Squillidae), 24 teleost and two elasmobranch fishes, three Octopodidae and polychaetes, and fresh shells of seven bivalve mollusks were identified Although crustacean and mollusk are probably the main prey of *O. vulgaris* in southern Brazil, fishes seem to be a regular and important part of the diet (Haimovici and Freire 2007).

6.1.1. Stock Identification

The distribution of *O. vulgaris* is continuous in the neritic waters of Southern and South-eastern Brazil along which spent females and pelagic paralarvae have been observed over the shelf and upper slope. The lack of oceanographic barriers and surface currents parallel to the coast (northward Brazil Coastal Current and southward Brazil Current) do not favor isolated stocks in the region. Moreira el al. (2011) observed high variability of six microsatellite loci of *O. vulgaris* but did not identify a consistent geographical pattern that could be associated to isolated populations or stocks. Therefore, at present, a single stock is considered to exist along Southern and Southeastern Brazil.

6.1.2. Fisheries

Since at least the 1970s *O. vulgaris* has been caught as part of the incidental catch of double rig otter board trawlers targeting shrimp in coastal waters (>30 m) that land in harbors of Rio de Janeiro, São Paulo and Santa Catarina Estates. It was also landed by semi-industrial double rig decked trawlers smaller than 15 m length, fishing primarily inshore (<30 m) along São Paulo State and targeting the sea-bob shrimp *Xiphopenaeus kroyeri* (Costa and Haimovici 1990; Haimovici and Mendonça 1996; Graça et al. 2002; Perez et al. 2007; Tomás et al. 2007; Graça et al. 2002).

The industrial longline pot octopus fishery was introduced by the Santos (SP) fishing fleet in 2003 and quickly spread to the other main ports of the region (Ávila-da-Silva et al. 2014). Most fishing boats from Santos were wooden or steel converted pair trawlers, 15 to 24 m long and 180 a 365 HP, equipped with hydraulic winches. The fishing gear consists of a main line, usually 10 to 12 miles long with 1,500 to 2,500 pots attached to short secondary lines. Inox steel snaps are used to fix and remove the secondary lines to the main line. Initially PVC pipes were used as pots, but were soon replaced by a plastic model used in Korea. This plastic model is 33 m long with a diameter of 16–18 cm diameter and is ballasted inside with one to two kg of concrete. The lines are anchored at regular distances and generally no buoys are used to display the positions. Lines are deployed along parallel isometric lines and the skippers use GPS to locate them for retrieval. Lines and pots are usually left at sea between fishing trips. Fishing trips range from 5 to 15 days. The São Paulo fleet fishes mostly between latitudes 23°S–27°S and 40 to 135 m depth. The number of pots per boat reached 35 thousand in

2005 and 2006, but decreased to 15 to 23 thousand in former years (Ávila-Da-Silva et al. 2014).

6.1.3. Catches/Landings

Almost all *O. vulgaris* is landed by industrial fisheries but small scale artisanal fishing with hand lines and baited barbless hooks exists along rocky shorelines for which landings are not recorded. Until 2002 all recorded landings were by trawlers. The mean annual total octopus landings between 1979 and the beginning of the longline pot fishery in 2003 was 432 t and represented 0,10% of the total marine landings fisheries for the period. Between 2004 and 2012 total octopus mean annual landings increased to 1,370 t and the maximum landings were over 1,800 t in 2007 and 2008. On average, 66% of Santa Catarina and São Paulo landings were attributed to the longliner pot fishery. No data discriminated by gears are available for Rio de Janeiro. São Paulo and Rio de Janeiro landings for 2013–2015 show some recovery following the fall of production in 2010 (Figure 20).

During the period in which larger catches were recorded (2004–2009), up to 41 longliners fishing with pots landed in São Paulo, 21 in Santa Catarina and 10 in Rio Grande do Sul, with mean landings per trip being 2,894 kg (n = 1,694), 3,597 kg (n = 360) and 3,624 t (n = 36) respectively. Most landed octopus weighted between one and two kilograms (Ávila-Da-Silva 2014; Univali/CTTM 2010, unpublished results).

6.1.4. Economic importance

The species *O. vulgaris* is of small economic importance when considering marine fishing in Brazil overall. Until 2003 it represented less than 0.1% of the total marine Brazilian recorded landings and was all consumed in the national market, mainly São Paulo, where is it is appreciated by the Italian and Japanese descendant communities. Since the inception of the longline pot fishery in 2003, *O. vulgaris* in the Brazilian landings increased to 0.27%. Favorable exchange rates, and higher production stimulated fishery products exports in the early 2000s (Silva-Filho et al. 2005). Between 2004 and 2009 55% of the total landings of *O. vulgaris* - that is, most of those landed by the pot fishery - was exported, yielding a total of 27 million US$. The European Union, in particular Spain, was the main importer (85%) followed by the United States and Japan (Archidiacono and Tomás 2009; Ávila-Da-Silva et al. 2014). The world financial crisis of 2007, the Brazilian currency appreciation against the dollar and increasing oil prices

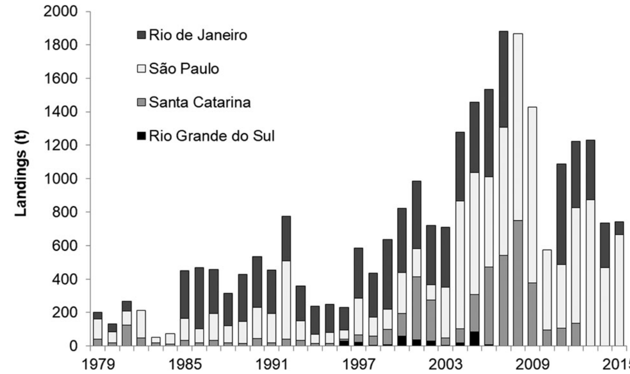

Figure 20. Reported annual landings of *Octopus vulgaris* in the Southern and Southeastern Brazil states. Sources in the text.

discouraged exports, and probably limited the total effort in the pot fishery.

6.1.5. Fishery management and stock assessment

The exponential growth of the longline pot fishery between 2003 and 2004 can be explained by several factors (1) the success in fishing octopus in the outer shelf of São Paulo (2) the favorable exchange rate and the access to the export market (3) the cheap conversion of trawlers and bottom longliners fishing on overexploited stocks (4) the free access to a non-regulated fishery.

In 2005 the Federal Secretary of Aquaculture and Fisheries published a norm that limited the number of licenses to fish octopus with longline pots to 25 fishing boats with former licenses for other gears. Each fishing boat was authorized to use up to 20,000 pots and after two years remain in the fishery or return to operate with their former license. Furthermore, a minimum ML of 110 mm for the retained octopus was established; and to minimize conflicts with boats fishing with other gears, fishing, was limited to beyond the 70 m isobaths. It also imposed the presence of observers in 25% of the fleet. All the 25 licenses were granted to boats based in São Paulo. As the fishery quickly expanded southwards and northwards, in 2008 18 licenses were renewed for São Paulo and another 10 for boats based in Santa Catrina for fishing in southern Brazil. In practical terms the enforcement capacity of the federal fishery agency is limited and a number of unlicensed boats fished irregularly with no control on the number of pots per boat, which may have reached 40 thousand per boat (Ávila-Da-Silva et al. 2014).

In terms of assessment, only a short series of catch and effort data is available from São Paulo and shows an increase from ca 400 kg per 1,000 examined pots in 2004 to ca 900 kg in 2008 followed by a decrease to

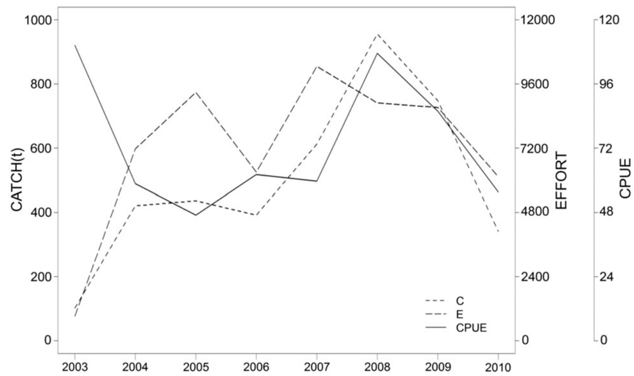

Figure 21. Catch (C), effort (E) in 1,000 examined pots and catch per unit effort (CPUE) in kg per 1,000 examined pots for the pot longline fishery based in São Paulo, Brazil between 2003 and 2010. (Avila da Silva et al. 2014)

400 kg in 2010 (Figure 21). It is not clear if natural fluctuation in the abundance or overfishing was responsible for the decrease. Former recovery of the landings in 2011–2015 (Figure 20) suggest the first hypothesis. On the other hand, the number of days at sea increased from eight to twelve and the distance traveled by boats landing in Sao Paulo increased from 50–100 nm in 2008 up to 70–150 nm in 2009–2010, suggesting the necessity to explore further fishing grounds due to decreasing yields (Ávila-Da-Silva et al. 2014).

6.2. *Octopus insularis*

This is a medium to large sized octopus that can attain a weight of over 2,000 g. It lays small eggs and displays the large fecundity common in the warm tropical coastal waters along northern, north-eastern and central Brazil and its oceanic islands (Leite et al. 2008a; Sales et al. 2013). Its known distribution has recently been expanded to the two tropical Mid Atlantic islands of Ascension and St. Helena (Amor et al. 2015) and the North Caribbean Sea along Mexico (Lima et al. 2017). It is also likely to occur in the Southern Caribbean Sea but its presence has not still been recorded.

Off the Brazilian oceanic islands, this octopus is associated with hard substrates as reefs, bedrock, rubble, gravel, sand beds and rocky bottoms, regardless of the presence of algae, at depth up to 40–50 m (Leite et al. 2009a). Juveniles have only been recorded in shallow waters less than 5 m deep (Leite et al. 2009a). Like most benthic octopods, *O. insularis* feed on a wide variety of prey species, with small crabs being predominant in their diet. It can be considered a specialized generalist (Leite et al. 2009b) as its dominant preys change between regions (Leite and Haimovici 2006). It uses mainly chemotactile exploration to locate its prey but can adopt several hunting strategies, such as opportunistic visual attacks, depending on variables such as size, opportunity, and habitats (Leite et al. 2009b). It performs intense searches for food during short hunting trips, with the frequent use of cryptic body patterns during foraging trips suggesting that this species is a "time-minimizing" forager in order to minimize the risk of being preyed on (Leite et al. 2009b).

In a year-long study of the life cycle of *O. insularis* in a coastal shallow environment (15–35 m) of vermetid reefs, corals and coralline algae along Rio do Fogo in northeastern Brazil, mature specimens were recorded year round, with peaks of maturation strongly correlated with the cycles of sea surface temperature and wind intensity (Lima et al. 2014). The largest male in this study was 1,600 g and largest female 1,940 g. Males matured at a considerably smaller size than females, the mean ML and BW at which 50% of males attained maturity were $ML_{50\%}$: 60 mm and $W_{50\%}$: 212 g and 90% were mature at 85 mm and 443 g. Females attained 50% sexual maturity 95 mm and 493 g and over 90% were mature at 130 mm ML and 1,130 g. In culture, a female laid 83,000 eggs 2.06–2.47 mm long and the ML of the hatchlings was 1.50–1.92 mm (Lenz et al. 2015). The number of intraovarian oocytes in mature females ranged from 60 to 120 thousand (Lima et al. 2014). Sperm in oviducal glands of immature females is evidence of early fecundation along growth. By growing larger, females of this species increase their fecundity and accumulate energy reserves for parental care as feeding stops after spawning (Hanlon and Messenger 1996; Mather et al. 2010).

6.2.1. Stock identification

In a phylogenetic study using Cytochrome Oxidase subunit I (COI) for samples of *O. insularis* from the western Atlantic by Lima et al. (2017), 20 haplotypes were recorded. The highest genetic diversity was found along northeastern Brazil and the nearest Fernando de Noronha island. Haplotype nets and neutrality test points suggest a recent population expansion, and AMOVA tests indicate three main stocks in the Northern Caribbean Sea, Northeastern Brazil and Central Brazil. Despite having a small planktonic paralarvae favoring dispersion, other characteristics such as low mobility of adults may limit the connectivity along its distribution range in three stocks that appear to be structured by marine currents and seamounts chains.

Figure 22. *Octopus insularis* fisheries along central and northeastern Brazil (Haimovici et al. 2014) (A–C) Gaff fishing on shallow reefs during low tides (D) Free diving fishing. (E–F) Small scale experimental fishing with pots. (H) Industrial pots longline fishery.

6.2.2. Fisheries and management

The main species of octopus fished along central and north-eastern Brazil and its oceanic islands is *O. insularis*. Several hundred tonnes are fished each year in four geographically distinct fisheries (Haimovici et al. 2014) (Figure 22).

6.2.2.1. The coastal reef fishery along Central and North-eastern Brazil. Octopus are fished along more than 2,000 km of coastline from Bahia to Ceará states. Octopus are caught over the shallow coastal reefs during low tides with gaffs (handhold hooks) and free diving along the reefs base and rocky coastlines (Figure 22A–C).

These small-scale fisheries are mostly a part time and seasonal activity undertaken for self-consumption and supply to local restaurants and tourists (Martins et al. 2012). The total quantity of octopus fished is unknown, but in 2000 on a typical coastal reef along Bahia State the mean daily catch per fisher recorded was 1.54 kg and total annual catch was estimated as 4,457 kg (Jambeiro 2002). Although smaller octopus are caught during the main tourism season (late spring to early autumn), yields are higher and prices in 2000 attained an average of 10 US$/kg (Jambeiro 2002).

Most *O. insularis* are caught in marine protected areas where small scale fishing is permitted. There are no specific rules for this fishery but environmental legislation for conservation of the reefs include the banning of the use of levers or bleaching water to extract the octopus from their burrows, as well as the prohibition of anchoring boats on the reefs. Young octopuses (100 to 400 g) are more commonly caught as larger spawning females move to deeper waters out of the reach of the fishers. At its current level there is no evidence that the populations are affected and environmental education to raise awareness among the local population to preserve their reefs occurs in many localities (Martins et al. 2012; Haimovici et al. 2014).

6.2.2.2. Fernando de Noronha fishery. The island of Fernando de Noronha, 430 km off mainland Brazil, is an important touristic destination Around part of the island, free divers catch *O. insularis* with gaffs along the rocky coastline at depths from 2 to 25 m (Figure 22D), and small octopus are collected over the reefs during low tide, mostly by women and children due to the restricted access of the island. From 2003 to 2005 the life history and fishery of *O. insularis* were studied to support its management. Fishers were found to be mostly native, aged between 18 and 55 years, having dived for octopus since their youth for family consumption (Leite and Haimovici 2006; Leite et al. 2008b, Leite et al. 2008c). These are not full-time fishers and the most active fishers dived on average twice a week, with mean harvest weighing 7.95 kg. In 2004, 45 divers fished between 3 and 6 t annually. Half of the catch was for self-consumption and the other half sold to restaurants and hotels, supplying at least 11% of the local demand. The mean weight of the octopus sold by divers was 940 g, and the price per kg oscillated between 5 and 10 US$. The octopus fishery has small economic importance, but it is part of the local culture (Leite et al. 2008c).

The population of *O. insularis* of Fernando de Noronha does not seem to be at risk by recreational and small scale fishing. Most of the island and its surrounding waters are a National Park in which fishing is banned. The total area of water within the depth range of 0–20 m around the island (where *O. insularis* is found) is at least 20 km^2, 30 times larger than the 0.6 km^2 in which fishing is legal. Furthermore from December to April fishing is inhibited by strong winds which reduce visibility. No spawning females were observed in shallow waters, and it is thought that large females may move deeper to spawn, out of the range of the free diving fishery. Octopus is part of the charismatic fauna of the islands and management is focused to guarantee their conservation in the island. Regulated small scale fishing by locals is not a threat for the *O. insularis* population around the island. The management plan approved in 2005 includes a) a limited number of licenses issued only to local residents; b) the banning of all gears except gaffs to minimize illegal fishing of lobsters; c) the banning of irritants such as bleach to force the withdrawal of octopus from burrows; d) a minimum ML of 80 mm and e) the prohibition of fishing on the shallow reefs, to protect the nursery grounds and allow the recruitment to deeper areas (Leite et al. 2008c).

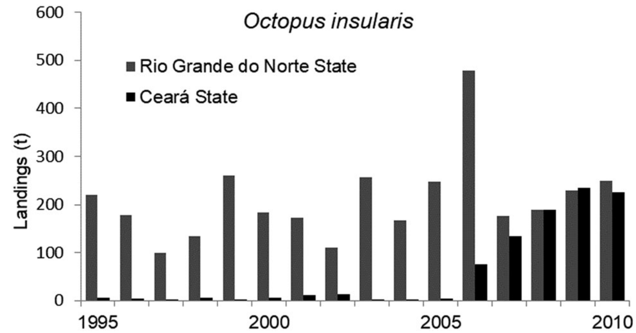

Figure 23. Reported annual landings of *Octopus insularis* in Northeastern Brazil Rio Grande do Norte State (gray) and Ceará Estate (black) sources in the text.

6.2.2.3. The Rio Grande do Norte diving fishery. Along the 410 km of Rio Grande do Norte State, 20,000 small scale fishers in 98 coastal communities are involved in fishing. Lobsters are the main fishing resource but *O. insularis* are also important. Mean annual octopus landings recorded (1994–2010) were 219 t, with catch most years oscillating between 100 t and 250 t, apart from 2006 which had exceptional catches of 478.5 t (Figure 23).

Octopus are fished with gaffs by both freediving and scuba fishers along the narrow continental shelf of Rio Grande do Norte. Free divers use small, 3.5 to 4.5 m long flat bottom boats called “paquetes” (Figure 22E). Scuba divers fish from 7.5–10.0 m boats with larger internal motors. Most boats have GPS for locating their fishing grounds. Although fishing for octopus using scuba equipment is illegal, it is used by fishers mainly targeting lobsters, who then also target octopus especially during the seasonal closure of the lobster fishery.

The municipality of Rio do Fogo situated in the Costa dos Corais, a large marine protected marine area of 180,000 ha, 90 km north of the capital Natal is responsible for half of the catches of octopus in the State of Rio Grande do Norte (Vasconcellos 2008). A recent study by Andrade (2015) showed that around 34% of the ca 4,000 ha urban population of Rio do Fogo are workers (n: 238), or their dependents (n = 1,017), associated directly or indirectly with the production and service chain of octopus (Andrade 2015), e.g., fishers, buyers, transporters. The final consumers in the chain are mostly restaurants and hotels. The price increase from the first sale by the fisher and the last buyer in a Natal fish shop is 82% and the initial hydration (storage in fresh iced water to increase body weight) and the four step sales chain makes octopus an expensive dish at a restaurant, as cooked octopus attains only 63% of the weight.

The octopus fishery is *a de facto* free access fishery for local fishers but there is an informal geographical division of the fishing grounds between coastal communities. In the free diving fishery in Rio do Fogo, the median landing CPUE between 2002–2010 was 3.7 Kg/day- fisher, with a minimum of 2.7 kg/day-fisher in 2002, a maximum of 5,0 Kg/day-fisher in 2009. The lack of significant changes suggests that there was no overexploitation during that period (Andrade 2015).

Fishing octopus with pots from small boats was investigated in Rio do Fogo as an alternative to fishing for octopus when underwater visibility is low in the windy season from June to November (Figure 22F). In experimental fishing between 2011 and 2013, the mean rate of occupancy of the pots collected every 7 days was 8.5%; the mean weight of the octopus was 815 g and ranged from 302 to 2,005 g. Leaving the pots for 14, 21 and 28 days did not yield significantly larger catches than those left for 7 days. No significant differences were observed when pots of different colors (green, yellow, red and black) were used. Shortly after beginning the experimental fishing, fishers began producing their own pots using PET bottles and cement. These pots cost seven times less than the PVC pots, the owners could mark them for recognition and lasted longer. A comparison of the profitability of a pot fishery with free diving for fish, lobster and octopus as targets showed that fishing with pots was economically viable during the low visibility season, however, a critical, and still unsolved problem was the theft of the catch and the longlines (Andrade 2015).

6.2.2.4. The Ceará State longline pot fishery. Recorded landings of octopus in Ceará State ranged from 2.0 to 12.5 t between 1995 and 2005. With the development of the Itarema pots fishery landings increased rapidly since 2006 to attain 225.5 t in 2010 (Figure 23).

In 2005 a fleet of mid-sized decked boats begun fishing *O. insularis* with longlines of pots in a 2,000 km^2 on gravel bottoms at depth ranging from 20 to 40 m deep on the narrow shelf of northern Ceará State between 39°30′W and 40°30′W (Braga et al. 2007). The fishing boats are 10–15 m long, powered by motors over 60 HP and have a small cabin at stern (Figure 22G). They were provided with GPS, VHF radios and echo sounders and geared with hydraulic winches to pull the longlines. The longlines main lines are of twisted polyester and polypropylene of 10 mm of diameter, 2,000 to 4,000 m long, each with 200 to 400 pots attached with snaps to 0.5 m secondary lines of 3 mm twisted polyester. Initially plastic pots were similar to those used for *O. vulgaris* in south-eastern Brazil that soon were replaced by slightly smaller locally produced polyethylene pots 30 cm long, 17 cm of diameter, reduced to 11 cm in the mouth, with a larger base ballasted with up to 3 kg of concrete. Smaller pots are more adequate for the smaller sized *O. insularis* and shorter secondary lines and heavier ballast avoid wearing due to rolling over the stone and gravel bottoms over which the species is fished.

For each trip fishing boats spend around 5 days at sea and fish with ca 8,000 pots. Longlines are moored to the bottom with anchors and their position recorded in the GPS. No buoys are used for localization to avoid theft. Longlines are examined at around two weeks intervals (Haimovici et al. 2014). The mean weight of the octopus caught are between 600 and 700 g. Bivalves and gastropods conchs present in pots occupied by octopus are collected (Figure 22H) and sold for artisanal works and collectors to complement the rent of the fishers (Matthews-Cascon et al. 2009).

Although the pot longline fishery begun as an alternative to lobster fishing during the seasonal closure of the lobster fishery from December to April, it has become an almost year round activity. Landings and catch per day in grams per pot and day of soaking of the pots longline fishery are higher between the rainy season from August to December, yield falls in the dry season and some boats stop fishing from January to April (Figure 24). In the dry season, the percentage of females in the catches decrease and the number of pots with spawned females increase suggesting that large mature females leave the fishing grounds towards higher depths to spawn (Marinho 2011; Batista 2016).

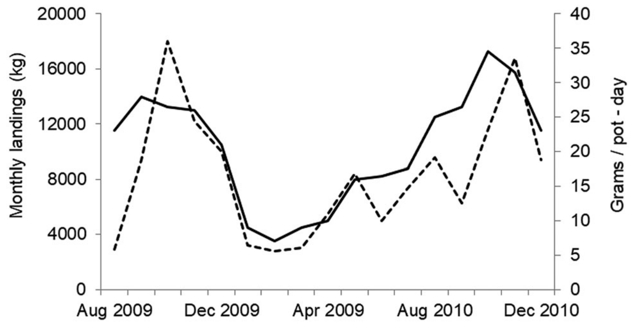

Figure 24. Reported monthly landings and catch per unit effort (CPUE) in grams per pot and day fishing by the pot longline fishery based in Itarema, Ceará State between August 2009 and December 2010 (Marinho 2011).

In 2008, the number of longliners was of 9 and increased to 17 in 2010. Each boat used a mean of 8,241 pots at sea (Haimovici et al. 2014). In 2010 there were no signals of overfishing, unfortunately data on the former years are lacking. The operating costs of the pots longline fishery are reduced because no bait is required, fuel consumption is low and the fishing grounds are near the harbor. In 2008, expenses for a five day fishing trip expenses were the equivalent to the first sale price of 150 kg of octopus, or 600 kg in per month while the mean monthly catch was of 2,137 kg.

The development of the pots fishery has some marketing limitations. The mean weight of *O. insularis* in the catches of the pots fishery is 600–700 g, too small for export that requires octopus of over 1,000 g. Almost all catches are consumed in the region. Initially in 2005 the *O. insularis* fishery was regulated by the same rules that govern the *O. vulgaris* fishery in Southeastern Brazil. In 2007, the minimum size limit of 110 mm ML was relaxed and the maximum number of licensed boats was temporarily established in 25, each fishing with up to 5,000 pots. At present the licenses have expired and fishery statistics collection has been discontinued. The fishery can be considered as free access and unmanaged.

6.3. *Eledone massyae*

The small *E. massyae* is an endemic octopus with large eggs that rarely attains more than 200 g found from the Southwest Atlantic with records from central Brazil to San Jorge Gulf in Argentina (Haimovici and Perez 1991; Ré 1998a; Haimovici et al. 2007). In the outer shelf of southern Brazil early stages of sexual maturation are more frequent from summer to spring and both males and females attain full maturity in early summer. Mature females bear up to little more than one hundred of oocytes of up to 12 mm long. The size at maturity of females was estimated at approximately 50mm (75g). The spawning grounds are still unknown, but probably are in hard substrates from the shelf break. (Perez and Haimovici 1991). In the Buenos Aires province the peak of mature and mated females was observed in spring (Ré 1998a). Along southern Brazil its main preys are benthic crustaceans, but polychaetes, gastropods, cephalopods, bony fishes and amphipods were also recorded (Perez and Haimovici 1995).

6.3.1. Fisheries

Because of its small size and low fecundity *E. massyae* is not a target for fishing but it is caught as bycatch in the trawl fisheries targeting shrimp along the region. The only recorded landing in Argentina was 76 t in 1986 as bycatch in a shrimp trawl fishery along Mar del Plata (Ré 1998b). In Rio de Janeiro mean landings were 10.7 t between 2011 and 2015 (Fiperj 2016). It is probably discarded or consumed by the fishers when it is caught in small numbers.

6.4. *Octopus tehuelchus*

This is a small sized octopus with large eggs and low fecundity that can reach little more than 200 g and is found from Southeastern Brazil to the San Jorge Gulf in Argentina (Haimovici and Perez 1991; Ré 1998a). In Argentina, the highest abundance were recorded from in the intertidal and infralitoral up to 90 m depth. of the north Patagonian gulfs of San Matías, San José and Nuevo (lat 43°S), where the species inhabits rocky bottoms using holes for protection and breeding (Iribarne 1991a, 1991b; Ré 1998a). In Brasil *O. tehuelchus* is found in the inner shelf on gravel and soft bottoms and uses large gastropods shells for refuge and spawning (Alves and Haimovici 2011).

In the Northern Patagonian waters specimens attain two years of life but some specimens, mostly females, may reach three years (Pujals 1982; Iribarne 1991a, Storero et al. 2016). After hatching, growth is rapid: males can reach adult size (28 mm ML, 30 g) with three months (Iribarne 1990, Ré 1998a). The peak of maturity of males is attained between November and March of the second year of their lifetime, however, some mature males are observed year round. Males start copulating 2–3 months before females attain full maturity. Females maturation starts in spring and a high proportion of females are mature in autumn, size at maturity is 64 mm ML and between 15 and 18 months old and the maximum number of laid eggs was of around 220 (Ré 1989; Iribarne 1991a, 1991b; Ré 1998a). In this region *O. tehuelchus* is an active and generalist predator on mollusks, crustaceans, mainly mussels and hermit crabs and cannibalism is important in this species during summer and autumn (Ré and Gómez Simes 1992). Growth slows down in winter (Ré 1998a; Sotero et al. 2016).

In southern Brazil, *O. tehuelchus* it was recorded from the inner shelf mostly less than 50 m depth on mud, sand or gravel sediments where large gastropod shells are used as shelters (Haimovici and Perez 1991; Alves and Haimovici 2011). Females are more numerous in shallower waters and attain a larger size than males. Fully mature males and females were observed in all seasons and mean ML at maturity was 46 mm for females and 27 mm for males. The maximum recorded number of laid eggs was around 240 measuring 8 to 14.5 mm long.

6.4.1. Fisheries and management

The only fishery of this species is located in San Matías Gulf were it has been fished for more than 60 years. Largest catches between 1965–1973 when, between 100 and 300 t were recorded annually. Since then catches decreased sharply to less than 50 t per year (Iribarne 1991a; Ré 1998b; Narvarte et al. 2006). Octopus are caught by fishermen using hooks to remove them from the holes of the rocky bottom during low tides or diving in shallow waters from late spring to autumn (March–April). Since 2004, *O. tehuelchus* is also captured by providing plastic PVC tubes as artificial shelters. This last method is highly efficient but has the potential to capture large numbers of incubating females (Osovnikar et al. 2006). Since 2005, some restrictions were implemented, such as limiting the number of fishermen to 10 and the number of traps per fishermen to 3,000, also the fishing season was restricted from December to April.

6.5. *Enteroctopus megalocyathus*

This species is distributed throughout the southern coast of South America, from Chiloe Island (∼42°S) in the southeast Pacific Ocean (Rocha 1997; Ibáñez et al. 2009) to San Matías Gulf (42°S) in the southwest Atlantic Ocean (Ré 1998a). In the Southwestern Atlantic specifically, this species is distributed from the San Matías Gulf to Beagle Chanel, including Malvinas Islands and Namuncurá Bank. Individuals are found from the intertidal region up to 140 m of depth (Ré 1998a), usually associated to rocky bottoms.

In general terms, the maturity cycle of the species is annual with a clear peak of maturity in spring and summer. A low proportion of females at advanced maturity stages are found in July, and of newly spawned eggs in August; however, there is a suggestion of a weaker second spawning period in winter. Males reach maturity earlier in the year and at a smaller size than females (Ortiz et al. 2011). The smallest mature male sampled was 528 g of BW and 102 mm of ML. The smallest advanced mature female was 659 g of BW and 105 mm of ML. The size at maturity was 135.4 mm (1,072 g) for males and 158.5 mm (1,613 g) for females. Ortiz et al. (2011) suggested a bathymetric migration in spring and summer when most brooding females migrates out of shallow waters (less than 20 m deep) towards deeper and thermally stable sites suitable for spawning. This could explain the drop in the number of individuals at advanced maturity stages approaching shallow waters during summer. In addition, sex ratios were close to 1:1 in spring and summer, suggesting that both sexes would move from nearshore to offshore areas and vice versa nearly at the same time. The maximum estimated fecundity for the species in the northern Patagonian Gulfs was of ca 6,500 oocytes Ortiz et al. (2011). Longevity estimates based in the analysis of modal progression of sizes of along three consecutive years of samplings was estimated in 24–36 months (Ortiz 2009). It is a key species in the trophic web of benthic ecosystems in Patagonia. This species is an opportunist predator with ontogenetic changes in the diet. In Patagonian waters, at least 26 prey items were observed: 12 species of crustaceans (the most representative are *Peltarion spinosulum*, *Cyrtograpsus* sp. y Munida sp.), 8 species of teleost belonging to the families Nototheniidae, Tripterygiidae and Clinidae, 3 species of polychaeta belonging to the families Nereidae, Polinoidae and Eunicidae, and 3 species of mollusks belonging to the family Otopodidae suggesting a high level of cannibalism.

6.5.1. Fisheries

In northern Patagonia the red octopus is harvested by small-scale fisheries that operate by diving in shallow waters or by extracting the animals from rocky intertidal shores. In the north Patagonian Atlantic coast (San José and Nuevo gulfs), the species is harvested mainly by diving using an iron-hook to extract octopus from holes and crevices located in isolated rocky outcrops or in submerged abrasion limestone platforms (Ré 1998b; Ortiz et al. 2006). The fishing period is restricted from March to November, when octopus

Figure 25. Historical octopus catches for the Northeast Atlantic (Source: Eurostat/ICES database on catch statistics – ICES 2011, Copenhagen).

abundance in shallow waters is highest (Ré 1998a, 1998b). Although fisheries of *E. megalocyathus* are unregulated and there are no official statistics of their landings, Ré (1998b) estimated captures from 10 to 15 t per year for this area. Further south, Cinti et al. (2003) estimated around 9–10 t for intertidal harvesting in Camarones Bay (44°42′S 65°54′W) and its surrounding areas.

7. North-Eastern Atlantic and Mediterranean

As the same octopus species are targeted throughout European waters, the Northeast Atlantic and Mediterranean (FAO statistical areas 27 and 37, respectively) regions are discussed together. Previously considered a minor fishery resource, the past 30 plus years has seen an increase in the importance of these fisheries, with cephalopod fisheries in Europe today playing a significant role in the region (Pierce et al. 2010). Initially averaging 14,017 and 17,867 t in the early 1950s, total reported cephalopod landings in the Northeast Atlantic and Mediterranean, respectively, have increased over the second half of the previous century. In recent years (2000–2016) total cephalopod catch has averaged at 54,542 t for the Northeast Atlantic and 56,837 t in the Mediterranean (FAO 2016). Catch records from 1950–2016 indicate octopus catch contributed between 17–47% (NE Atlantic) and 26–49% (Mediterranean) to total cephalopod catch. Data for more recent years (2000 onwards) shows octopus to make up almost a third of all cephalopod landings in the Northeast Atlantic (∼29%), and close to half in the Mediterranean (44%). Total octopus catch in these two regions has averaged at 15,646 and 25,133 t, respectively; with the highest reported octopus landings for this century being 31,319 t

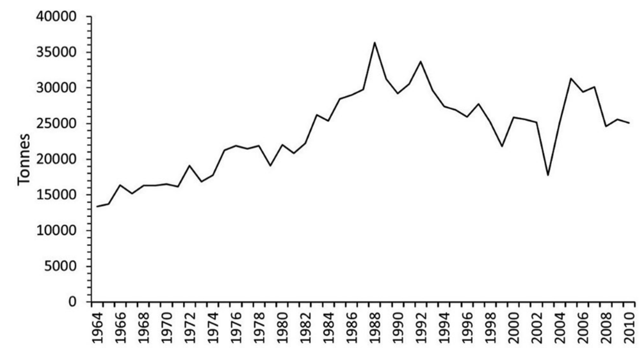

Figure 26. Historical octopus catches for the Mediterranean (Source FAO, Global Capture Production Statistics 1950–2016.).

(Mediterranean). It is clear from Figures 25 and 26 that the historical octopus catches in the Northeast Atlantic and Mediterranean reflect the growing importance of this fishery over the decades. Octopus landings in European waters consist solely of species belonging to the Octopodidae family, and include *O. vulgaris*, *E. cirrhosa* and *E. moschata*.

7.1. *Octopus vulgaris*

This species is particularly abundant in the Eastern Atlantic Ocean and Mediterranean Sea (Belcari and Sartor 1999), inhabiting rocky, sandy, and muddy substrata from the coast to the edge of the continental shelf at depths up to 200 m (Cabranes et al. 2008). In the Gulf of Cádiz, most of the population concentrates on the continental shelf, down to 100 or 150 m depth (Guerra 1981). A similar depth distribution is observed in the Mediterranean with most *O. vulgaris* inhabiting depths <100 m (Belcari et al. 2002).

Male to female sex ratio appears to be relatively similar for both the Northeast Atlantic and Mediterranean (1.06:1 and 1:1, respectively) with no evidence of significant seasonal variation (Quetglas et al. 1998; Silva et al. 2002). Although spawning occurs throughout the year, as detailed by Pierce et al. (2010), spawning peaks vary depending on locality. For example, two peaks have been observed in Portuguese waters in winter and summer (Moreno 2008); and spring and autumn off Morocco (Faraj and Bez 2007) and the Canary Islands (Hernández-García et al. 2002). These populations fall within the main upwelling regions along the Northeast Atlantic coast (Pierce et al. 2010). In the Gulf of Cadiz, spawning peaks in April–May and August (Silva et al. 2002), with other authors also reporting a main spawning peak in summer (Rodríguez-Rúa et al. 2005; Moreno 2008). A summer spawning peak has also been observed in Mediterranean populations (Sánchez and

Obarti 1993; Mangold 1997; Belcari et al. 2002b). Males mature earlier than females (Rodríguez-Rúa et al. 2005), and therefore reach maturity at a smaller size. In the Gulf of Cadiz size at maturity has been estimated as 10.4 cm and 671 g for males, and 17.6 cm and 2,023 g for females (Silva et al. 2002); and 850 g for males and 1,250 g for females on the Atlantic coast of Andalusia, south of Spain (Rodríguez-Rúa et al. 2005). Total fecundity ranged between 70,060 and 605,438 oocytes (mean = 315,197 ± 135,865) (Silva et al. 2002).

Upon hatching, paralarvae are planktonic, only adopting the benthic lifestyle upon settlement at ~7.5 mm ML (Villanueva 1995). In the coastal areas off Greece, a main peak of benthic settlement was observed during summer, and a secondary, irregular peak during late autumn (Katsanevakis and Verriopoulos 2006). Katsanevakis and Verriopoulos, (2006) estimated that more than 50% of the just-settled individuals will eventually die after 3 months, with mortality rate declining as individuals grow larger. Juvenile recruitment is sensitive to unpredictable environmental fluctuations (Cabranes et al. 2008). Adults and juveniles may feed on crustaceans, teleost fish, other cephalopods, and polychaetes (Pierce et al. 2010). In the eastern Mediterranean, specifically off the coast of Spain; the diet is predominantly comprised of fish and crustaceans (Quetglas et al. 1998), with a high percentage of that (80%) being crustaceans (Guerra 1978; Sánchez and Obarti 1993; Quetglas et al. 1998); whilst off Portugal bivalves make up the highest proportion of the diet (Rosa et al. 2004).

7.1.1. Fisheries

It is taken throughout the year as a target species in a number of small-scale coastal fisheries operating at depths of 20–200 m in the Northeast Atlantic and Mediterranean (Pierce et al. 2010). The *O. vulgaris* fisheries are of substantial importance in southern Europe (Pita et al. 2015), and this is especially true for Spain and Portugal. In the Spanish multi species demersal fishery operating in the Gulf of Cadiz (NE Atlantic), *O. vulgaris* constitutes one of the most important species in terms of landed catches (Silva et al. 2002). Both trawl and artisanal fleets participate in this fishery, with the latter using species-specific gear such as clay-pots, locally called "alcatruces or cajirones"; hand-jigs, locally called "chivos" and "pulperas," and traps (Silva et al. 2002). The clay pot fishery exclusively dedicated to catching *O. vulgaris* is made up of 185 artisanal vessels, most of which are 5.3 t of gross tonnage (GT) and 55 hp (Sobrino et al. 2011). Catch volume fluctuate annually, depending on the abundance and availability of *O. vulgaris* (Sobrino et al. 2011).

A census of the artisanal fleet operating out of Galicia (the main fishing region in Spain, also NE Atlantic) recorded almost 5,000 vessels operating in the coastal waters (Otero et al. 2005). Moreover, in terms of cephalopod catch for this fishery, the *O. vulgaris* catch is the largest when it comes to volume (Otero et al. 2005). It is targeted using traps (called "nasa de polbo"), which are fairly specific to octopus, and which forms 80–90% of the total catches in this gear (Pierce et al. 2010). In Portugal, the octopus fishery is of considerable social and economic value, and small-scale fishing is increasingly economically dependent on this resource (Pita et al. 2015). Pots and traps of various types are among the most widely used gears in these Portuguese small-scale fisheries (Erzini et al. 2008). Depending on fishing vessel size, vessels operating in the small-scale fishery may carry from 750 up to 1,000 traps (Erzini et al. 2008). In the Algarve region, the most widely used octopus traps are metal frame, hard plastic netting, single entry traps (Erzini et al. 2008).

In the Mediterranean, octopus are also exploited by a variety of gears including commercial trawl gear and artisanal gear such as fyke nets, pots and traps (Tsangridis et al. 2002). In the Kavala and Limenas regions of Greece (Eastern Mediterranean), fyke nets consisting of two or three chambers made of netting and hoops are used for catching (almost exclusively) octopus, and are operated in shallow coastal waters between 8 to 30 m deep (Tsangridis et al. 2002). In Vilanova, Spain (Western Mediterranean), trawls, trammel nets, pots and traps are used. Collecting data for these three areas, Tsangridis et al. (2002) found trawls are responsible for most of the octopus landings, and that trawls exploit mostly small and immature individuals whilst artisanal fleets exploit larger mature individuals In the Balearic Sea (Western Mediterranean), it was found that octopus represented between 20–40% of total trawl catch (Quetglas et al. 1998).

7.1.2. Catches

As reported by Cabranes et al. (2008), catches of *O. vulgaris* around the Iberian Peninsula (NE Atlantic and Mediterranean waters of Portugal and Spain) represent 97–99% of the total catch of this species in the whole ICES area. Historical (2000–2005) and official nominal (2006–2015) *O. vulgaris* catches, as provided

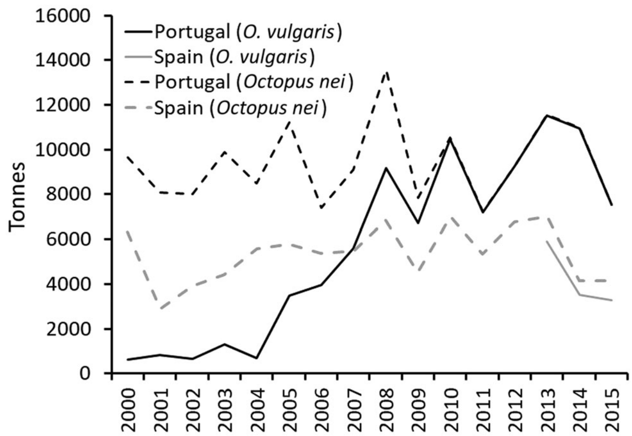

Figure 27. Solid lines: Historical (2000–2005) and official nominal (2006–2015) Northeast Atlantic *Octopus vulgaris* catches as provided by Portuguese and Spanish authorities. Source: Eurostat/ICES database on catch statistics and Eurostat/ICES data compilation of catch statistics - ICES 2017, Copenhagen. Dashed lines: Northeast Atlantic catch of unidentified octopus. Source: FAO, Global Capture Production Statistics 1950–2016.

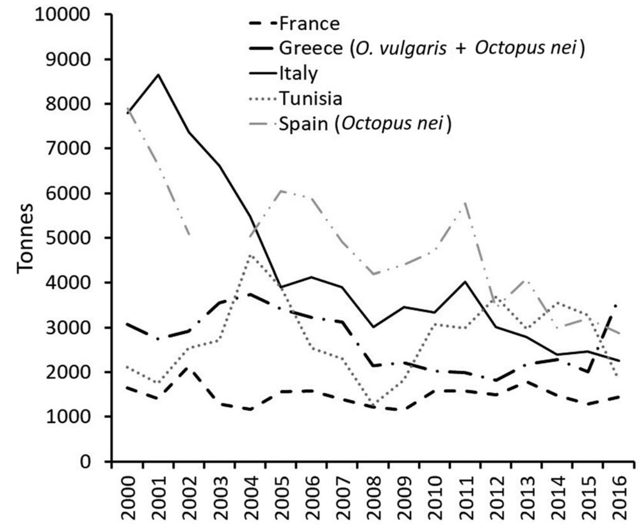

Figure 28. Reported Mediterranean *Octopus vulgaris* catches for France, Italy and Tunisia. Spanish catches are for unidentified octopus, and catches for Greece are those for *O. vulgaris* and unidentified octopus combined. Source: FAO, Global Capture Production Statistics 1950–2016.

by Portuguese and Spanish authorities, are given in Figure 27. Although official *O. vulgaris* landings are reported from 2000 onwards, only from 2010 onwards are the majority of landing data identified down to species level. As *O. vulgaris* is the major species landed and hence makes up the majority of the octopus catch for both Portugal and Spain, total octopus catch is a relatively good indicator of *O. vulgaris* catches. Reported Northeast Atlantic octopus catches for Portugal have ranged from 7,249 t to a high of 13,577 t between 2000 and 2015. Although a great deal of fluctuation is evident in annual catches, there does not appear to be a significant downward or upward trend. Northeast Atlantic octopus catches by Spain are generally lower than those reported for Portugal, fluctuating between 2,895 and 6,998 t. In the Mediterranean, however, Spanish catches of octopus have dropped consistently every year, from 7,889 t in 2000 to 2,867 t in 2016 (Figure 28). Prior to 2005, Italy generally reported the highest *O. vulgaris* catches for this region (no unidentified octopus data submitted and hence *O. vulgaris* data used). Catches have, however, also steadily declined and in recent years Italy has only been the third largest producer of *O. vulgaris*, with a low of 2,256 t reportedly landed in 2016. Except for a peak of 4,638 t landed by Tunisia (landings identified to species level) in 2004, reported *O. vulgaris* catch for Tunisia and France, and the combined *O. vulgaris* and octopus *nei* catch for Greece has remained below 4,000 t (2000–2016), with France reporting a maximum catch of only 2,128 t. Other countries reporting specific *O. vulgaris* landings for the Northeast Atlantic, although at much lower volumes, are France, Netherland and Ireland (Table 4).

7.1.3. Stock identification

Results to date indicate that there is some genetic structuring between populations of *O. vulgaris* within the Mediterranean (Casu et al. 2002), within the Atlantic (Cabranes et al. 2008), and between the Mediterranean and Atlantic (Casu et al. 2002). Within the Mediterranean, two clear genetic groups, where identified, corresponding to the western and eastern Mediterranean basins (Casu et al. 2002). The results showed, however, that all of the populations analyzed were conspecific, namely there is no evidence of higher taxonomic separations either within Mediterranean or between Atlantic and Mediterranean populations (Casu et al. 2002). Cabranes et al. (2008) found a fine spatial substructure in O. vulgaris populations in the Atlantic which was a function of geographical distance. Their results did not show significant differences between pairs of samples separated by <200 km (Portugal–Cádiz), and so the authors concluded that from a fisheries management perspective, the results could be considered as supporting coordinated management of neighboring stocks around the Iberian Peninsula specifically.

7.1.4. Fisheries management

Management of cephalopod stocks in European waters remains limited; and octopus fisheries in the

European Union (EU) are excluded from quota regulations under the Common Fisheries Policy (Pita et al. 2015). Instead, countries are responsible for implementing their own octopus fishery management measures. Pierce et al. (2010) reviewed the management of cephalopod fisheries for EU countries. These authors found that Southern European countries appear to manage their cephalopod fisheries more actively than northern European countries; which they linked to likely being a reflection of the long history of these fisheries and the local socio-economic importance of the species and fisheries. Spanish fleets in the Gulf of Cadiz are limited to having no more than 1,000 pots and 250 traps per vessel, and no more than 2,000 m of pot or trap line. Fishing is also restricted by distance to the coast and a one month closed season is implemented annually. In Galicia (Spain), vessel size and the number of fishers determines the number of traps that can be carried, with a maximum of 350 traps allowed. Catch per day is also limited and a two month closed season implemented. Spanish fleets fishing in the Mediterranean are limited to a certain number of pots, depending on fishing area, and traps allowed per vessel. Area specific closed seasons are also implemented and fishing is only allowed at certain depths, depending on the areas fished. In Spain, there is a MLS for *O. vulgaris* of 1,000 g. In Portugal, <3,000 pots are allowed per vessel; and <500, <750 and <1,000 traps allowed, depending on vessel size, and MLS is 750 g. In Greece, a limited number of plastic cylindrical pots (<1,500) and fyke nets (<1,000 pairs) are allowed per vessel, a three month closed season implemented and there is a MLS of 500 g.

7.1.5. Economic importance

Cephalopods are an important fishery resource in the EU, not only in terms of quantities landed, but also in terms of trade (Pierce et al. 2010). In addition to fishing and landing cephalopods, a number of countries deal in cephalopods as import and export products. The *O. vulgaris* fishery is of substantial importance in southern Europe specifically (Pita et al. 2015). In Portugal there is an increasing dependence of the fisheries economy on cephalopod landings, and landings and their economic value have maintained a significant growth (Pierce et al. 2010). Here the octopus fishery has considerable social and economic value and small-scale fishing remains increasingly economically dependent on this resource (Pita et al. 2015). In Spain although octopus landings have decreased, their total value remained fairly stable (1998–2003, Pierce et al. 2010).

7.2. Eledone sp

7.2.1. Eledone cirrhosa

This is a common species in European waters with a range extending from 67°N, south to the northwest African coasts in the Northeast Atlantic (Guerra 1992); and throughout the Mediterranean Sea up to depths of 770 m (Massy 1928; Belcari et al. 2002). The highest densities of *E. cirrhosa* were found to be in the Gulf of Lions, in the Ligurian and northern Tyrrhenian seas and in the northern Aegean Sea (Belcari et al. 2002). Females are generally larger than males reaching a maximum size of 190 mm ML, with males having a maximum size of 135 mm ML (Pierce et al. 2010). In addition to the size differences between sexes, Pierce et al. (2010) also highlight the role of area in size at maturity, with Mediterranean populations reaching maturity at smaller sizes compared to the Northeast Atlantic (Belcari and Sartor 1999a and Belcari et al. 2002a in Pierce et al. 2010). In the Mediterranean, sexual maturity generally occurs earlier in the western basin (spring–summer) than in the eastern basin (summer–autumn) (see Belcari et al. 2002 for references). It is a summer spawning species, with fecundity ranging from 2,000 to 9,000 eggs, depending on area (Boyle et al. 1988; Pierce et al. 2010; Rossetti 1998). Recent studies have been conducted in the NE Atlantic in relation to its distribution and abundance (Regueira et al. 2014), feeding (Regueira et al. 2017), growth (Barratt and Allcock 2010; Regueira et al. 2015) and reproduction (Regueira et al. 2013).

7.2.2. Eledone moschata

The musky octopus, *E. moschata*, is considered a typical Mediterranean species (being limited in the Atlantic Ocean to the southern coasts of Portugal and the Gulf of Cadiz), found at depths of 15–200 m (Belcari and Sbrana 1999; Belcari et al. 2002; Guerra 1992). Females mature at slightly larger sizes compared to males. As reported in Pierce et al. (2010), females reach maturity at a ML of 12 cm in the Gulf of Cadiz (Atlantic), whereas those in Tunisian waters (Mediterranean) reach maturity at a somewhat smaller size of 11 cm (Ezzeddine-Najai 1997; Silva et al. 2004). It has a prolonged spawning period, extending from autumn through to summer (October to July in the Gulf of Cadiz; and November to July in the southern Mediterranean) (Ezzeddine-Najai 1997; Silva et al. 2004). In the northwestern Mediterranean, however, the spawning period is somewhat shorter, being restricted to winter and spring (January to June, Belcari et al. 2002).

7.2.3. Fisheries, catches and economic importance

Both *E. cirrhosa* and *E. moschata* are mostly caught by bottom trawl fisheries (Pierce et al. 2010), along with *O. vulgaris*. Although generally not thought of as having any economic importance in Northeast Atlantic waters and often being discarded, these two species represent a commercially important resource in the Mediterranean basin, and *E. cirrhosa* is considered one of the most important commercial cephalopod species in the Mediterranean (Belcari et al. 2002; Pierce et al. 2010). A juvenile *E. cirrhosa* fishery in the NW Mediterranean is described by Sánchez et al. (2004). Compared to *O. vulgaris* catches, catches of *E. cirrhosa* in the Northeast Atlantic are minimal, ranging between 102 and 417 t (2006–2015) for Portugal; and 483 and 648 t for Spain (2013–2015) (Figure 29). For the Mediterranean, *Eledone* catches are not separated by species, with both horned and musky octopus catches been reported together. Here catches are higher, with Tunisia reporting an average catch of 710 t (2000–2016) and Italy an average of 529 t (2009–2016) (Figure 30). Reported *Eledone* catch for Croatia is the highest, averaging at 4,566 t (2000–2016), with a maximum catch of over 8,500 t in 2007 (Figure 30).

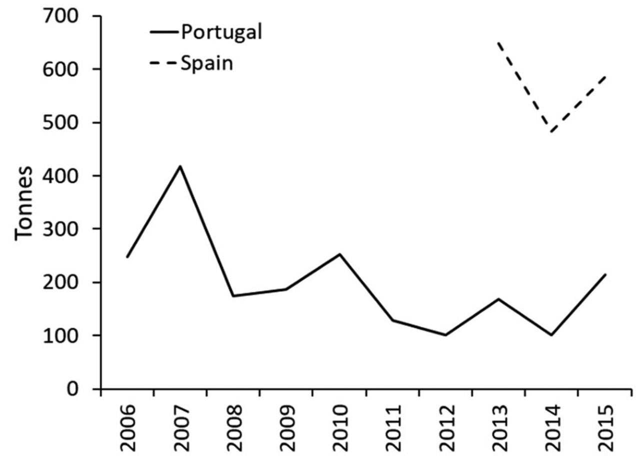

Figure 29. Official nominal Northeast Atlantic *Eledone cirrhosa* catches (2006–2015) as provided by Portuguese and Spanish authorities. Source: Eurostat/ICES data compilation of catch statistics - ICES 2017, Copenhagen.

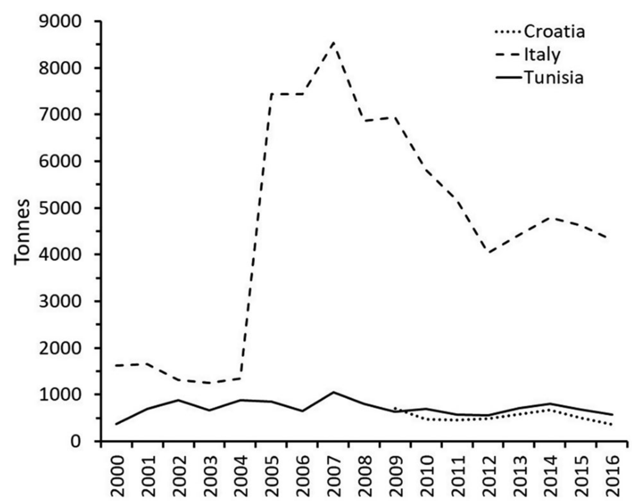

Figure 30. Reported Mediterranean *Eledone* catches for Croatia, Italy and Tunisia. Source: FAO, Global Capture Production Statistics 1950–2016.

8. South- and Central-Eastern Atlantic

A number of octopod species are known from South and Central-Eastern Atlantic (FAO statistical areas 47 and 34, respectively): stretching from Morocco in the north to Cape Agulhas in the south. Most of the octopod species occurring in this region are not considered of any value for fisheries due to their gelatinous quality and pelagic habitats, e.g., *Argonauta argo* (Linnaeus, 1758), *Argonauta hians* (Lightfoot, 1786), *Argonauta nodosus* (Lightfoot, 1786), *Ocythoe tuberculata* (Rafinesque, 1814), *Tremoctopus violaceus* (delle Chiaje, 1830), *Haliphron atlanticus* (Steenstrup, 1861), *Vitreledonella richardi* (Joubin, 1918), *Bolitaena pygmaea* (Verrill, 1884) and *Japetella diaphana* (Hoyle, 1885). Shallow-water *Eledone schultzei* (Hoyle, 1910) is not taken even by subsistence fishers because of its small size (mean mass 65 g; Oosthuizen 2003). Deepwater octopods, even when common, are also not of particular interest to fisheries, e.g., *Bathypolypus valdiviae* (Thiele, 1915), *Benthoctopus* sp. complex of species, and *Graneledone* sp.

The only species subject to exploitation in this region are the *O. vulgaris* complex of species (see below), *A. burryi*, *E. magnificus* and *P. tetracirrhus*. Only *O. vulgaris sensu stricto* (s. str.) and *O. vulgaris* type III, however, are subject to directed fisheries, with the remaining species caught as bycatch in the trap-based crustacean fisheries, the small trawl fisheries targeting shrimp and/or finfish (*P. tetracirrhus*, *E. magnificus*) and small inshore subsistence fisheries.

Fisheries science and academic research is uneven across the region: in the north, considerable research effort has resulted in several reviews (e.g., Bravo de Laguna 1989; Caveriviere et al. 2002). In the south research started in the earnest in the 1997. In South Africa, there were two early directional papers on *O. vulgaris* (presumably type III) from the Durban area (Smale and Buchan 1981; Buchan and Smale 1981). There was a pioneering study on *E. magnificus* in Namibia (Villanueva and Sánchez 1993). Other works concerning *O. vulgaris* appeared in 2002–2003 (Smith and Griffiths 2002; Smith 2003; Oosthuizen 2003), and *E. magnificus* in 2006 (Smith et al. 2006; Groeneveld et al. 2006). These latter works concerned only South African waters.

8.1. Octopus vulgaris

For the purpose of this review, *O. vulgaris* refers to both *O. vulgaris* s. str. distributed along the west coast of Africa in the FAO area 34 (NW Africa), and *O. vulgaris* type III in the FAO area 47 (southwestern Africa). This species complex may occur as deep as 250 m, but is usually limited to shallow waters of up to 100 m. Most studies conducted in South Africa were based on individuals collected shallower than 30 m.

Both groups have a similar life cycle. Smaller individuals are found in the intertidal zone in South Africa (0.4 kg on average) compared to subtidal areas (1.2 kg on average; Oosthuizen 2003). The largest octopuses are found in deeper water and may reach over 4 kg, with females being larger than males. In Senegalese waters, however, Caveriviere et al., (2002) states that females may reach 5 kg and males 6–8 kg. This is possibly an error as both Oosthuizen (2003, South African waters) and Kivengea (2014 PhD, Kenyan waters) report females to be marginally larger and considerably heavier than males in their extensive sampling. Van Heukelem (1976 PhD) reported that males were larger and heavier than females in his sample of *O. maya*. The species *O. vulgaris* may occupy a number of habitats, such as rocky bottoms, reefs, grass beds and soft sediment habitats. Bottom temperatures above 7 °C are preferred. They undertake some limited migrations, usually seasonally, overwintering in deeper waters and moving shallower in spring/summer. Breeding migrations are also undertaken when adults approach maturity. They are generally mostly active at night, retreating to their dens during the day; but this also depends largely on local conditions and is very variable. For example, in some regions octopods are most active during the day. Dens are easier to identify on soft substrates as they are surrounded by shells and various other debris. Prey includes crustaceans, mollusks and fish.

Females retreat to their dens to lay eggs (100,000–500,000 eggs). They brood eggs for up to 5 months, remaining immobile and not feeding during this period. They die shortly after the small octopods hatch. Laying eggs and brooding them occurs only once during a female lifespan (semelparity). The size at maturity for both males and females is highly variable, depending on factors such as location and time of the year (both being related to temperature and other physical parameters). Kivengea (2014) found that size at maturity (at 50% level) was 10.5 cm and 10.8 cm for males and females respectively. Hatchlings (1.7 mm ML on average = 1.2 mg) resemble adult octopods (proportions between arms and body being obviously different; they are also semi-transparent). They go through a planktonic phase lasting from weeks to months. After settlement they live up to two years.

8.1.1. Stock identification

Although there are several studies addressing stock structure problem (e.g., Oosthuizen 2003; Oosthuizen et al. 2004; Warnke et al. 2004; de Luca et al. 2016), there is no full clarity about worldwide stock identity. *O. vulgaris* s. str. and type III are forming clinal relationship. The type III is closely related to *O. vulgaris* s. str. from Senegal and adjacent waters (0.79% divergence) and marginally less to that from the Mediterranean (1.32% divergence). There is, however, a divergence jump when octopi from Taiwan and/or Venezuela are added to the analysis (Oosthuizen 2003). On the other hand, de Luca et al. (2016) reported differentiation in the Mediterranean region compatible with the island model instead of a clinal divergence.

8.1.2. Catches and effort

According to FAO catch records, global catches of *O. vulgaris* have reached and exceeded 100,000 t/year four times in the history of fisheries: in 1972, 1974, 1975 and 1983 (Figure 31). So-called "not identified octopods," however, also pertain mostly to this species, which adds between 120,000–160,000 t annually. Therefore, these annual catches reached and exceeded 200,000 t annually many times in the history of the fisheries; this result may be further questioned and corrected upwards (e.g., Belhabib et al. 2012; see below) because of the illegal fishing and gross underreporting in FAO area 34 and possibly other areas. The *O. vulgaris* which occurs in NW African waters constitutes about 30% (and possibly more) of the world catches. In this region *O. vulgaris* is the most important cephalopod exploited. Its importance decreases southward, where it is replaced by a cuttlefish *Sepia hierredda* (Rang 1835). There are small or no landings of *O. vulgaris* south of Senegal. There are three "stocks" of *O. vulgaris* for FAO area 34: Dakhla

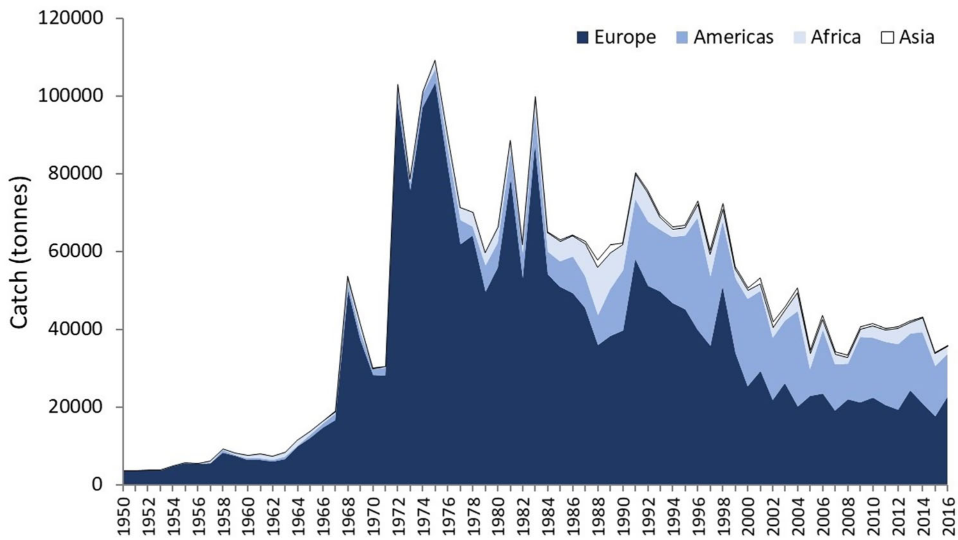

Figure 31. Reported global *Octopus vulgaris* catches for 1950–2016. Source: FAO, Global Capture Production Statistics 1950–2016.

stock (26–21°N), Cape Blanc stock (21–16°N), and Senegal-Gambia stock (16–12°N).

It is estimated (Belhabib et al. 2012a) that in Morocco, 41.5% of the catches were not reported (calculated summarily for the period 1950–2010). Belhabib et al. (2012a) have reconstructed Moroccan catches (all species), finding steady growth from 311,780 t in 1950 to 1,563,124 t in 2010. Cephalopod catches were also increasing quickly in this period: Mediterranean region: 2,866 t in 1950 to 4,394 t in 2010; central region: 1,958 t in 1950 to 42,390 t in 2010 (with a peak of 71,789 t in 2000); southern region: 1,663 t in 1950 to 73,576 t in 2010 (with peak of 113,524 t in 2000). The species *O. vulgaris* constituted 65–75% of the total cephalopod landings. In addition, there were catches of distant water fleets (of more than 19 countries) in this period, with chronic under-reporting of these catches to FAO (Belhabib et al. 2012b). Octopus featured prominently in the catches of some countries (e.g., Spain: total catches typically 378,000/year, octopus 5.4%, i.e., over 20,000 t; Italy 562,500 in 1968, with octopus share of 20%, i.e., 112,500 t). Fortunately, as the Moroccan fleet were improving their catches, distant water fleets were gradually phased out; however, there was a substantial overlap. It is therefore unsurprising that cephalopod resources of the region (octopus in particular) are considered to be seriously depleted, with unreported catches and substantial discards still troubling these fisheries. This is illustrated by the decreasing CPUE observed for small scale fisheries: 1981–11.63 (t per boat per year); 1991–9.10; 2010–6.78.

It is more difficult to assess the percentage of octopus in catches off Mauritania, Senegal and Gambia. Massive under-reporting, lack of records and illegal activities are in abundance in this region (Belhabib et al. 2012c). Reconstructed total catches were 59,400 t in 1950, 2,300,000 t in 1976, and 1,900,000 t in 2010. It may be assumed that *O. vulgaris* constituted up to 10.5% of these catches, but when seasonal variation is added, it may drop to 8% or less. Still, it would translate to 4,752 t in 1950, 184,000 t in 1976 (peak), and 152,000 t in 2010. CPUE in two selected regions stayed similar over the measurement period (1998–2002: 22.5, 26.1, 25.9, 27.9 and 23.4 respectively).

Thus, as the official (FAO) records estimate the total catch of *O. vulgaris* from Area 34 to be 60,000 t on average, the corrected records show total catches at their peak as over 330,000 t per year.

Catches of *O. vulgaris* in Southern African waters are still on exploratory stage and do not exceed 100 t per year for both an experimental fishery and bycatch by trawlers and trap fisheries for lobster.

8.1.3. Fishing methods and fleet

Octopus directed fisheries uses bottom trawls and pots; bycatch is substantial in the crustacean trap fisheries; artisanal fisheries use pots, spearfishing, diving and collecting from rock pools. All these methods except pots can result in catching an array of species. Only a "pot" method is considered an octopus-specific method (it should be called "shelter method" because sometimes pvc pipes are used). This fishing gear consists of long lines with a number of shelters attached at intervals. The lines are anchored and buoyed at each end. The shelters could consist of PVC pipe or tyres encased in concrete, either closed off in the midline or at one end. The type of shelters (mixed or uniform), their number and spacing as well as soak time, will be at the discretion of the individual fisher. The difficulty in using this method over a loose and moving substrate (e.g., frequent occurrence in southern African waters) is that shelters and lines may get covered in mud, silt and small rocks and then are difficult or impossible to recover.

The fleet of vessels taking octopus in the FAO Area 34 is extremely diverse. In Moroccan waters, the freezer trawler fleet oscillates between 200 and 300 vessels (up to 1999, there were also up to a hundred Spanish freezer trawlers). These vessels fishing on average 120 days per year, with trips lasting several weeks. These vessels are 30–40 m in length, with a tonnage of 200–600 GRT, and engine power 600–2,000 HP. Local coastal trawlers are much smaller, with an average of 60 GRT and 400 HP. There are about 100 of these vessels in operation. The artisanal fishery uses small wooden dories called pateras (<6 m). The number of boats in operation was 2,700 in 1981 and 2,600 in 2010, but at times has reached staggering numbers (almost 16,000 in 2004).

In Mauritania, the freezer and ice trawler fleet numbered 177 vessels in 2006 and 146 in 2007. Spanish vessels were 34 m long with 287 GRT and 896 HP on average, whilst local vessels were slightly smaller with 258 GRT (2006). The artisanal fishery uses wooden, aluminum or plastic canoes and pirogues, with numbers in operation increasing from the 1950s (125) to 2005 (3,950).

In Senegal and Gambia, mostly Spanish ice trawlers target octopus. The exact number of vessels operating in the region is not available, but probably does not exceed twenty. Their length is about 36 m, 244 GRT and 771 HP. There is also a thriving artisanal fishery, details of which are lacking. In Namibia and South Africa *O. vulgaris* is caught as bycatch in the small local ice and freezer trawlers targeting hake. These vessels do not exceed 30 m in length and 200 GRT. There are approximately 130 such vessels in operation. Some bycatch is also made by the crustacean trap fishery, which has approximately 300 vessels in operation (see Sauer et al. 2003).

An experimental *O. vulgaris* fishery was run in South Africa from 2004 until 2009, and again from 2012 until now (2016). Results are being processed and total catches are not available as yet.

8.1.4. Duration of fishing period

In the FAO Area 34 fishing activities for *O. vulgaris* are carried out for most of the year; season in Mauritania lasts nine months (Belhabib et al. 2012c). Various closures were, however, instituted throughout the history of the fisheries (e.g., Banc D'Arguin National Park, no trawling shallower than 20 m, and closed seasons of various duration (up to eight months). As pointed out by Belhabib et al. 2012, most of these measures are poorly enforced.

8.1.5. Stock assessment

As illustrated above, catch records in the FAO Area 34 is incomplete at best, and false and misleading at worst. These "catch statistics" more often than not form an input for stock assessment. There are several models proposed and/or in use for these cephalopod fisheries (e.g., Grant et al. 1981; Bravo de Laguna 1989; Laurans et al. 2002; Jouffre et al. 2002a, 2002b). In the Report of the FAO/CECAF Working Group on the Assessment of Demersal Resources (2012), the use of the Schaefer dynamic production model for the region was mentioned. Results are given in Table 3. These results suggest that *O. vulgaris* is severely overfished in Area 34. Due to a questionable input for Mauritanian and Senegalese fisheries, the risk of irreversible stock depletion is even greater than that indicated.

8.1.6. Economic importance

In terms of export value, *O. vulgaris* from Area 34 (Morocco average data for 2008–2011, per year) is worth approximately 5.2 mln $for fresh product and 240.5 mln $for frozen product. These are official export figures for Morocco only. Jouffre (1998) has stated that *O. vulgaris* is an important fishery resource in terms of value in Mauritania. Total value for the region (excluding foreign fleets and landings and sales made elsewhere, outside of the Area 34) should be at least doubled. The sheer number of vessels and small and big packing factories in the region indicates the huge importance of these industries to the local economy (not only as a source of income but also as a job creation opportunity). The mode of exploitation indicates, however, large risk of collapse of these resources, although Jouffre (1998) stated that *O. vulgaris* "seems to tolerate overfishing better than other species." This fact, even if true and objectively evaluated, should not prompt fisheries managers to tolerate a risk to the valuable resource.

8.2. Enteroctopus magnificus

This species was fairly recently described (Villanueva et al. 1991) and research about its biology is underway.

Table 3. Results of the Schaefer dynamic production model for the region, as reported by the FAO/CECAF Working Group on the Assessment of Demersal Resources (2012).

Stock/abund. Index	Fcur/FSYcur	Bcur/B0.1	Fcur/F0.1	Bcur/BMSY	Fcur/FMSY
Dhakla/surveys	90%	50%	147%	55%	132%
Cape Blanc stock/CPUE Mauritanian cephalopod freezer trawlers	90%	51%	143%	56%	129%
Senegal-Gambia/Senegalese industrial fleet	75%	25%	144%	28%	130%

Table 4. Reported North Atlantic and Mediterranean *Octopus vulgaris* catches for other countries.

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
NE Atlantic											
France	0	20	3	37	37	70	131	96	59	93.72	
Netherlands	0	0	0	0	0	1	1	1	1	0.3	
Ireland	3	1	3	0	0	0	2	0	0	0.11	
Mediterranean											
Turkey	1114	664	681	649	509	322	361	284	254	215	246
Croatia	0	0	0	146	141	149	166	192	314	329	257
Albania	82	82	82	109	47	113	165	170	173	124	154
Lebanon	24	24	23	22	21	20	19	18	17	6	3
Montenegro	20	19	23	15	16	13	15	12	15	14	14

Source: FAO, Global Capture Production Statistics 1950–2016.

It is endemic to Namibia and South Africa, but occurs also around Marion Island (Villanueva et al. 1991). It was found inshore (15 m) at Marion Island, but usually occurs in deep waters along the west coast of South Africa and Namibia (adults 300–500 m, 450 m on average; Lipinski, Dr Fridtjof Nansen records). Smith et al. (2006) has described its basic biology on the basis of 384 individuals taken as a bycatch in the spiny lobster trap-based fishery (mean depth 110 m), and 75 individuals collected from demersal bottom trawl surveys (mean depth 235 m). Trap-obtained individuals were caught along the South African south coast (from Mossel Bay to Port Elizabeth). Maturity in Smith et al. (2006) sample was reached by 50% males at a weight of 4.6 kg, and females at 5.8 kg. It seems that reproduction is more frequent in summer than in autumn or winter. It is large-egg octopus (4–9 mm) with relatively low fecundity (potential fecundity up to 10,000 eggs). It feeds mainly on crustaceans (84% for trawl caught octopuses) (Villanueva 1993; Groenevald et al. 2006). The most frequently taken fish species was jacopever *Helicolenus dactylopterus*. Longevity has not yet been researched, but Smith et al. (2006) has considered two hypotheses: one-year or 2–3 years life cycle.

8.2.1. Stock identification, catches and effort, fishing methods and fleet, duration of fishing period, stock assessment and economic importance

As mentioned above, *E. magnificus* is not well researched. In particular, there is lack of information about detailed distribution, abundance, biomass and production of this species. It is relatively widely distributed in the region, with the possibility of some geographic disjunction. Trawl and trap catches suggest a continuous distribution between Namibia and South Africa, with the Marion Island population almost certainly being separate. It is caught as bycatch by trawl fisheries around southern African coasts at depths ranging from 80 to 600 m. Reported landings for years 1979–1997 were 65–115 t per year. In addition, there is unreported bycatch in south coast sole and lobster trap fisheries. Not much is known about seasonality of these catches, nor their distribution. It is felt that it is more sparsely distributed that *O. vulgaris* type III, but still worth an exploratory effort, well controlled and properly documented. The *E. magnificus* bycatch is so far sold to local and international markets, mostly to North America and Europe (Smith 1999; Oosthuizen 2003). There is lack of information about value of these sales.

8.3. Other species

The species *A. burryi* is distributed mostly in the western Atlantic, from North Carolina to northern Brazil. It is small with 7 cm ML and a total length (TL) of 25 cm, and occurs up to 200 m over bottoms of sand, broken coral and shells. Not much is known about its biology. The species *P. tetracirrhus* is distributed in the Mediterranean Sea and along western African coast up to the Equator, at depths 25–720 m. It is small (13 cm ML, TL 28 cm), occurs mainly over muddy substrates. It may appear in demersal catches in November and December. Both these species are caught in small quantities throughout the region (FAO Area 34).

9. West Indian Ocean

The West Indian Ocean (WIO) region, or FAO statistical area 51, includes the western part of the Indian Ocean, the Red Sea, Persian Gulf, and Arabian Sea (Gulf of Aden and Gulf of Oman). Octopus are an important resource for coastal communities throughout the region (Rocliffe and Harris 2016). According to the FAO, 1,397 t of octopus was caught in this region in 1990, increasing to 2,517 t in 2015, contributing 0.75% to global octopus production.

9.1. Southwest Indian Ocean

9.1.1. *Octopus cyanea*

This species, commonly known as the "big blue octopus" or "Day octopus," is distributed throughout the Indo-Pacific region, from the African coast in the east to the Hawaiian Islands in the west; and as far north as the Gulf of Aden and the Red and Arabian Seas. It is an important part of coral reef communities (Yarnall 1969) throughout the tropical Indo-pacific. Although generally inhabiting reef flats, mature females move into deeper subtidal waters to spawn (Oosthuizen and Smale 2003; Smale and Buchan 1981; Whitaker et al. 1991), cementing clusters of 150,000–700,000 eggs to a surface and brooding them until they hatch (Van Heukelem 1976). The larvae are planktonic, remaining in the water column for 1 to 2 months before settlement (Raberinary and Benbow 2012) and adoption of the benthic lifestyle of the juvenile and adult stages. It is thought that dispersal during the planktonic phase is wide ranging, with larvae traveling up to several hundred kilometers in ocean currents (Murphy et al. 2002; Casu et al. 2002).

Females tend to mature at a larger size than males, for example off southwest Madagascar 50% maturity of female and male *O. cyanea* occurred at 2,246g and 643 g respectively (Raberinary and Benbow 2012). Although this same trend was seen off the coast of Tanzania, *O. cyanea* here appear to mature at an overall smaller size (600 g for females and 320 g for males, Guard and Mgaya 2002). Rabineray and Benbow (2012) report maturity variance differed greatly between the male and female weight frequency distributions, with males being consistently mature by 643 g whereas the weight at maturity for females varied to such an extent that BW cannot be used as a proxy for maturity in females.

Although likely to spawn all year round as suggested by data collected off southwest Madagascar (Raberinary and Benbow 2012), peak spawning and brooding periods have been recorded in Rodrigues and Tanzania. In Rodrigues, peak spawning occurs from November to December (JT Genave unpublished data, as cited in Sauer et al. 2011); and in Tanzania in June with a smaller peak in December (Guard and Mgaya 2002).

9.1.2. *Octopus vulgaris*

This species is widely distributed in the SWIO and is commonly caught along with *O. cyanea*, although in smaller numbers (Rocliffe and Harris 2016). Being so widely distributed, it is one the most well studied cephalopod species in the world (Mangold 1997) and aspects of the biology of this species have been investigated in a number of regions. There appears to be no published studies specific to it life cycle and reproductive biology in the SWIO region, however.

9.1.3. Stock identification

Although it is likely that paralarval dispersal contributes to the maintenance and replenishment of octopus stocks at a regional level (Raberinary and Benbow 2012), it is not yet known whether *O. cyanea* populations in the SWIO are self-sustaining in the supply of new larval recruits or whether the larval supply travels large distances, e.g., from an up current location (Benbow and Harris 2011; Gough et al. 2009). In order to identify genetic linkages, the genetic analyses of octopus throughout the western Indian Ocean region has been noted as an important focus of future research (Benbow and Harris 2011). According to morphological and genetic analysis, *O. vulgaris* specimens from the St. Paul and Amsterdam Islands in the southern Indian Ocean match *O. vulgaris sensu stricto* from the Mediterranean (Guerra et al. 2010).

9.1.4. Fisheries

Although for centuries octopus in the SWIO were originally caught for barter and subsistence, the establishment of foreign-owned collection companies has transformed these fisheries into valuable commercial fisheries (Rocliffe and Harris 2016). This is particularly true for Madagascar, Kenya and Tanzania, which are the largest exporters of octopus in the SWIO (Rocliffe and Harris 2016). Throughout much of the WIO, octopus are caught by either walking along the lower reaches of intertidal reef flats at low tide in search of octopus dens (small holes, often marked by small piles of stones and discarded shells) known as gleaning; or by snorkeling or diving along the reef edge. Once a den has been located, the octopus is removed using spears, harpoons or steel rods and killed. Both gleaning and diving are the common fishing method used in Kenya, Madagascar, Mozambique, Rodrigues, Seychelles, Tanzania and Zanzibar (Rocliffe and Harris 2016). Gleaning is the primary fishing method used in the Comoros (Rocliffe and Harris 2016). Although in some regions of the SWIO this was traditionally a fishery dominated by women and children, the increased demand for the product on the international market and the greater income opportunities has increased male participation (Guard and Mgaya 2002). Some 1,400 and 7,313 fishers participate in the octopus fisheries of Rodrigues and Zanzibar respectively (Rocliffe and Harris 2016). In Kenya and Madagascar an estimated 6,500 and >40,000 fishers, respectively, participate in the artisanal fishing sector (Rocliffe and Harris 2016) which targets octopus amongst other commercially valuable species.

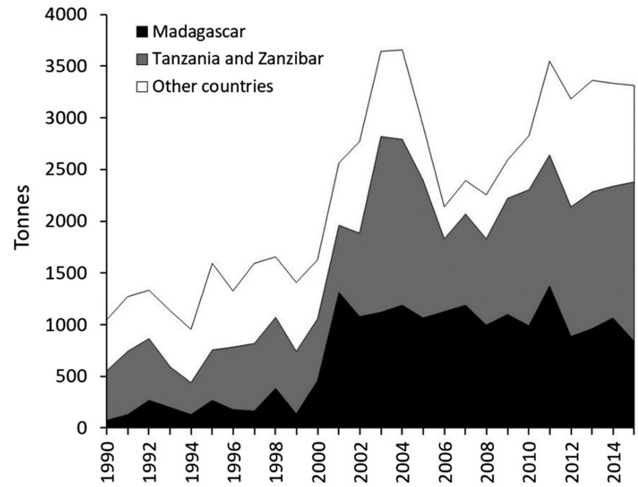

Figure 32. SWIO octopus catches for Madagascar, Tanzania and other countries (Mauritius, Kenya, Reunion, Mozambique, Seychelles and South Africa).

9.1.5. Catches/landings

The Day octopus *O. cyanea* makes up the majority percentage of octopus catch in Madagascar, Reunion, Tanzania, Zanzibar, Kenya, Mozambique and Rodriguez. The species *O. vulgaris* is also commonly caught, although in much smaller numbers and often only constituting a small percentage of overall octopus catch. Seychelle catches differ in that the primary species caught is *O. vulgaris* (IOC 2014). The two species *A. aegina* and *Cistopus indicus* (Férussac and d'Orbigny, 1835) are also present in catches from Mozambique (Rocliffe and Harris 2016). Octopus catch data for Tanzania and Zanzibar (combined), Mauritius, Kenya, Reunion, Mozambique, Seychelles and South Africa has been sourced from the FAO Global Capture Production database (1950–2015). As data for Madagascar is unavailable, octopus export data sourced from the Comtrade Database (https://comtrade.un.org/) is used as a conservative proxy for catch data, following Rocliffe and Harris (2016). This gives some indication of catch as generally in Madagascar all octopus catch is sold (Barnes-Mauthe et al. 2013) and an estimated 93% exported (Moreno 2011 as cited in Rocliffe and Harris 2016). The bulk of octopus catch for the SWIO region is from Madagascar, Tanzania and Zanzibar (Figure 32). Catches appear to have increased substantially since the early 2000s, from an average of 217 t (1990–2000) to 1,087 t (2001–2015) in Madagascar; and 576 t (1990–2002) to 1,241 t (2003–2015) in Tanzania and Zanzibar. Reported catch for other SWIO countries for the period 1990–2015 is small in comparison, averaging at 324 t (Mauritius), 242 t (Kenya), 91 t (Reunion), 53 t (Mozambique), 30 t (Seychelles) and 11 t (South Africa). Higher catches from Mauritius and Kenya are responsible for the notable increase in catches from the "Other countries" group observed in recent years (Figure 32).

9.1.6. Fisheries management

Octopus fisheries in the SWIO are primarily managed by locally imposed rotational closures (Madagascar and Rodrigues) and/or seasonal closures (Madagascar and Kenya), size limits which are often voluntary (Comoros, Madagascar, Seychelles, Tanzania and Zanzibar) and gear limits (Comoros). Tanzania and Zanzibar have also implemented licensing of fishers.

9.1.7. Economic importance

Artisanal fishing for octopus is a highly important economic and subsistence activity for local coastal communities in the East African region (Guard and Mgaya 2002). In particular *O. cyanea* is of considerable commercial value to artisanal fisheries in coastal East Africa and Western Indian Ocean island states (Raberinary and Benbow 2012). Catches are generally sold through a network of collectors which supply national and international export markets (L'Haridon 2006 as cited in Raberinary and Benbow 2012). Both domestic and foreign-owned trading and collection companies now operate throughout the region, and the top five buyers of octopus originating from the WIO are Portugal, Italy, France, Mauritius and Spain (Rocliffe and Harris 2016). According to Rocliffe and Harris (2016) an average of 3,224 t of octopus was exported per year between 2008 and 2012 from the western Indian Ocean, with an average value of US$12.2 million per year. In southwest Madagascar, octopus accounts for 60–70% of the value of marine resources purchased by collection and export companies (L'Haridon 2006 as cited in Raberinary and Benbow 2012).

9.2. India

The West India Ocean (WIO) region of India includes the Indian west Coast and the oceanic waters of Lakshadweep Islands. Cephalopods are largely caught by the commercial neritic trawl fisheries operating from the Indian sub-continent, although a smaller subsistence fishery also exists in the Lakshadweep Islands. Three main species of commercial importance are primarily caught by the trawl fishery, namely *Amphioctopus neglectus* (Nateewathana and Norman, 1999) (*Octopus neglectus*), *Amphioctopus marginatus* (Taki, 1964) (*Octopus marginatus/Octopus dollfusi*) and *C. indicus*. Apart from these major commercial species, *A. aegina*, *O. cyanea* and other *Octopus* spp. are also landed sporadically (CMFRI 2012). The octopus resource contributes a relatively small contribution to the Indian cephalopod landings, which has gradually increased over the years. It contributes an average of only 7.3% to total cephalopod production, ranging between 3.7–12.1% during 2007–2015 (Figure 33). Annual estimated octopus landings ranged from 2,904 t in 2007 to a peak of 8,123 t during 2012 (Figure 33). The landings have leveled off recently around an average production of 4,669 t during 2013–2015 (Figure 33).

9.2.1. *Amphioctopus neglectus*

The species *A. neglectus* is distributed from the waters of the Andaman Sea, Gulf of Thailand, Cambodia, Vietnam, Taiwan and west to Kerala, in the southern part of India (Norman et al. 2014). It is the most important octopus species commercially exploited along the west coast of India, and is caught at depths of 30 to 90 m. Generally abundance is higher along the narrower shelf of the southwest coast. Males are more frequently caught in commercial fishing operations (Mohamed et al. 2009). Commercially caught individuals were recorded to have a ML range of 20 to 95 mm and a weight range of 8 to 190 g (Kripa et al. 2000, Sundaram and Khan 2009, Mohamed et al. 2009). Off the coast of India, males with mature gonads were encountered in the trawling grounds throughout the year suggesting year-round spawning. Females in advanced maturation stages were more common in May, October, January. The smallest mature specimen in the exploited population measured about 30 mm ML. while, fifty percent of the population matured at 35 mm ML (Mohamed et al. 2009). Genetic studies have not been carried out for *A. neglectus* found along the

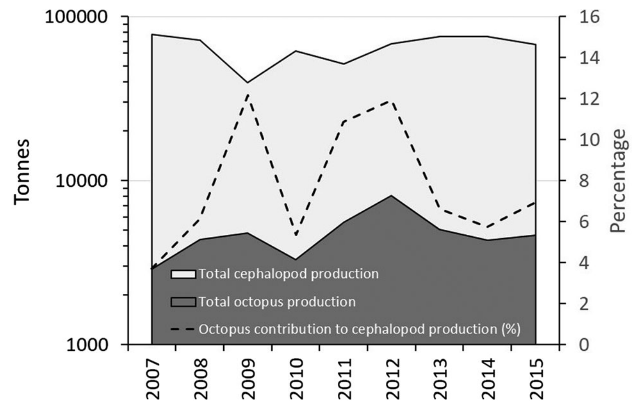

Figure 33. Cephalopod production on the west coast of India. Data source: National Marine Fisheries Data Center of Central Marine Fisheries Research Institute, Kochi, India.

Indian Coast. Considering the biology and distribution of the species, the stock along the Indian coast is likely to be a continuous single stock.

9.2.1.1. Catches/landings.

The *A. neglectus* fishery started in early 1991, consequent to the shift from single-day fishing cruises to multi-day cruises by the shrimp trawlers operating along the southwest coast. Among the octopus landed, *A. neglectus* was the dominant species in the fishery contributing 82% to the total octopus catch on southwest coast (Cochin Fisheries Harbor, Kripa and Joseph 1995). The catch statistics do not categorize the small fraction of *Amphioctopus rex* (Nateewathana and Norman, 1999) caught in the *A. neglectus* fishery. Most of the octopuses caught along the coast are fished by multi-day trawlers. In preference to larger octopus, *A. neglectus* are caught and preserved, as their small size makes them an ideal product to be sold on the overseas market as "frozen baby octopus."

The *A. neglectus* catch increased from 107 t in 1991 to 430 t in 1992, before declining to 27 t in 1993. The fishery recovered in 1994, along with the growing export market in EU, USA and south East Asia. In the recent past (2007–2015), the average catch from the coastal states of Kerala, Karnataka, Goa, Maharashtra and Gujarat, was estimated at 2,571 t. Landings reached a maximum of 4,313 t in 2012, followed by the decline in production since 2013. This species contributed 53.68% to the average octopus catch during this period, with catches from the southwest portion of the coast making up nearly 90% of total west coast catches. The catch rate in multi-day trawl fishery varied from 0.09 kg/h in 2010 to 0.2 kg/h in 2012 and peak abundance was in August months (Figure 34).

9.2.1.2. Fisheries/fishing methods/fleet.

This octopus is principally caught by bottom trawlers operating up

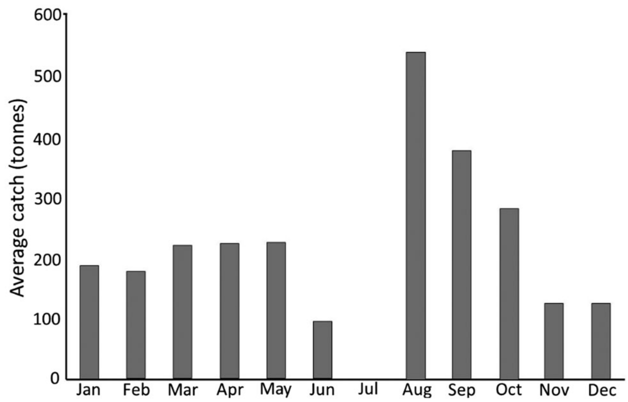

Figure 34. Estimated catch (2007–2015) of *Amphioctopus neglectus* by season. Data source: National Marine Fisheries Data Center of Central Marine Fisheries Research Institute, Kochi, India.

to 200 m deep (Kripa and Joseph 1995, Mohamed et al. 2009). Catch and effort data from the west coast suggests that there are two main fishing seasons, a major season from August to October and a minor season from March to May (Figure 34).

9.2.1.3. Fishery management and stock assessment. Mechanized fishing, including trawling is closed during the southwest monsoon (June–September) for a period of ranging from 47 days (June 15 to July 31) to 61 days (starting from 1 June to 31 July). The minimum cod-end mesh size of the trawler is regulated at 35 mm. Among these closed season and mesh size regulations, the former regulation is very strictly enforced, while compliance for the latter is poor. The annual total mortality rates of *A. neglectus* stocks exploited from Cochin Fisheries Harbor using the length converted catch curve increased during 1997–2002 (CMFRI 2004, Project Report). The exploitation rates indicated that the stocks were optimally exploited along the coast during 1997–2002. Juvenile exploitation of fast growing and high value species like cephalopods results in considerable economic loss, due to growth overfishing. A MLS was set to protect juveniles, maintain spawning stocks and to control the sizes of *A. neglectus* caught in trawl fishery. The MLS for landing was set at 45 mm ML (Mohamed et al. 2009).

9.2.2. *Cistopus indicus*

This is a shallow water subtidal species occurring on soft sediment substrates up to depth of 50 m (Norman et al. 2014). The species is reported from South China Sea (Norman and Lu 2000); Hong Kong (Norman and Hochberg 1994); Philippines (Norman and Sweeney 1997); Thailand (Nateewathana 1997); Celebes (Toll and Voss 1998) and is part of a species complex under the genus *Cistopus* from India (Sreeja et al. 2015). It is a relatively large octopus, typically attaining sizes of 180–229 mm (Norman et al. 2014; Sundaram and Deshmukh 2011). In Indian waters, large sized specimens were reported in commercial fishery landings during September.

It is largely piscivorous (Sundaram and Deshmukh 2011) with fish forming the majority of the diet in both males and females. Prawns and cephalopods were also found to form a significant component of the diet. It appears crabs are only occasionally consumed. Diet analysis revealed that over half of males and females analyzed had empty guts, with only ~2% having full stomachs. No differences in the feeding habits of males and females were evident.

Males have been found to be dominant in the commercial catches, with a skewed sex-ratio of 1:0.36 male:female. Also using commercial catch data, it was found that 29.7% males were immature, 55.7% mature and 14.6% gravid. Among females, 5.3% were immature, 30.3% mature and 64.4% gravid. For trawl caught *C. indicus* in the region, ML ranged between 20–229 mm, and between 15–40 mm for dol net caught individuals. All females were mature above 130 mm ML. The size at 50% maturity for females was reported at 82.7 mm ML. Ova diameter ranged from 2 to 6 mm and the Gonadosomatic Index (GSI) of females increased from October onwards, peaking in March and thereafter declining till November, indicating a peak spawning period during March–May (Sundaram and Deshmukh 2011).

9.2.2.1. Stock identification. The stock management of octopus is done at a regional level and genetics studies have not been undertaken for the west coast of India.

9.2.2.2. Catches/landings. Since 1991, the 9 t of catch reported exclusively from Cochin Fisheries Harbor rose to 1,691 t reported in 2012 from the entire west coast. The estimated annual catch by trawlers ranged from 389 t to 1,655 t with an average value of 807 t during the period 2007–2016. Trawlers contributed 85% of the average annual catch. *Cistopus* spp. catch showed an increasing trend up to 2012, but decreased thereafter. Annual catch rates varied between 0.018 kg/h in 2013 and 0.08 kg/h in 2012. Seasonal trends show peaks in August and April. Catches are relatively fairly distributed along the coast, with the southwest region contributed 59% of the catches, and the northwest 41%.

9.2.2.3. Fisheries/fishing methods/fleet. Although 98% of *Cistopus* landed are caught by trawlers, incidental catches are also landed by other fishing vessels operating in inshore waters such as non-motorized crafts, mechanized as well as motorized out-board dol (fixed bag-nets) netters, outboard gill netters and out-board liners.

9.2.2.4. Fishery management and stock assessment. Mechanized fishing, including trawling is closed during the southwest monsoon (June–September) for a period of ranging from 47 days (June 15 to July 31) to 61 days, starting from 1 June (midnight of May 31) to 31 July. The minimum cod-end mesh size of the trawler is regulated at 35 mm. The former regulation is very strictly enforced, while compliance for the latter is poor.

9.2.3. Other species

The species *A. marginatus* is distributed in tropical continental waters of the Indian Ocean, from Durban, South Africa, to Red Sea, India, south-east Asia, Taiwan, Philippines and Japan, as well as east to north-eastern Australia (Norman et al. 2014). It is the second most abundant species in the Indian west coast (21.7%). Nearly 87.6% of the catches were caught from the southwest coast. This species tends to be caught across the region throughout the year by demersal trawlers, with peak landings during August–October. Typically, the resource is distributed at depth of about 30–40 m on the shelf. The ML of the species landed at New Ferry Wharf ranged from 50 to 90 mm during December–March while larger specimens up to 120 mm were observed during April–May. Sarvesan (1969) made some observations on the brooding behavior of this species. The contribution of the species in the octopus catch increased from 6% in 1991–1992 (Kripa and Joseph 1995) to 21.72% during 2007–15 (NMFDC CMFRI, Kochi).

The Sand bird octopus, *A. aegina*, is distributed in the Western Pacific, Indian Ocean, Red Sea and Japan, and southwards to Mozambique. This species formed 1.16% of the total octopus landed from the southwest coast of India. Catch ranged between 53 t in 2007 and 127 t in 2010, with an average annual catch of 55.6 t during 2007–2015.

A major species reported from Lakshadweep Islands is *O. cyanea*. Nearly 99% of the catch in the recent past from Kavaratti and Agatti Islands was comprised of this species (Aditi and Deepak 2015), although earlier studies (Appukuttan et al.,1989) reported the exploitation of *O. vulgaris*, *O. cyanea* and *A. neglectus*. Appukuttan et al. (1989), has given a detailed account of the fishing for octopus in Lakshadweep Islands. They are caught during low tide, with octopus burrows and crevices being easily detected by the presence of loosely kept coral stones and discarded freshly eaten crab shells at the entrances. In deeper waters, masks are used to search for burrows. Long steel rods of 1–1.5 m in length are used to remove the octopus. As soon as the animal is caught, the mantle is turned inside out, known as "turning the cap," to remove the ink sac and alimentary canal. The annual yield from Kavaratti Islands, estimated at 1.9 t in 1985 increased to 139 t during 2008–2009 with a CPUE of 0.52 kg/person/h (Aditi and Deepak 2015). Catch rates in Agatti were higher at 2.93 kg/person/h, resulting in higher catches estimated at 963 t. In Agatti Islands, there was substantial increase in octopus catch in recent times from a meager production of 2.5 t in 1985 (Appukuttan et al. 1989). Since CMFRI and NMFDC does not collect fishery statistics from Lakshadweep Islands, and since there is no consolidated estimate of octopus catches from the Lakshadweep Islands, an indirect estimation of 300–350t per annum from ten Islands was made based on the known catch rate range, number of fishers and number of fishing days.

The species *O. vulgaris* is caught by dolnetters operating at a depth of 14–16 m (Sundaram and Sarang 2011). The octopus caught in dolnets are generally alive. The species is observed in the fishery almost throughout the year with a peak period of abundance during January–April. The *O. vulgaris* fishery of Lakshadweep Islands is mainly for self-consumption and for use as bait in local tuna fishery (Appukuttan et al. 1989), but statistics relating to catches by species are not detailed.

9.2.4. Economic importance

There was no local demand for octopus, except in the Lakshadweep Islands, hence octopus are mainly exported. Previously, the entire catch was salted in the harbor and sold at Rs. 5–10/kg. The wholesale market price of Rs.3–5 per kg in 1991 (Kripa et al. 2000, increased to Rs. 13/kg in 2001 (Sundaram and Sarang 2004) and Rs.60/kg in 2008 (Sundaram 2010). By 2013–15, the wholesale prices in the landing center stabilized at Rs. 80–90/kg.

Today, octopus are taken to fish processing units within 4 to 6 h of being landed, where they are processed. About 10.7% (US $532 million) of the marine product export earnings during 2013–2014 was from cephalopods, of which octopus contributed 3.65% (US $19.4

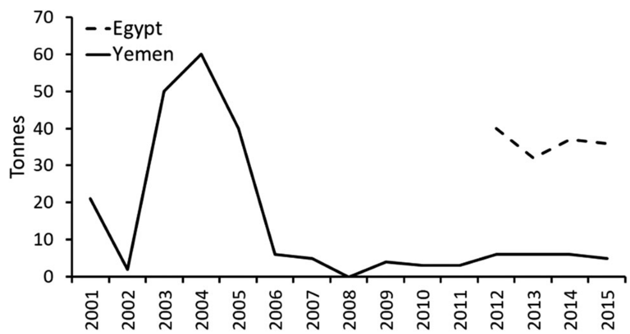

Figure 35. Reported octopus catches for Yemen and Egypt.

million). They are processed as frozen blocks, individually quick frozen, individually frozen (blast frozen) and cooked products. Nearly 26 different product styles are exported to markets in European Union (47% by quantity), south-east Asia (36%), USA (7%), Japan (4%), middle east (2%) and others (4%). Recently, domestic demand for octopus has emerged in isolated pockets catering to the demand of Chinese restaurants in Mumbai (Sundaram 2010). Octopus are chilled on board the multi-day trawlers, often without grading. By the end of the fishing cruise these are auctioned (unsorted) off at fish landing centers. "Whole octopus" forms the maximum (53%) share of the octopus exported from India.

9.3. Other countries

Artisanal fisheries in both Egypt and Yemen target octopus, amongst other valuable marine resources. Octopus is considered one of the many key species in the artisanal fisheries in Yemen, where artisanal fishing accounts for over 90% of total marine production. An analysis of these key species and their contribution in catch and value in 2012, indicated cephalopods contributed 6.9% to total marine catch, with octopus (6 t) making up a very small percentage (0.003%) of this (Alabsi and Komatsu 2014). Although relatively high during 2003 to 2005 with catches of up to 60 t, in the last decade catches have averaged 4.4 t per year (Figure 35). Small-scale fishermen typically use small fiberglass boats (with outboard engines) of 7–16 m length, and larger wooden boats (10–20 m), with inboard or outboard engines (Alabsi and Komatsu 2014). Fishing is highly seasonal, controlled by monsoon winds and the availability of species, with fishermen often shifting targets and gears when certain species are no longer profitable (Alabsi and Komatsu 2014). Only reported since 2012, catches from Egypt are higher, averaging at 36 t per annum (Figure 35). Although no other catch data for the region is available, in a report on the potential development of fisheries of the Arab states (Feidi 1998), the Gulf of Aden was noted as being an underexploited fish-rich area, where crustaceans and cephalopods are available and could withstand further exploitation.

10. East Indian Ocean

(WITH NOTES ON THE CENTRAL AND SOUTH-WESTERN PACIFIC)

The east Indian Ocean region (FAO area 57) is for the purpose of this review, defined as the waters between Kanyakumari in Tamil Nadu Southern India to Cape Howe on the Victorian and New South Wales border in Australia. The area encompasses the following countries: India, Sri Lanka, Bangladesh, Myanmar, Thailand, Malaysia, Indonesia, East Timor and Australia. Due to available information, however, the focal points for this paper are India, Thailand and Australia.

Octopus fisheries in the East Indian Ocean region are a mixture of targeted and bycatch species, with a broad range of fishing methods and catch rates. From dugout canoes to mechanized vessels equipped with the latest technology, octopus fishing fulfills: subsistence needs, niche and mass markets across the region. Exploitation rates follow a similar pattern, with some stocks potentially overfished, whilst others are at a developmental phase. Regardless of exploitation rate, method, gear or area within the region, a commonality in these fisheries is the need for further research on the biology, ecology and population dynamics of the harvested species, especially as octopus fishing expands throughout the region over recent and coming decades.

10.1. India

Octopus fisheries have become increasingly important over the last decade due to surging export demand to the United States and European countries. In the eighties and nineties, there was no specific demand for octopods within India except as a bait fishery. Sundaram (2010) stated that octopods were one of the least exploited species in India even though they occur all along the Indian coastline and surrounding islands. Octopus now, constitute 5.92% of the total catch of cephalopods along the east coast of India (Table 5). The predominant species landed are *A. marginatus, A. neglectus, A. aegina, O. cyanea* and *C. indicus*.

The first comprehensive checklist for cephalopods of the east coast (Chennai coast) was published by

Table 5. Estimated total cephalopod and octopus landings (t) in from the east coast of India during 2007–2015, with percentage of octopus landed per total cephalopods.

Year	Cephalopods (t)	Octopus (t)	% Octopus
2007	15,996	684	4.28
2008	23,759	946	3.98
2009	27,865	871	3.12
2010	35,026	705	2.01
2011	37,275	2,067	5.54
2012	31,309	1,638	5.23
2013	29,026	1431	4.93
2014	23,958	1,572	6.56
2015	57,149	6,755	11.82
Mean	**31,263**	**1,852**	**5.92**

Data Source: National Marine Fisheries Data Center of Central Marine Fisheries Research Institute, Kochi, India.

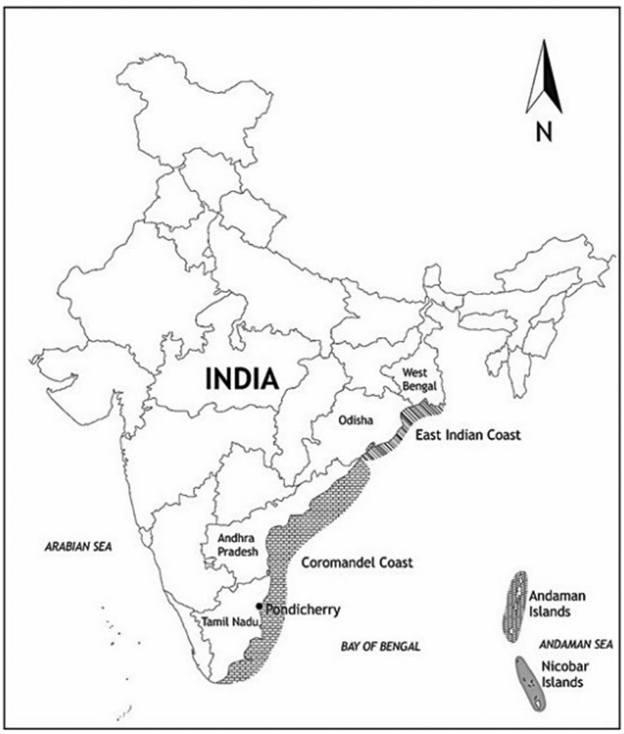

Figure 36. Geographic regions of the east coast of India.

Jothinayagam (2007) comprising 10 species of octopods, of which three species have taxonomical issues in current day classification. The Zoological Survey of India in the same year published the fauna of the Chennai coast, updating the cephalopod work of Jothinayagam (Zoological Survey of India 2007). The work of Silas et al., (1985) listed 38 octopus species in the Indian waters with about 30 species reported in the east coast of India (Table 5).

The east coast of India is divided into four biotic provinces (Figure 36), namely the East Indian Coast, the Coromandel Coast, the Andaman Islands and the Nicobar Islands. Historical reports identify the island areas of Andaman and Nicobar, Gulf of Mannar, and Palk Bay as prime locations for octopus abundance (Silas et al. 1985). The common names for octopus vary in each state and union territory. In Tamil, octopus are called Pei Kanavai, Cha kanavai, Visha kanavai and baby kanavai; Ashtapadhi in Oriya and Astopodi in Bengali.

10.1.1. Amphioctopus aegina

The Sandbird octopus, *A. aegina*, is distributed in the coastal waters of Asia from 30–120 m depth. Distribution in the East Indian Ocean is reported from China and Taiwan), south to Malaysia and Indonesia, west to at least Chennai, India (eastern Indian coast) and from the Philippines (Norman et al. 2014). Consequent to the increased demand in octopus, the hitherto discarded octopus resources gained significance in commercial quantities and this benthic species was commonly found in the continental shelf off Tamil Nadu and was recorded in Maharashtra (western Indian coast) (Sundaram and Jadhav 2013). Thus, extending the known geographical distribution further from Chennai.

The Sandbird octopus is a common species of commercial importance caught in trawl nets in Mandapam waters on the Palk Bay and the Gulf of Mannar, southeast coast of India. The life cycle of *A. aegina* was studied in the laboratory condition by Promboon et al. (2011). Similar to other benthic octopus species, the life cycle of *A. aegina* has embryonic, planktonic and settling phases. Laboratory studies indicate that female octopus release eggs after 2–3 days of mating in the morning hours (Ignatius and Srinivasan 2006). The egg capsules are spindle shaped and whitish in color, measuring 3.18 ± 0.5 mm length and 1.04 ± 0.07 mm width. The egg capsules are woven together with a cement secreted by the oviducal gland during laying. The number of eggs per cm of a string (festoon) was 29–32. Females provide parental care, where during brooding she continuously cleanses and aerates her eggs. Embryonic development takes 18–20 days at 28 °C. The ML of the newly hatched octopuses is 3.07 ± 0.15 mm. Females die within 17 ± 8.6 days after the eggs hatch, with males dying within a few days after.

Dorsal mantle length (DML) for octopuses caught in the commercial fishery ranges from 33 to 87 mm. Gravid females with a DML range of 67–85 mm, typically have oocyte counts of 2,962 to 8,820 oocytes (average = 5,690 oocytes) (Ignatius 2005). Fecundity is highly variable between different areas. Male *A. aegina* attain maturity at approximately 40.8 g TW, while mature females weigh closer to 78.8 g. This species spawns throughout the year with an increase in males with mature stages at specific times of the year (Ignatius et al. 2011a).

The TL at first maturity was documented as 7.17 cm for the females and 5.7cm for males. Four maturation stages were recorded for females namely immature, maturing, mature and spent, while two maturation stages were recorded for males namely mature and immature (based on the presence or absence of spermatophores in the Needham's sac). The GSI values range from Stage I: 0.023–2.98; Stage II: 3.71–5.89 and Stage III: 8.081–19. 39 for females. In males, the mean GSI values were 1.76 ± 0.21 (immature) and 2.95 ± 0.69 (mature). Males had a higher sex ratio during the sampling period (1.71:1.00–October 2001 to September 2002) showing a variation from the usually expected 1:1 ratio. The study also reported higher number of males in all months except June and July (2002). The results reveal presence of mature females throughout the study with a maximum percentage of mature ovaries recorded during October, January and February. As for males, more than 50% were found to be mature throughout the year with highest values during September–November and January–March.

Primary peak in spawning activity was reported to occur during January–February followed by a second peak in October (Ignatius 2005). The spawning season coincided with the withdrawal and onset of the north-east monsoon where temperature falls below the normal average of 27 °C. From the collected samples, average oocytes per gram was estimated to be 488 ± 51.9 whereas the length of spermatophores in males ranged from 2.7–3.8 mm (Ignatius 2005).

Laboratory studies reveal brooding females spent most of the time in hides caring for festoons without feeding for the entire period (Ignatius 2005).

The gut content analysis recorded fishes and crustacean as the main prey items.

10.1.2. *Amphioctopus membranaceus*

This octopus possesses the iridescent ringed ocellus found in many ocellate *Amphioctopus* species. As one of the first ocellate members of this genus to be described and illustrated (showing the iridescent ring within a dark ocellus), the name *membranaceus* has been used widely for almost two centuries for many Indo-West Pacific species of ocellate octopuses. As no additional animals have been attributed to the original species, it remains poorly known and defined but is considered as valid as the type species (Norman et al. 2014).

The webfoot octopus *A. membranaceus* is a common species found in the east coast of India. Rao and Rao (2013) observed some aspects on the biology of this species from Visakhapatnam coast, Andhra Pradesh during 2008.

All the four aforementioned maturity stages were observed in female *A. membranaceus*. Length and weight at maturity was recorded as 22.5 cm in females, with a minimum length of 20.0 cm for ripe females. The sex ratio was 1.00:1.54 for males to females indicating a dominance of females during most part of the study except in June, August and November (2008–2009). Presence of higher maturing and mature ovaries in September (2008) reveals the peak spawning season for *A. membranaceus*. The estimated fecundity for female *A. membranaceus* ranged from 20,432 to 62,324 oocytes with a mean of 32,569 ± 2,693.801 oocytes in the coastal waters of Visakhapatnam. The gut content analysis recorded fishes and crustacean as main prey items.

10.1.3. Other species

One of the species also caught on the east coast of India is *A. marginatus*, however detailed biological information on the species from this region is not available except some preliminary observations on parental care in *A. marginatus* (*O. marginatus*/*O. dollfusi*) under captivity (Sarvesan 1969). The eggs were laid in festoons and the female octopus brood their eggs throughout the development period until hatching occurs. The incubation period was reported as two weeks. The hatchlings ranged in size between 3.3 and 3.8 mm ML. The species *A. neglectus* supports a commercial octopus fishery using bottom trawl methods along the entire west coast of India. Other species caught include *C. indicus* and *O. cyanae*. The latter is of considerable commercial value to artisanal fisheries in coastal waters of south-east coast of India (Tamil Nadu) and Andaman Islands. The recent demand in export market has resulted in renewed commercial exploitation of the resource from the southeast region. Research on the biology and life history of the species have not been carried out from Indian waters.

10.1.4. Catches/landings

The total cephalopod landings across India remained at very low production levels up to the early 1970s and significantly increased above 200,000 t in 2013 (Sathianandan et al. 2014). A threefold increase in octopus landings from the east coast of India was witnessed during 2015 with 6,755 t landed (Table 5).

Table 6. Octopus species composition (%) for different fishing gears along the east coast of India.

Gear type	Species					Mean octopus catch (t)
	Amphioctopus neglectus	*Amphioctopus marginatus*	*Cistopus indicus*	*Amphioctopus aegina*	*Octopus cyanea*	
Multi-day trawling (%)	25.0	36.9	38.1			997
Single-day trawling (%)			35.2	64.8		640
Hook and line (%)					100	214
Mean catch (t) 2007–2015	267	368	493	294	431	1852

Data source: National Marine Fisheries Data Center of Central Marine Fisheries Research Institute, Kochi, India.

Species composition for different fishing gears demonstrated that the greatest quantity of octopus were caught via trawling. The most dominant species recorded during 2007–2015 across all gear types was *C. indicus* (26%), *O. cyanea* (23%), *A. marginatus* (20%), *A. aegina* (16%) and *A. neglectus* (14%) (Table 6).

10.1.5. Fisheries

Historically, octopus were caught in specially designed shell traps, exclusively for the bait, in hook and line fisheries along the Palk Bay (Hornell 1917). These traps were set using gastropod shells (~30 shells per line) fastened at 5 or 6 feet intervals along a rope. Several ropes were tied end to end and laid in shallow water overnight. Small octopus were reported to shelter in the cavities of the shells. Hundreds of these shell-trap lines were in use along the weedy shallows of Palk Bay (Ramanad coast of Tamil Nadu). A smaller species of octopus locally called sangu kanavai (Polypus) was largely caught in this bait fishery. Another species of small octopus, Visha kanavai (literally "poisonous octopus") was also occasionally caught in shell traps in relatively less proportion (1–2%; Hornell 1917).

Currently there is no specific gear type for large scale commercial octopus fishing along the east coast of India. Instead, octopuses are caught from the continental shelf in bottom trawl nets operated by mechanized trawlers. Traditional small scale fishing methods still exists (Sundaram and Dias 2008) where trap setting, harpooning or poisoning of rock pools and bottom set gill netting is still practiced. Because of the increasing economic value of the octopuses, they are now being targeted in bottom trawls all along the east coast.

Currently *O. cyanea* are caught by hook and line operated in depth between 10 and 15 m in the coastal waters (NMFDC CMFRI, Kochi). Almost the entire octopus production from hook and line is considered to be constituted by *O. cyanea* in the region. The seasonal peaks in landing in hook and line is during October–January. Besides this, the species constitute 67% of the multi-species bottom trawl catch, that undertake daily trips along the Tamil Nadu coast. An annual average catch of 431 t was estimated from the region during 2007–2015 (NMFDC CMFRI, Kochi).

Trawler

Mechanized trawlers contribute to more than 50% of annual fish landing in India totaling 1.4 million t during 2013 along the east coast (Sathianandan et al. 2014). Trawlers were introduced during the 1950s as a result of the Indo-Norwegian Project and have dominated the fishery in the country's coastal waters since then. Size varies from 11–20 m overall length and varies from state to state. The trawl fishery contributes 88.4% of the octopus fisheries along the east coast of India (Table 6).

Vallams

Traditional country craft called "Vallams" are operated in the Gulf of Mannar and Palk Bay, to operate bottom set gill nets. Octopods are caught as incidental bycatch. A decade ago octopuses were discarded from this fishery, now due to local and export demand they are retained regardless of size or species.

Dugout canoes

The tribal community comprising Andamanese, Nicobarese and Shompens use dugout canoes with outriggers to venture into the sea. Spear fishing for reef fishes and octopuses is often carried out using this craft. The Nicobarese canoe is made from the wood of a jackfruit tree and is called a "*Hodi*." Length of the canoes varies from 3 to 9 m, with a breath of 0.3 to 1 m. The arecanut tree is used to make the outrigger. Nowadays this particular craft is coated with Fiberglass Reinforced Plastic (FRP).

Trawl nets

Different kind of trawl nets used in trawling process include conventional fish trawl, fish/shrimp trawl, shrimp/fish trawl, one-boat fish trawl, two-boat fish trawl and two-boat mid-water trawl. The cod end of the nets varies with the fish being targeted. While 35 mm is the recommended mesh size for the cod-end, most trawl units use trawl nets below this size. This gear is considered destructive because of the damage it causes to the benthic environment.

Octopods are collected along with other cephalopods, which are sorted, preserved in ice and brought ashore to the landing centers for auction.

Gill nets

A variety of bottom set gill nets exist along the south-east coast of India to target species like fishes, crabs, lobsters, etc. The mesh size varies from 40–120 mm. Octopods are usually attracted to the fishes and crabs that are usually entangled in this gear, in order to feed on them and are incidentally caught at the time of net retrieval.

Linrech/chok (Spears)

Spearing is a primitive traditional fishing method popular among the Nicobarese for catching octopus. The spear is locally made with iron rods to which a string made of rubber is attached at the end (Ravikumar et al. 2016). The spears are used to catch octopus both in rocky areas as well as deep water where snorkeling or skin diving is adopted. In the case of deepwater fishing, to keep the spears buoyant and for easy retrieval, bamboo or wooden sticks are attached to the spears.

Fishing with light

Dried coconut leaves, dried bamboo leaves, etc. are closely tied together, folded and lit to illuminate the rock pools near the shore. This fishing method is carried out in Car Nicobar by the tribal population to exploit the photoaxic behavior exhibited by octopuses (Ravikumar et al. 2016). Besides dried coconut leaves, other light sources like torches, lamps, etc. are also used.

Poison fishing

The seeds of *Barringtonia asiatica*, commonly called the "*sea poison tree*" (Locally called *Kinyav*) is used as an Ichthyotoxic agent for poisoning species trapped in rock pools during low tide. The seeds collected from the wild are dried, powdered and sprayed in the tidal pool. Sometimes wheat flour or dust is used to make the water turbid (Ahmed et al. 2013) so as to frighten and poison the trapped fishes or octopus. Shavings taken from the seeds are also used as a poisoning agent. The shavings are dropped in tide pools to immobilize octopus and small fishes.

10.1.6. Fishery management and stock assessment

Ignatius et al. (2011b) studied the growth and mortality rates of *A. aegina* by applying length based methods. The mortality rates were estimated at 5.68 for total mortality (Z), 3.02 for natural mortality (M) and a fishing mortality (F) of 2.66. This study pointed out that the maximum exploitable rate was 0.5730 against the exploitation rate of 0.47 during October 2000 to December 2002. By applying growth parameters, the estimated growth of *A. aegina* was 7.45 cm DML at the end of first year and 9.34 cm at the end of the second year. The study concluded that this species takes 1.5 years to attain the observed length of 8.7 cm and requires more than 36 months to reach asymptotic length of 10 cm, with a life span of ~3 years.

Octopus are exploited mainly in trawls and the mechanized trawling is regulated along the east coast of India through a seasonal ban for a period of 46 days (15 April to 31 May). There is no specific fishery management available for octopus in India. Most research studies identify octopus as an untapped resource. Besides, stock assessment of octopus species in the east coast of India are considered inadequate.

10.1.7. Economic importance

Octopod fishing has been part of the hunting process for Nicobari tribes in the islands and is an important seafood in their culture. There is no report of consumption of octopus from the north-east coast of India like West Bengal and Odisha whereas, southern Andhra fisher folk cook octopus meat just like squids and cuttlefish. In the south-east coast, consumption of octopods is common and popular among fishing communities. It is cooked either by boiling and making it into a curry or dried and pickled. Hornell (1917) explained how the fishermen processed the octopus by turning the body inside out referred to as "*turning its cap*," forcing the visceral mass out. This was the simplest of methods to degut and then the mantle skin is removed clean. More recently, octopods are gaining popularity in local restaurants and are served as a delicacy.

Indian seafood exporters target octopus markets in the United States and Europe. The demand for Indian octopus has increased due to overexploited resources in the West African countries like Morocco and Mauritania (Krishnakumar 2014). Most of the products exported include octopus whole cleaned, octopus frozen, octopus fresh chilled, octopus fresh – baby, Individual Quick Freeze (IQF) octopus tentacles, IQF whole cleaned octopus, other value added products like IQF octopus cut and cooked (V cut) and frozen octopus tray packs.

A sudden demand in the export of juvenile octopods weighing 10–100 g began in 2014 because of the poor landings in Vietnam market (Krishnakumar 2014). Smaller octopus species, *A. neglectus* were

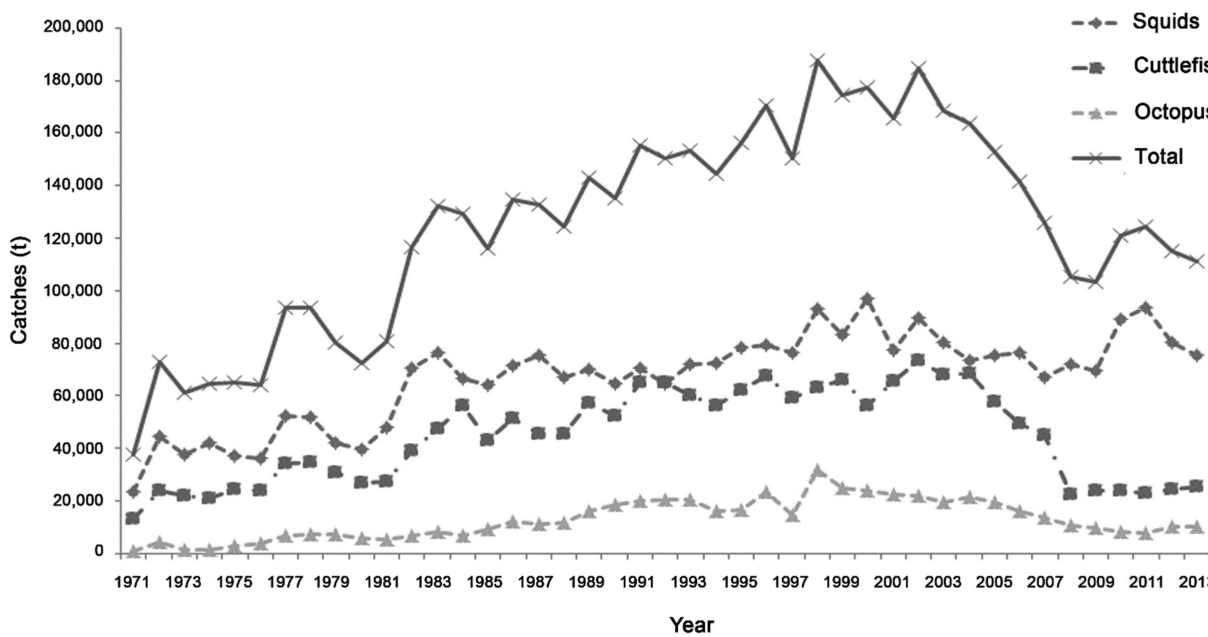

Figure 37. Total cephalopod catches (t) in Thai Waters during 1971–2013.

collected in large quantities from the west coast. Juvenile octopuses collected from the east coast in Palk Bay and Gulf of Mannar regions are transported to processing units in Kerala (west coast of India) for processing (IQF and block frozen) as "baby" octopus for export. Presently, the export demand for baby octopods is high especially in the southeast coast of India.

10.1.8. Economic importance

Octopus are a non-conventional food in the domestic seafood markets of India (Sarvesan 1974; Kripa et al. 2000). In Andaman and Nicobar Islands octopuses are sought for being used as food and regular "octopus hunting" is pursued. Their use as bait is widespread in the south-eastern coast of India (Sarvesan 1974). Fishermen traditionally dried and sold these octopuses in the local market. Recently, development of new lucrative export market for octopus has led to an increase in the exploitation of this species and frozen processing (Kripa et al. 2000).

10.2. Thailand and surrounds

The Gulf of Thailand, is an inlet of the South China Sea in the Southwest Pacific Ocean. It is a semi-closed sea and has an area of about 350,000 km^2. The Gulf is a shallow body of water with an average depth of about 30–40 m and a maximum of 85 m. Another sub-region is the East Andaman Sea, a part of the East Indian Ocean along the western part of the Thailand Peninsular, which covers the continental shelf to about 95°E. Its average depth is about 200 m with a maximum of more than 4,000 m. The currents and water circulation in both areas are under the influence of 2 annual monsoons; the Southwest Monsoon and the Northeast Monsoon. The rainy season can last as long as 6 months in the upper part of the Gulf and up to 8 months in the Thailand Peninsular. Freshwater discharge from four major rivers in the upper-part of the Gulf and from many small rivers on the Peninsula enriches the waters of the Gulf with sediments and nutrients. As a result, the salinity can fluctuate from freshwater of zero psu after heavy rain and consequent floods in the upper-part to 33 psu in the middle of the Gulf. Conditions are more stable in the Andaman Sea because of the greater volume of seawater and the lower volume of freshwater discharge.

The total economic-cephalopod yields of Thailand comprise approximately 50% loliginid squids, 40% sepiid cuttlefish and 10% octopus (Kittivorachate 1980; Supongpan 1995; Chotiyaputta et al. 2002). Over the last four decades, from 1971–2013, the annual yield of octopus in Thai waters varied between 700 t and 32,000 t (Figure 37) (DFO 2015). These annual yields have constituted about 30 to 70% of the total annual octopus yields of about 22,000–35,000 t from the Southeast Asian region (FAO 2014). Other countries that fish for octopus are Indonesia, Malaysia and the Philippines with approximate annual yields of about 1,300–11,000 t (FAO 2014). In Thailand, various species of octopus are either locally consumed or processed, on both a small and large scale, for export in a variety of frozen and dried products. Thailand is one of the world's major exporters of cephalopod products to overseas markets, especially to Japan and the European Union.

The major species captured in this region by local fishermen are all benthic species except the argonauts. Ten species are recorded in Thai Waters (Nabhitabhata et al. 2009, Nabhitabhata and Nateewathana 2010; 2016), namely *A. aegina*, *Amphioctopus exannulatus* (Norman, 1993), *A. marginatus*, *A. neglectus*, *A. rex*, *Amphioctopus siamensis* (Nateewathana and Norman, 1999), *Callistoctopus luteus* (Sasaki, 1929) (previously *Octopus luteus*), *C. indicus*, *O. cyanea* and *A. hians*. There are no detailed catch statistics of individual species, however, as all catches are routinely mixed and roughly categorized as (loliginid) squids, (sepiid) cuttlefish and octopus according to the size of each individual on landing. Moderate-sized species (e.g., *Amphioctopus*) are mixed with juveniles of larger species (e.g., *Cistopus*). The gear used for large scale fishing are mainly trawlers (otter-board trawlers, paired trawlers). Any small species caught (e.g., *A. hians*) are discarded onboard as trash fish or retained and later processed into fishmeal for aquaculture feed.

Artisanal octopus fishing is mainly done by trapping. Octopus trapping originated in the early years of this millennium in the eastern Gulf of Thailand and was soon widespread throughout the country (Srikum and Somchanakit 2011). Based on yields and available studies, only the marbled octopus, *A. aegina* is described.

10.2.1. *Amphioctopus aegina*

This is the most abundant species both in the Gulf of Thailand and in the East Andaman Sea. Previously quoted in fishery statistics under the name *O. dollfusi*, *A. aegina* has a ML of 20–100 mm (Nateewathana 1997, Norman and Hochberg 2005). The octopus is solitary with crepuscular and homing behavior (Promboon et al. 2011). Its habitat ranges in depth from the intertidal zone to about 40 m and is most abundant in 1.5–20 m depth on sand, muddy sand and sandy mud substrates (Srikum and Somchanakit 2011, Petchkamnerd and Suppanirun 2014). Petchkamnerd and Suppanirun (2014) determined that the ML of mature females can range from 35 to 102 mm. Females generally reach first maturity at a ML of 56.4–62.6 mm, which corresponds to the ML of 54.7 mm at the first mating observed in laboratory (Promboon et al. 2011). Female fecundity is approximately 5,000 eggs (1,000–12,000) (Thitiwate 2003, Petchkamnerd and Suppanirun 2014, Ratanakaminee et al. 2014). The male to female sex ratio is 1:0.5–0.9, depending on the locality (Phanichpong 1985, Sukhsangchan 2011, Petchkamnerd and Suppanirun 2014, Ratanakaminee et al. 2014). On the basis of mature female to total female ratio, reproduction is considered to occur throughout the year with three non-prominent peaks during February–March, August and December (Petchkamnerd and Suppanirun 2014, Ratanakaminee et al. 2014). GSI peaks are from January to July in females (3.2–3.7) and February to December in males (1.4–3.3) (Thitiwate 2003, Ratanakamineeet al. 2014).

In the laboratory, the average number of eggs laid by a single female is about 7,000 (Promboon et al. 2011). The egg capsules are about 3 mm long and 1 mm wide and take about 18 days to hatch at 30 °C. The hatchlings have a ML of 2.7 mm and are planktonic for 20–25 days before settling as benthic juveniles. The daily growth rate in the laboratory is approximately 4% by length and 13% by weight (Nabhitabhata 2014). Mating occurs at about 125 days after hatching, when the male and female are 47.0 and 54.7 mm in ML, respectively. The life span of *A. aegina* in captivity is about 200 days (Promboon et al. 2011).

10.2.2. Stock identification

Age, growth and growth rate are determined from length frequency data. Length frequency analysis is based on von Bertalanffy growth model. Bhattacharya method is generally used to separate normal distribution curves from the total distribution plot. The modal progression analysis is consequently used to relate the mean lengths of different cohorts and to estimate the asymptotic length and growth parameters (Petchkamnerd and Suppanirun 2014). CPUE has been estimated from the catch composition fished by research vessels as a routine monitoring activity. The MSY is estimated from Schaefer surplus production models and Fox derivatives (Supongpan 1983, 1995; Chotiyaputta et al. 2002).

10.2.3. Catches/landings

During the years 1971– the octopus yield annually ranged from 700–32,000 t (DOF 2013), which represented about 10% (2–17%) of the total cephalopod yield (60,000–188,000 t) from Thai waters (Figure 38). From year to year, approximately 36–99% of the yield has come from the Gulf of Thailand and 1–64% from

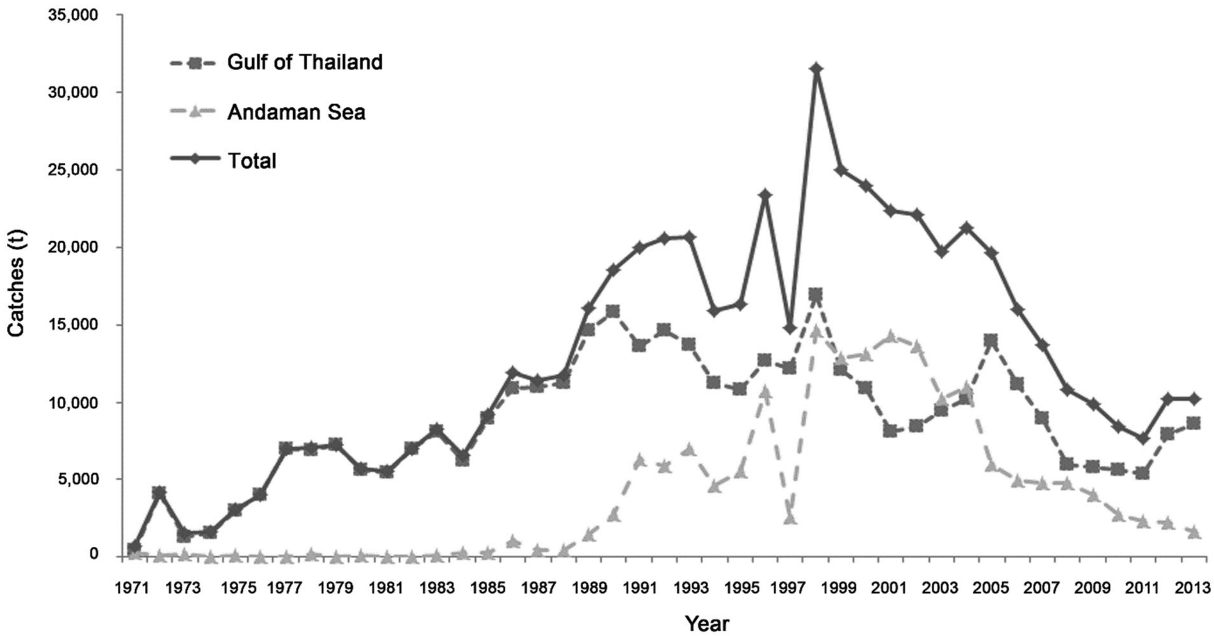

Figure 38. Total octopus catches (t) in the Gulf of Thailand and the East Andaman Sea during 1971–2013.

the East Andaman Sea (Figure 38). The potential yield of octopus stock in Thai waters had been estimated at about 7,000–11,500 t, with a corresponding optimum fishing effort of 4.47 million standard hours (Supongpan and Kongmuak 1981, Supongpan 1995, Chotiyaputta et al. 2002). Supongpan (1995) and Chotiyaputta et al. (2002) estimated that the MSY of the octopus stock had already been reached by 1982. Such estimates, however, were based on the overview that octopus resources in Thai waters belonged to a single homogeneous stock.

10.2.4. Fisheries

Octopus fisheries in Southeast Asian countries can be categorized by the type of fishing gear used. Firstly, for the small-scale or artisanal fisheries, commonly used gears include gill net, small push net, hook and line, cast net, traps, etc. (Ogawara et al. 1986; Slack-Smith 2001). Fishing boats are non-powered or equipped with an outboard engine (so called "long-tail boats" in Thailand) or a small inboard engine. Second, for the large scale or commercial fishing, gears are of various types, including, otter-board trawl, beam trawl and pair trawl, large push net and large-scale octopus traps. All of the commercial fishing boats are powered with inboard engines and can be classified according to length, as small (<14 m), medium (14–18 m) or large (18–25 m and >25 m) (DOF 1997).

At present, there are two major types of fishing gear used to capture octopus in this region:

Trawl nets

Trawl nets comprise of beam trawls, otter-board trawls and pair trawls. Most of the annual yield of octopus in Thai waters is captured by trawlers. Trawl netting can be operated all year round. Otter-board trawl nets are used on small, medium and large fishing boats, fishing from inshore to offshore areas. The catch rate is 0.7–0.9 $kg.hr^{-1}$ of which octopus makes up about 30% of the cephalopod catch composition (Cholatharn 1980, Sinanuwong 1981). The annual yield from otter-board trawlers alone is approximately 70–80% of the total octopus yield from all types of fishing gear in this region (Supongpan and Kongmuak 1981, Supongpan 1983). Octopus caught by this kind of trawling are mixed with other demersal organisms. Beam trawling is operated mostly inshore by small to medium size boats, but octopus are not the target species. Pair trawling by medium to large fishing boats is operated offshore with a catch rate of 0.9–2.4 $kg.hr^{-1}$: about 10% of cephalopods are captured by this gear type (Sinanuwong 1981; Supongpan 1983).

Octopus traps

Octopus traps are both an artisanal and a commercial fishing gear depending on the size of the boat and number of traps. Commercial fishing uses larger boat and consequently more traps (Petchkamnerd and Suppanirun 2014). This fishing gear is highly efficient due to the homing behavior of the octopus and has a long history as Japanese octopus pots (Slack-Smith 2001). Octopus trapping is selected to be the detailed focus hereafter, since the gear for this type of fishing was originally designed specifically for and targeted on octopus.

The octopus trapping emerged in about 2004 from the eastern Gulf of Thailand and soon became an important gear for octopus fisheries (Srikum and Somchanakit 2011). The species *A. aegina* makes up more than 90% of the octopus annually fished by traps with a small amount of *A. rex* fished in some seasons (Petchkamnerd and Suppanirun 2014). The trap is a gastropod shell, noble volute *Cymbiola nobilis*, of about 100 mm in length and 25 mm in aperture width. The apex of the shell is cut off and with a hole bore in to the posterior for rope. This fishing gear is colloquially called "Kung-King" from the sound of its colliding shells make when the gear is being carried. About 150–500 shells are tied to a line by polyethylene string of 3–5 mm diameter at 2–6 m intervals. Intervals are increased when boats are equipped with a mechanical winch and/or in localities with a good yield. These shell-traps can last more than 10 years (Srikum and Somchanakit 2011, Petchkamnerd and Suppanirun 2014).

Considered a semi-passive gear, the trap line is laid on the bottom substrate and equipped with floats for positioning and flags for ownership. The fishing depth varies from 1.5 to 18 m depending on the location and size of the boat, the larger the boat, the deeper the fishing. The trap lines are placed parallel to the shoreline, with 150–5,000 traps in each track and a distance of 20–200 m between lines (Srikum and Somchanakit 2011, Petchkamnerd and Suppanirun 2014).

Fishing boats of two sizes are used for octopus trapping; the small boats (6–12 m length) can carry 600–15,000 traps and the large boats (12–22 m) with inboard engines can carry up to 40,000 traps (Srikum and Somchanakit 2011, Petchkamnerd and Suppanirun 2014). If more than 2,000 traps are used, the boat is equipped with a mechanical winch.

Traps are left for 1–3 days before harvesting in the early morning. Octopus trapping can be done all year round in the central-west part of the Gulf of Thailand (Petchkamnerd and Suppanirun 2014), from November to May in the eastern Gulf, and from April to October in the lower-west part of the Gulf (Srikum and Somchanakit 2011). In the western part of the Gulf, the fishing period for each month is 7–8 days and in the eastern part 14–20 days. Traps are cleaned every 2 or 3 months (Srikum and Somchanakit 2011).

The species *A. aegina* accounts for 99–100% of the yield from trapping and the remainder, less than 1%, is made up by *A. rex* (Nateewathana and Norman, 1999). The species *A. rex* (40–50 mm ML) can be trapped only in deeper waters, further from the shoreline and only in some locations and certain times of the year, i.e., July to October in the central-west of the Gulf (Petchkamnerd and Suppanirun 2014). Yields are approximately 0.10 kg for 10 traps (0.04–0.22 kg) with a peak in November–February and April–August (Srikum and Somchanakit 2011, Petchkamnerd and Suppanirun 2014). Statistics of the total yield from octopus traps in the region is still unknown.

The advantage of octopus trapping is its flexibility; fishing can be started with a low investment for a small number of traps which can be gradually increased depending on success (Petchkamnerd and Suppanirun 2014). The trap itself is easy to operate, with fewer working hours and a longer duration of materials compared to other gears (Srikum and Somchanakit 2011). The price of the volute shell rapidly increased by more than 3-fold in eleven years (2005–2016), however, from US$0.25 per piece to US$0.83. Importing them from neighboring countries has been a temporary solution. The fishermen have tried to find substitutes. They have used the pieces of PVC pipe (100–150 mm long), pieces of old automobile tyres (100–150 mm long), glass bottles (80–140 mm long), and even shells of a freshwater gastropod, *Pomacea canaliculata* (with a cement coat). But, in the fishermen experience, their size and weight are less appropriate (compared to volute shells), and consequently have not gained favor (Petchkamnerd and Suppanirun 2014). The artificial volute shells made of resin-plastics are also tried, but their efficiency is currently unknown.

10.2.5. Fishery management and stock assessment

From the point of view of natural resource conservation, the advantage of octopus trapping is that mostly, the full-grown stock is exploited and there is no fishing for a period of 10–21 days in each month which allows for natural stock recruitment. But the disadvantage is that brooding females are also captured. Petchkamnerd and Suppanirun (2014) reported that 34–98% of the total yield is comprised of individuals with a ML of less than 62.6 mm, the size at first maturity. Additionally, the increasing popularity of octopus trapping is consequently reducing stocks of the noble volute (*C. nobilis*).

A major threat is octopus trappers coming into conflict with trawlers, gill netters, push netters and clam-dredgers exploiting the same fishing grounds.

Traps are lost when they are in the line of a trawling operation. The Notification of Changwat Surat Thani (a local government authority) in 2011 is an example of a resolution that has been settled in some communities along the central-west coast of the Gulf of Thailand based on the agreement of public and local stakeholders. It assigned limited zones (zoning or spatial partitioning) for each type of fishing all the year round and limited the fishing periods for each type of fishing gear in the zone (temporal partitioning) (Petchkamnerd and Suppanirun 2014). Such measures not only reduce conflicts, but also increase the chance of natural stock recruitment. As well as the price of noble volute shells, another problem is the continuous increase in the price of gasoline.

The Notification of Thailand's Ministry of Agriculture and Cooperatives issued in 1981 is a regulation prohibiting push netting and trawling within 3 km of the shoreline. Some local provincial governments have extended this limit to 5.4 km (3 nautical miles). Zoning of Marine Protected Areas and Marine National Parks as well as other zoning under different names with similar purposes can also indirectly enhance the stocks.

Resource management measures should include the installation of artificial reefs in certain areas as sanctuaries from trawling. Another measure should be the enhancement of aquaculture to restocking of *A. aegina* and *A. rex* by seed production in hatcheries and consequent seed releasing, as has been previously carried out by Thailand's Department of Fisheries during 2000–2003, and *in situ* seed production similar to the current "Squid Seed Bank" created by local communities in southern Thailand (Nabhitabhata and Segawa 2014).

10.3. Australia

Australia currently has two dedicated octopus fisheries in the Eastern Indian Ocean region, the Western Australian *O.* aff. *tetricus* fishery and the Tasmanian *O. pallidus* fishery. Apart from these two fisheries, the majority of octopus landed in Australia are caught as bycatch in commercial lobster pot fisheries in Western Australia, South Australia, Victoria and Tasmania. The primary octopus species landed in this region in order of quantity, whether targeted or bycatch, are: *O.* aff. *tetricus* (~200 t), *O. pallidus* (70 t) and *Macroctopus maorum* (Hutton, 1880) (*Octopus maorum*) (~40 t). Other species occasionally caught by commercial fishers include *O. tetricus* in Tasmania, *O. cyanea* in Western Australia and *Octopus berrima* (Stranks and Norman, 1992) in South Australia and Tasmania. The Australian domestic market has traditionally been slow to embrace octopus, particularly in the fresh form. Value added products (i.e., pickling), however, are considered a delicacy and receive a premium price. A gradual increase in demand has led to the exploration of new fishing grounds and the refinement of fishing techniques and technology. Recreational fishing for octopus in Australia is at a relatively low level in comparison to teleost species and has not been fully quantified.

10.3.1. *Octopus aff. tetricus*

The Perth octopus *O.* aff. *tetricus* is a medium sized species (max 4 kg), endemic to the south-west temperate waters of Australia, distributed from Shark Bay (25.4744° S, 113.4878° E) in the north to the South Australian border (31.67° S, 128.88° E). Previously regarded as the same species as *O. tetricus* found on the east coast of Australia and New Zealand, recent research by Amor et al. (2014) identified *O.* aff. *tetricus* as a distinct species. Although, a new species name is yet to be allocated, both *O.* aff. *tetricus* and *O. tetricus* are closely related to the cosmopolitan *O. vulgaris* species complex (Guerra et al. 2010; Amor 2011; Soledad Acosta-Jofré et al. 2012).

The documented depth range for *O.* aff. *tetricus* is 5–70 m, inhabiting rocky reefs, seagrass meadows and sandy substrates (Edgar 1997; Norman and Reid 2000). Recent research has indicated that along the west coast of Australia mature females may migrate to offshore reefs to find appropriate shelters in which to brood eggs, which are followed by mature males looking for mates (Leporati et al. 2015).

Maximum size for females is ~ 4 kg, of which a considerable proportion is contributed to reproductive investment; males reach a maximum size of ~2.5 kg. A distinct increase in growth rate has been observed with rising sea surface temperature (SST) up to 21 °C, which can then drop dramatically at >22 °C. This temperature limit is aligned with long-term SST data for the geographic range of the species, and increased mortality observed in tank reared juveniles when temperatures exceed 22 °C (Leporati and Hart 2015; S. Kolkovski pers. comm.).

Octopus aff. *tetricus* has a merobenthic (with paralarval stage) life history strategy, laying ~100,000 eggs that take ~30 days to hatch (Joll 1976). Hatchlings spend ~50 days as paralarvae in the water column before settling on the benthos (S. Kolkovski,

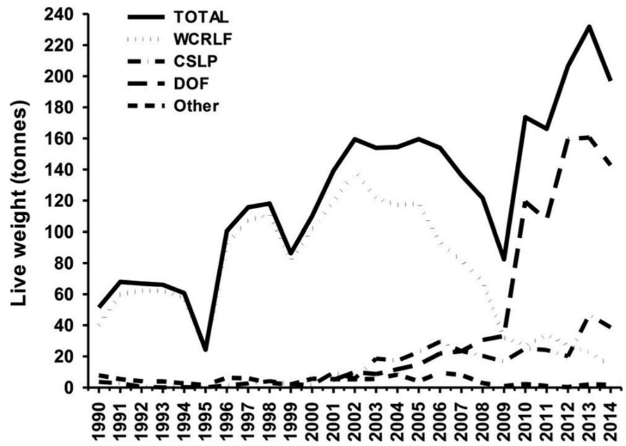

Figure 39. Commercial catch (t) of octopus in Western Australia since 1990. Catch is divided between the main sectors West Coast Rock Lobster Fishery (WCRLF), Cockburn Sound Line and Pot Fishery (CSPLF), Developmental Octopus Fishery (DOF) and other (bycatch from trawl and miscellaneous pot fisheries). Taken from Hart et al. (2015).

pers. comm.). Maximum longevity for both genders has been estimated at ~1.5 year using stylet increment analysis (Leporati and Hart 2015). A semelparous species, average age at maturity is ~12 months for females and eight months for males. The *O.* aff. *tetricus* population breeds throughout the year with hatching pulses occurring every six months, during periods of transitional temperatures (Leporati et al. 2015). The ability of females to mate prior to maturity and store sperm for up to 16 weeks, helps ensure females can lay eggs when necessary, rather than being completely bound by environmental cues (Joll 1976).

Continual spawning throughout the year ensures that two or more generations are present within the population at any given time. Males mature on average 4.5 months earlier than females and continue to mate with available females until death, providing males with potentially a 12-month viable mating-period. This gives males the opportunity to mate with numerous mature and immature females during their lives, thus enhancing the probability of reproductive success. Due to the later maturation of females and their subsequent six-month spawning window, however, the opportunity for males to mate with the next generation is minimized (Leporati and Hart 2015).

10.3.1.1. Stock identification. The extent of *O.* aff. *tetricus* eastern distribution is currently unknown due to a lack of samples from the Great Australian Bight region. In this instance, however, it is assumed the eastern boundary is near the Western Australian and South Australian border. The existence of distinct populations within Western Australian waters has not been studied, yet given the broad expanse of the coastline and considerably different oceanic conditions between the west and south coast, it is considered relevant to treat the two areas as distinct stocks for management and research purposes.

10.3.1.2. Catches/landings. The total catch of octopus in Western Australia is currently 204 t. Landings primarily came from three fisheries: the Developmental Octopus Fishery with 149 t, the West Coast Rock Lobster Fishery with 14 t and the Cockburn Sound Pot and Line Fishery with 39 t. An additional 2 t has been estimated as recreational catch (Hart et al. 2015). The Developmental Octopus and Cockburn Sound fisheries both target octopus, whereas the Lobster fishery lands octopus as byproduct (Figure 39).

10.3.1.3. Fisheries/fishing methods. Commercial octopus fishing in Western Australia was first investigated by Japanese scientists during 1979–1981, in response to the high level of octopus predation and bycatch in the Western Australian rock lobster fishery (Joll 1977). During the 1980s, 90s and early 2000s the rock lobster fishery landed the majority of *O.* aff. *tetricus*, peaking at ~160 t in the early 2000s (Figure 39). In response, targeted octopus fishing was reinvestigated and the developmental octopus fishery established in 2001. The primary gear type used during this period and the following nine years was a plastic shelter pot attached to a demersal longline. A light open ended passive gear type, the shelter pots were restricted to relatively protected and shallow waters (<30 m) due to their tendency of being buried in more high energy environments. This restriction prevented the broad exploration of the coastline and subsequently resulted in catch rates remaining around 30 t for several years. In 2010 the trigger trap was introduced to the fishery. Consisting of a rectangular pot baited with a plastic crab connected to a tripwire that triggers a trap door when grasped by an octopus. This active gear type is set in blocks of three on a cradle similar to those used for lobster pots. The result is a significantly heavier gear type that can be easily hauled by a lobster fishing vessel. These capabilities led to the trigger trap being able to be set in all regions and opening up the coastline for explorative fishing. The impact of the trigger trap was instantaneous with catches increasing to 170 t in the first year of deployment.

The fishing power (i.e., CPUE relative to soak period) of a single cradle of trigger traps is ~30 times that of a single shelter pot per annum. Shorter soak periods for trigger traps are required due to the octopus being trapped inside. In addition, the catch composition of trigger traps is markedly different to shelter pots, where triggers traps predominantly catch large (>1 kg) mature males and shelter pots catch predominantly small (<1 kg) immature males and females. The depth profile of where the two gear types are generally deployed, also plays a part, where trigger traps are mostly set in waters deeper than 25 m and shelter pots primarily are set in water shallower than 25 m (Leporati et al. 2015).

The increased fishing efficiency of the trigger traps and the ability to explore deeper waters has prompted the exploration of 780 km of the western coastline of Western Australia, with the 1,600 km southern coastline is only beginning to be considered.

10.3.1.4. Fishery management and stock assessment. The *O.* aff. *tetricus* fishery is currently an interim managed fishery. As a limited entry fishery, effort control and spatial management are currently used to manage effort and expansion. A formal stock assessment has yet to be conducted for the fishery.

10.3.1.5. Economic importance. Commercial octopus fishing for *O.* aff. *tetricus* is still at a small scale relative to the potential of the stock (Hart et al. 2016). Regardless, what is presently caught is value added through processes such as pickling. The majority of product landed is currently sold on the domestic market.

10.3.2. Octopus tetricus

The Gloomy octopus or common Sydney octopus *O. tetricus* occurs along eastern Australia, from southern Queensland to southern New South Wales (Edgar 2000; Norman and Reid 2000). In recent years, however, this species has extended its geographic distribution along the coast of Victoria and around Flinders Island in north-eastern Tasmania (Villanueva and Norman 2008; DPIPWE 2009; Johnson et al. 2011; Edgar and Stuart-Smith 2014; Robinson et al. 2015). It also occurs in northern New Zealand, where it is classified under the name *Octopus gibbsi* (Amor et al. 2014). A distinct species, *O.* aff. *tetricus*, occurs in Western Australia (Amor et al. 2014). The gloomy octopus' depth range extends from 0 to approximately 60 m in shallow coastal waters and adjacent to rocky reefs (Jereb et al. 2013), sea grass or muddy bottoms.

10.3.2.1. Stock identification. A recent genetics study using microsatellites on individuals from along eastern Australia only, suggests that there are two subpopulations of *O. tetricus* along eastern Australia: One subpopulation that is common along NSW, Victoria, and Tasmania and a distinct subpopulation detected off Tasmania (Ramos et al. 2018)

10.3.2.2. Life history. The life history characteristics of *O. tetricus* have only been examined from specimens collected during commercial fishing operations at Flinders Island in north-eastern Tasmania. This species has a planktonic paralarval stage; maximum life span is estimated to be 11 months, with daily instantaneous relative growth rates of 0.014 ± 0.0006 (mean ± s.e.). Maximum mantle weight (MW) is 210 g and BW is 2.3 kg (Ramos et al. 2014). Mature females with developing eggs are found throughout the year, although greater numbers of mature females have been observed during the austral summer and spring. In contrast, mature males are observed all year round. Females reach size and age at 50% maturity at 132 g MW and 224 days, whilst males reach size and age at 50% maturity at 92 g MW and 188 days. Fecundity is high with around 278,448 eggs ± 29,365 s.e. produced (Ramos et al. 2015).

10.3.2.3. Recruitment. Size or age at capture have not been determined due to highly variable growth rates in response to environmental variability within *O. tetricus*, which is characteristic of cephalopod populations.

10.3.2.4. Fisheries. Along the east coast of mainland Australia octopuses are caught throughout the year using fish or prawn trawl nets in <100 m depth (Nottage et al. 2007; Emery et al. 2014). In northern New South Wales prawn trawls of 40 mm mesh size are used, whereas the central and southern New South Wales fisheries use fish trawls of ≥90 mm mesh size (Nottage et al. 2007).

The species *O. tetricus* is a by-product species of the small-scale *O. pallidus* fishery that operates off the northern Tasmania coast. Only one operator currently holds a license to fish for octopus in the fishery, employing two vessels. Octopus are caught using

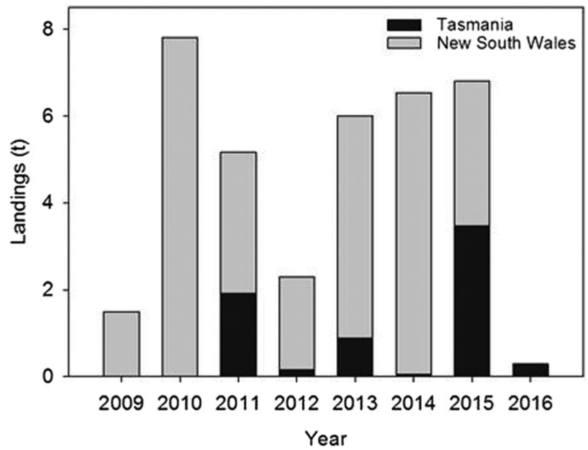

Figure 40. *Octopus tetricus* landings per state in Australia from 2009 through 2016. There is no landing data for Queensland and Victoria.

unbaited plastic pots of 10 cm high × 10 cm width × 30 cm long with a weight at the bottom of the posterior end. Approximately 500 pots are attached to a demersal longline 3–4 km long that is set at variable depths of 15–85 m (Leporati et al. 2009). Pots have proven an effective method of capture, allowing the fishery to rapidly expand production as octopuses use them as refuges to hide and brood eggs. An ecological risk assessment of the fishery conducted in 2012 considered the risk to *O. tetricus* from potting effort negligible (Bell et al. 2016).

10.3.2.5. Catches. In New South Wales, *O. tetricus* usually comprises 20% of the commercial octopus catch, although in some years it can be up to 40% (Nottage et al. 2007; Rowling et al. 2010; Hall 2015). Catches are higher from January through to May (austral summer and autumn), with a peak in March. The Estuary prawn trawl and Ocean trap and line fisheries harvest the greatest quantities of *O. tetricus* (Hall 2015). Prior to 2009, octopus landings were not recorded at the species level in New South Wales (Figure 40).

This species was recorded for the first time off eastern Flinders Island in north-eastern Tasmania in 2006. Octopuses landings were not recorded at a species level in Tasmania until 2010, therefore there is no accurate information on *O. tetricus* landings from 2006 to 2009. Tasmanian *O. tetricus* catches since 2010 have been highly variable, ranging from just 2 kilograms in 2010 to 3.5 t in 2015, which constituted less than 1% and 5% respectively of the total octopus commercial catch from the fishery (Figure 40). There appears to be no seasonal pattern to the catches of *O. tetricus* through time, however the majority of the catch in 2015 was caught in the austral spring (September to November).

It has been caught off north-east Flinders Island; for instance, in 2015 the majority of catch (3.1 t) was caught in this area. The remaining 0.4 t, however, was caught in the middle of Bass Strait, halfway between King and Flinders Islands. Estimated recreational catch surveys in Tasmania do not differentiate between octopus species so there are no accurate records of *O. tetricus* recreational landings. Given *O. tetricus* current spatial distribution, the impact of recreational fishing pressure is likely to be minimal.

10.3.2.6. Fisheries management and stock assessment. The bycatch of *O. tetricus* in the Tasmanian commercial *O. pallidus* fishery is regulated under the Tasmanian (Scalefish) Rules 2015. The fishery is managed through a combination of gear restrictions, spatial controls and limited entry. The Tasmanian octopus fishery is only allowed to operate in State waters north of the line of latitude 41° South (DPIPWE 2015a). Individual octopus pots cannot exceed five liters in volume and fishers can only use a maximum 10,000 pots, capped at 1,000 pots per line. Octopus pots must be unbaited, without a door, flap or other device that would restrict an octopus from escaping from the pot and cannot be used to take fish species other than octopus (DPIPWE 2015a). Other commercial fishers are only allowed to take maximum 100 kilograms of combined octopus species per day or be in possession of no more than 100 kilograms of combined octopus species at any point in time (i.e., on a single trip). The recreational fishery has a bag limit of five combined species of octopus per day, with fishers not able to possess more than ten octopuses at any point in time (DPIPWE 2015b).

Octopuses do not represent a significant portion of commercial and recreational fisheries in Queensland. Hence, they are only reported as incidental catch at a group level. The trawl fishery is permitted to retain octopuses caught but they cannot be actively targeted. The Ecological Risk Assessment for east Queensland did not identify any significant risk to octopus species from trawling (Pears et al. 2012).

10.3.2.7. Economic importance. The Tasmanian *O. tetricus* is a bycatch fishery that is sold frozen or it is processed (e.g., pickling) and sold in the domestic market.

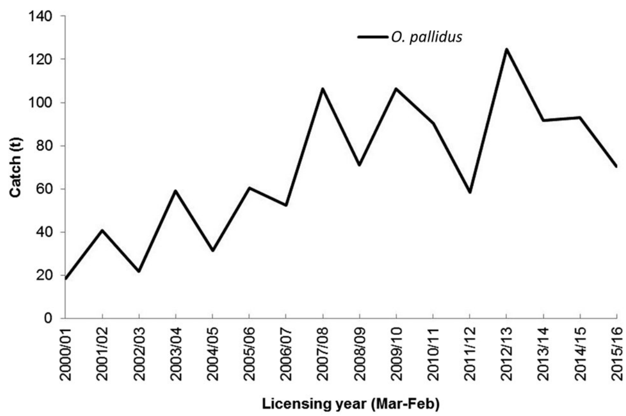

Figure 41. Total catch of *Octopus pallidus* in Tasmanian waters per licensing year during 2000–2016. Taken from Emery and Hartmann (2016a).

10.3.3. *Octopus pallidus*

While currently placed within the generic genus *Octopus*, the assignment of this species awaits major revision (Reid 2016). The species *O. pallidus*, also known as the pale octopus, is commonly found throughout temperate inshore south-east Australian waters (Stranks 1996; Reid 2016). It occurs on sandy substrates up to 275 m, among sponges, seagrass, and ascidians (Stranks 1988). A small holobenthic (without paralarvae stage) species, *O. pallidus* reaches a maximum size of ~1 kg, producing a small number of eggs (400 to 800 per spawning event) that hatch into large (~20 mm), well-developed benthic hatchlings (Leporati et al. 2008a). The maximum known age of *O. pallidus* is ~1.6 years based on stylet increment analysis (Doubleday et al. 2006; Leporati et al. 2008b). The species spawns all year round with peaks in late summer/early autumn; time of maturation is largely related to size, rather than age, with males maturing at a smaller size (<250 g) than females (~470 g). Spawning occurs throughout the year with an optimal period between late summer and early autumn (Leporati et al. 2008a).

Growth rates for this species are highly variable, both in the wild (1.32 to 6.9% BW/day) (Leporati et al. 2008b) and in constant conditions in the laboratory (Semmens et al. 2011), with little relationship between age and size. Modeled projections suggest that wild immature *O. pallidus* comprise a mixture of individuals displaying either exponential growth or "two-phase" growth (i.e., rapid exponential growth followed by a slower phase, best described by a power function), with the proportion of each depending on inherent growth capacities at the individual-level and food availability (André et al. 2009).

10.3.3.1. Stock identification. Stylet elemental analysis and genetics (microsatellites) suggest that *O. pallidus* populations are highly structured, forming distinct subpopulations across small spatial scales (100s of kms) (Doubleday et al. 2008a; Higgins et al. 2013). Genetic differentiation among sub-populations follows an isolation by distance model (i.e., the closer individuals are to each other the more genetically similar they are), which is consistent with dispersal mediated via benthic hatchlings and adults (Higgins et al. 2013).

10.3.3.2. Catches/landings. The total catch of the *O. pallidus* is currently ~70 t per annum. The fishery is comprised of two licenses operated by a single license holder. The small scale of the fleet, expanse of potential fishing grounds and natural fluctuations in the population, have produced considerable variation in landings over the past 15 years (Figure 41) (Emery and Hartmann 2016).

10.3.3.3. Fisheries/fishing methods. It is the target species for a pot fishery in the waters of Bass Strait in Northern Tasmania. The fishery was established in 1981 following an observation by fishers of a high prevalence of octopus in the stomach contents of sharks caught in the southern shark fishery. The octopus fishery was gradually built during the ensuing decades, with fishers exploring the waters of Bass Strait, whilst refining gear types and fishing techniques. Octopus are caught in passive shelter pots 10 cm high × 10 cm width × 30 cm long with a weight at the bottom of the posterior end. Approximately 500 pots are set on demersal longlines 3–4 km in length at depths of 18–85 m. The shelter pots are predominantly set on sand and silt substrates where they provide shelters in a structure poor environment. As a result of the function of the pots as a shelter, the pots predominantly catch mature females looking for a shelter to brood their eggs (Leporati et al. 2009).

10.3.3.4. Fishery management and stock assessment. In the *O. pallidus* fishery, operators are only allowed to fish in State waters north of the line of latitude 41° South (DPIPWE 2015a). Individual octopus' pots cannot exceed five liters in volume and fishers can only use a maximum 10,000 pots, capped at 1,000 pots per line. Octopus pots must be unbaited, without a door, flap or other device that would restrict an octopus from escaping from the pot and cannot be used to take fish species other than octopus (DPIPWE 2015a).

10.3.3.5. Economic importance. The *O. pallidus* fishery is small scale fishery that uses value adding (e.g., pickling) to service a mostly domestic market.

10.3.4. *Macroctopus maorum*

Geographic distribution of the Maori octopus, *M. maorum*, includes the north and south Islands of New Zealand, as well as southern Australia, from eastern Victoria to Perth (Western Australia) (Stranks 1988; O'Shea 1999; Norman and Reid 2000; Jereb et al. 2013).

It is considered the largest octopus species in Australasia with a body size up to 300 mm ML, TL to ~1 m, and body mass of 10 kg (Norman and Read 2000). The species inhabits intertidal and subtidal areas, from shallow waters to 300 m depth (O'Shea 1999). Adults mainly occur in soft-sediments, reef and fringe habitats in New Zealand (Anderson 1999), and earlier stages (newly settled and juveniles) can be found in intertidal pools in Tasmania (Stranks 1988). Whilst smaller individuals are more active during night time, adults can forage during daylight (Reid 2016). Burrowing behavior has also been reported in this species (Vafiadis 1998).

It is a selected feeder (Anderson 1999; Grubert et al. 1999), with a specialization towards decapod crustaceans, fish and bivalves (e.g., scallops) (Anderson 1999; Grubert et al. 1999). Cannibalism is conspicuous in this species (Grubert et al. 1999). Additionally, *M. maorum* is an important within-trap predator in the rock lobster (*Jasus edwardsii*) fisheries in South Australia (Brock and Ward 2004; Briceño et al. 2015) and Tasmania (Harrington et al. 2006; Briceño et al. 2016). Octopus depredation is highly variable at spatial and temporal scales, causing important economic and ecological uncertainties for the associated fisheries in south-eastern Australia (Briceño et al. 2015). It is consumed by a diversity of top predators, including sharks, large fishes, birds and mammals (see Lalas 2009), although its trophic role still needs further understanding.

The life span of *M. maorum* is unknown. Although stylet increment analysis has been applied, it may not be a feasible ageing method for *M. maorum* due to the soft, gelatinous structure of their stylets (Doubleday et al. 2011). It appears to be a spring-summer spawner, although a year-round mating and egg spawning strategy has been suggested in south-east Tasmania (Grubert and Wadley 2000). Ovary weight and fecundity were not correlated with body weight (Grubert and Wadley 2000). Potential fecundity can range from 56,000 to 232,000 eggs (Grubert and Wadley 2000). In captivity, females can spawn between 4,200 (Carrasco 2014) and ~7,000 eggs (Batham 1957; Anderson 1999). Eggs are attached individually (Anderson 1999), with an intermediate egg size of 6.43 ± 0.21mm length, 1.45 ± 0.11 mm width and 6.41 ± 0.52 mg of BW (Carrasco 2014). Embryonic development can take approximately 2 months at 16–18 °C in New Zealand (Anderson 1999; Carrasco 2014), with an intermediate paralarvae size (6.54 ± 0.39 mm TL and 7.46 ± 0.54 mg TW) (Carrasco 2014). Hatchlings are fully planktonic, with a unique chromatophore pattern (Anderson 1999; Carrasco 2014).

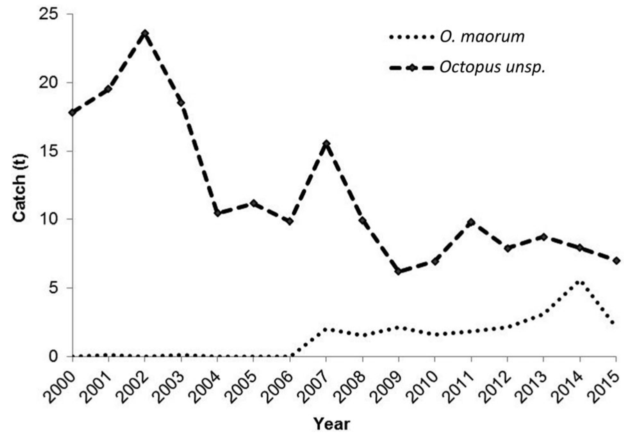

Figure 42. Annual catch of *Macroctopus maorum* between 2000 and 2015 in Tasmania.

10.3.4.1. Stock identification. Although *M. maorum* has a planktonic paralarval stage, genetic, morphometric and stylet chemistry data suggest that the species has a complex population structure within southeast Australia that is influenced by regional oceanographic features (Doubleday et al. 2008a, 2009). Genetic divergence was also observed between Australian and New Zealand populations. This species aggregates in large numbers (e.g., up to 70 individuals) in a shallow narrow embayment in south-east Tasmania (Grubert et al. 1999). Why this species aggregates is unknown, but genetic and chemistry data suggest that individuals originate from southwest Australia, with larval transport facilitated by the Zeehan Current (Doubleday et al. 2008b; Doubleday et al. 2009; Higgins et al. 2013).

10.3.4.2. Catches/landings. Catches of *M. maorum* in the *O. pallidus* fishery have been minimal, averaging 550 kilograms (kgs) over the last five years, with 343 kgs landed in 2015 (Emery and Hartman 2016). Catch was higher in the scalefish fishery, averaging 2 t over the last five years, with 1.5 t landed in 2015 (Emery et al. 2016). Catch of octopus is undifferentiated at a species level in the Tasmanian rock lobster fishery, but *M. maorum* is considered to be the main octopus caught in lobster pots (Harrington et al. 2006). Consequently, "unspecified octopus" landings averaged 6 t over the last five years, with 4.2 t landed in 2015 (Figure 42). Recreational fishing surveys conducted in Tasmania estimate the landed catch of unspecified octopus to be 1,443 individuals in 2012/13 (Lyle et al. 2014). Catch of undifferentiated octopus in the South Australian marine scalefish fishery averaged 13.3 t over the last ten years, with 10.5 t landed in 2015. Catch of undifferentiated octopus in the Victorian rock lobster fishery averaged 2.9 t over the last ten years, with 21.8 t landed in 2015.

10.3.4.3. Fisheries/fishing methods. The species *M. maorum* is landed as a byproduct species in various Tasmanian commercial fisheries including: (i) the *O. pallidus* fishery, which operates off the northern Tasmanian coast; (ii) the southern rock lobster (*J. edwardsii*) fishery, which operates State-wide and; (iii) the scalefish fishery, which also operates State-wide but predominately on the south-east coast. It may also be landed as a byproduct species in various Victorian and South Australian fisheries, primarily in the rock lobster and marine scalefish fisheries respectively.

The southern rock lobster has 312 licenses and between 205 and 220 active vessels. The fishery utilizes baited pots no more than 1.25 m high x 1.25 m width x 75 cm long, including at least three escape gaps, one 5.7 cm high x 40 cm wide and the other two 5.7cm high x 20 cm wide (DPIPWE 2011). Vessels are limited to the use of 50 pots, which are individually set at depths of up to 100 m.

The scalefish fishery has 286 licenses, of which 123 were active in 2014. It is a multi-species and multi-gear fishery, incorporating various vessel types and sizes. Examples of some gears used include: gillnet, hook and line, longlines, spears, drop lines, squid jigs, fish traps, purse seine nets, beach seine nets, dipnets and Danish seine (Emery et al. 2016).

In the recreational fishery in Tasmania, *M. maorum* are not a target but most likely to be caught during fishing operations involving gillnet, pot or spear.

In the Victorian rock lobster fishery there are 118 licenses and baited pots are used to catch the southern rock lobster (*J. edwardsii*) but also may opportunistically take octopus species, including *M. maorum*. The pots are 1.2 m high by 1.5 wide x 1.5 m long, with at least one entrance and escape gap. Vessels are limited to 120 and 140 pots in the eastern and western zones respectively.

In the South Australian marine scalefish fishery, there are over 60 species landed using 21 different gears, including octopus traps. These traps cannot be baited or have doors but may be of any size.

10.3.4.4. Fishery management and stock assessment. There is no formal stock assessment currently undertaken for *M. maorum* in Tasmania, South Australia or Victoria.

Catches of *M. maorum* in both the Tasmanian commercial *O. pallidus* fishery and the scalefish fishery is regulated under the Tasmanian (Scalefish) Rules 2015 and managed through a combination of gear restrictions, spatial controls and limited entry. There is a single quota management system in place to manage the commercial take of banded morwong. In the scalefish fishery, license holders are only allowed to take maximum 100 kilograms of combined octopus species per day or be in possession of no more than 100 kg of combined octopus species at any point in time (i.e., on a single trip) (DPIPWE 2015a). They are also only allowed to take a maximum of five combined octopus species per day or be in possession of more than five combined octopus species in Eaglehawk Bay (DPIPWE 2015a).

Catches of *M. maorum* in the Tasmanian southern rock lobster fishery is regulated under the Tasmanian (Rock Lobster) Rules 2011 and managed through individual transferable quotas (ITQs) with associated gear restrictions, minimum size limits, limited entry and spatial/temporal closures. Under these regulations, rock lobster license holders are only allowed to take maximum 100 kilograms of combined octopus species per day or be in possession of no more than 100 kilograms of combined octopus species at any point in time (i.e., on a single trip) (DPIPWE 2011).

The Tasmanian recreational fishery has a bag limit of five combined species of octopus per day, with fishers not able to possess more than ten octopuses at any point in time (DPIPWE 2015b).

There are no catch limits or regulations in the Victorian rock lobster fishery relating to octopus. The fishery itself is managed through individual transferable quotas (ITQs) with associated gear restrictions, minimum size limits, limited entry and spatial/temporal closures (DPI 2009).

There are no catch limits in the South Australian marine scalefish fishery relating to octopus but there are some spatial closures in place. The fishery itself is managed through a combination of input and output controls, gear restrictions, limited entry and spatial/temporal closures (PIRSA 2015).

Figure 43. Octopus dishes in China. (Image: XZ) (A) *Octopus sinensis* sashimi; (B) *Cistopus chinensis* boiled whole; (C) *Cistopus chinensis* fried whole.

10.3.4.5. Economic importance.

The economic importance of *M. maorum* has not been quantified. Sold primarily at fish markets for a niche market, the typical price per kilogram is relatively low in comparison to many other forms of seafood and value added products from other octopus species.

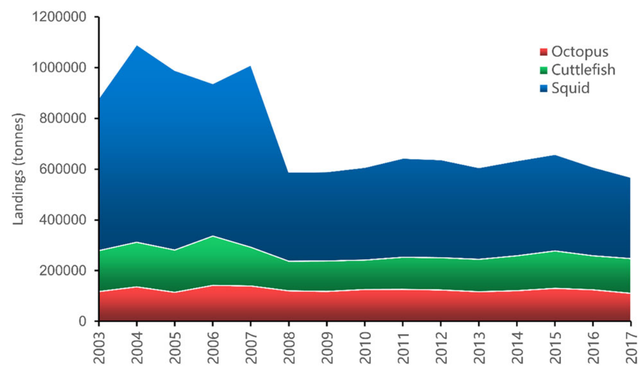

Figure 44. Cephalopod catch data (t) for China, 2003–2017 (data source: China Fishery Statistical Yearbook; does not include data from Taiwan).

11. North-Western Pacific

The Northwest Pacific region (Area 61 as defined by the FAO) is the western part of the Pacific Ocean between 22°N and 52°N to the west of 175°W and includes the East China Sea, the Yellow Sea, the Bohai Sea, the Japan Sea, and the Okhotsk Sea, including the coast of the Kamchatka Peninsula outside of the Bering Sea and the island of Sakhalin. The coastlines of China, Taiwan, the Korean Peninsula, Eastern Russia and the Japanese Archipelago are in this region. Data for three regions (China, South Korea and Taiwan) are available mainly just for "octopus" and, apart from general catch trends for octopus, few other details are available. These countries are therefore considered first, followed by brief introductions to Russia and Japan before discussion of individual species.

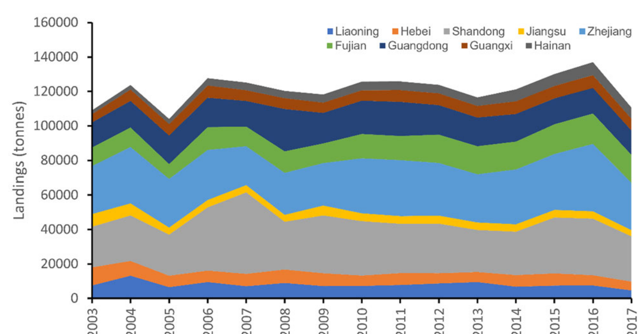

Figure 45. Total annual landings of octopus (t) from the main coastal provinces of China (2003–2017) (data source: China Fishery Statistical Yearbook).

11.1. North-Western Pacific country overviews

11.1.1. China

Octopus has been consumed in China since pre-historic times. Currently the most commercially valuable species are *O. sinensis*, "*O.*" *minor* and *A. fangsiao*. *Octopus sinensis*, the East Asian common octopus is of major economic importance in the southern waters of China, whilst "*O.*" *minor* and *A. fangsiao* are important on the northern coast (Shandong and Liaoning Provinces). Small catches of *Cistopus chinensis, Cistopus taiwanicus* and *Amphioctopus ovulum* are landed in some provinces, such as Fujian, Guandong and Guanxi. Species not treated in detail in this review are not fished commercially or are present as minor bycatch, and are included in catch statistics in the miscellaneous category "octopus."

Octopus sinensis, is the preferred species for charcoal grilling and "sashimi" (Figure 43A). Species of small mantle size such as *A. fangsiao*, *A. aegina, A. ovulum* and young *C. chinensis* are typically boiled or fried whole (Figure 43B, C).

Prior to 1987, China reported no octopus production figures to the FAO, and between 1987 and 2003, figures reported to FAO were only the annual catches from the west coast of Africa (*O. vulgaris*) and did not exceed 7,500 t (Jereb et al. 2013). The reported annual catch (available since 2003; Figure 44) appears to be fairly stable at just over 100,000 t, with Shandong and Zhejiang Provinces each recording landings of more than 20,000 t; followed by Guangdong Province. The two species *A. fangsiao* and '*O.' minor* are the main octopus species landed in Shandong Province, and *O. sinensis* in the Zhejiang Province. As a proportion of total cephalopod catches, the annual catch of octopus has risen to almost 20% in recent years (Figure 46).

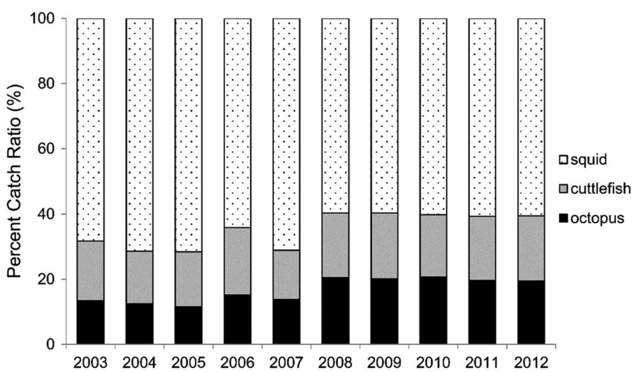

Figure 46. The ratio of catch for squid, cuttlefish and octopus in the Chinese coastal fishery.

11.1.1.1. Exports and imports to China. Reflecting the fact that the Chinese seafood trade is the largest in the world, China octopus catch accounts for almost half the global octopus catch (e.g. the 126,000 t taken in 2011 was 41% of the world's total). In 2009, the export quantity of raw octopus in China was 13,358 t with an economic value of US $4,480.5 million. The export quantity of processed octopus was 38,662 t with an economic value of US $15,892 million (data source: FAO 2013).

A significant amount of octopus is also exported from China: 67,908 t in 2017, 11 times greater than imports 5,873 t (Figure 47). Among imports, frozen octopus accounts for the largest proportion (95.9% and 97.7% respectively in 2017 and 2018; Fig. 47).

11.1.1.2. Species distribution in China. The main commercial species are listed in Table 7, the most important of which are *O. sinensis*, "*O.*" *minor* and *A. fangsiao* (Figure 48). All three are abundant, widely distributed and consequently important economically. In the markets they are often sold mixed as just 'octopus' ('zhangyu' in Chinese) and occasionally include *O. cyanea* and *C. luteus*.

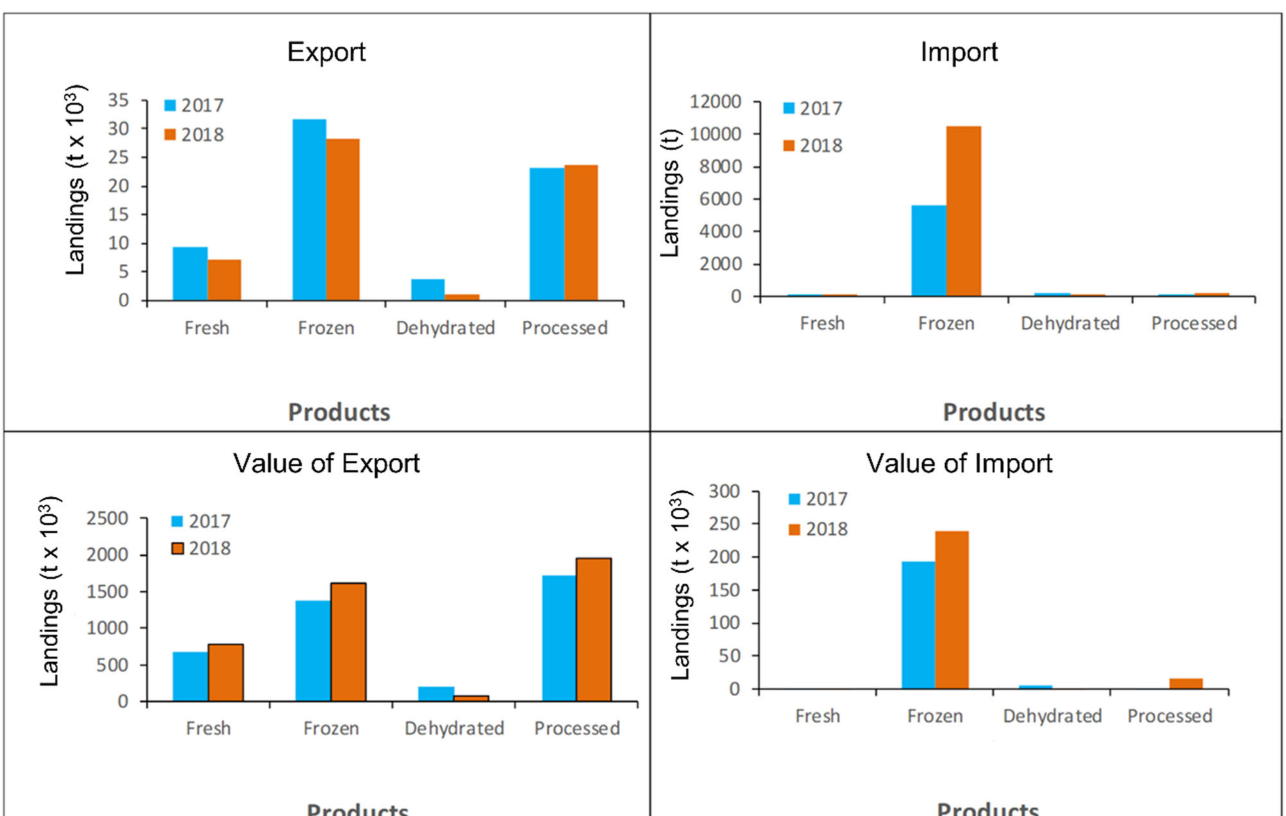

Figure 47. Exports and Imports of octopus in China in 2017 and 2018 (data source: Chinese Customs web site).

Table 7. Economic octopus species along the coastal waters of mainland of China.

Species	Bohai Sea	Yellow Sea	East China Sea	Taiwan Strait	South China Sea	Beibu Bay
Amphioctopus fangsiao	+	+	+	+	+	+
Amphioctopus ovulum	–	–	+	+	+	+
Amphioctopus aegina	–	–	+	+	+	+
Amphioctopus kagoshimensis	–	–	–	+	+	+
Amphioctopus marginatus	–	–	+	+	+	+
Cistopus chinensis	–	–	+	+	+	+
Cistopus taiwanicus	–	–	+	+	+	+
Callistoctopus luteus	–	–	+	+	+	+
"Octopus" minor	+	+	+	+	+	+
Octopus sinensis	+	+	+	+	+	+

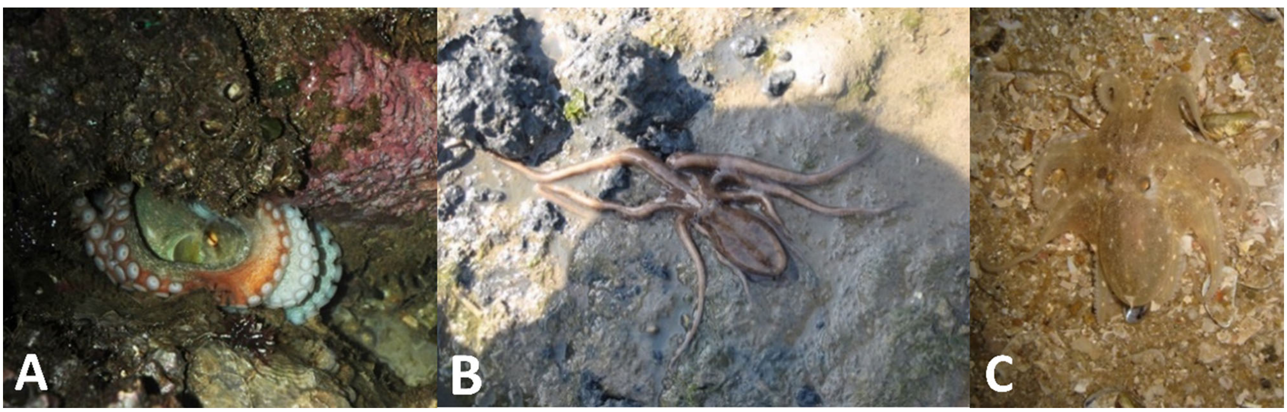

Figure 48. Chinese species of octopus (image: XZ). A, *Octopus sinensis*; B, *'Octopus' minor*; and C, *Amphioctopus fangsiao*.

11.1.1.3. Identification. A number of guides for Chinese cephalopods have been published which include octopuses, notably Lu (1998). Supplementary identification sources include Lu et al. (2012), Zheng et al. (2012, 2013) and Lu and Chung (2017). As with many octopus species, once dead they can be very difficult to distinguish. "Muzhuzhang" usually refers to *O. sinensis*. 'Duantuishao' or 'fangshao' usually refers to *A. fangsiao*, but also includes other species of *Amphioctopus*. "Luanshao" is considered to be *A. ovulum*, but found to include at least two other species (*A. rex* and *A. neglectus*) based on morphological identification and DNA barcoding (Tang, 2018).

11.1.1.4. Fisheries management. Fishing activity off the coast of China is strictly regulated by implementation of the Fisheries Law of the People's Republic of China, which was issued by the State Council in 1986. In view of overfishing and the severe decline of coastal fishery resources, the fishery administration at all levels strictly enforced the fishing license system and strengthened fishing management by establishing a protection system for aquatic resources, increasing protection for young fish, improving closed fishing zones and closed fishing season systems, prohibiting or restricting fishing gear and methods, using minimum mesh sizes and other measures to protect fishery resources. Conservation and management regulations for fisheries resources within territorial waters, including octopus, are developed and established by local (city or county) and state governments and ministries. For example, in order to better protect "*O.*" *minor* juveniles, the Ministry of Agriculture approved the establishment of a National conservation area for aqua-germplasm resources for "*O.*" *minor* in Moon Lake in Shandong Province in December 2012. A series of local standards were issued and implemented between 2013 and 2018. To date a total of ~2.3 million reared young octopuses have been released in the coastal waters of Shandong. The resulting harvest of '*O.*' *minor* in Moon Lake and the adjacent sea has increased by a mean of 10.5% year on year over the last nine years; a remarkable recovery.

11.1.2. Korea

The governmental organization Statistics Korea compiles and distributes all statistics for the Republic of

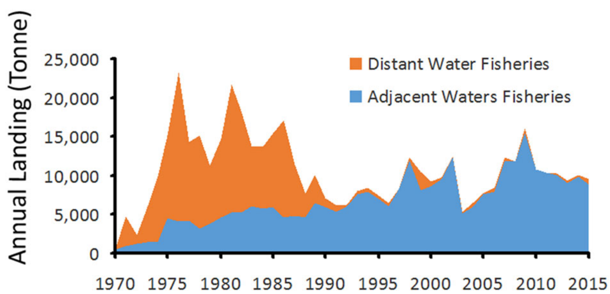

Figure 49. Annual landings of octopus off Korea (data source: Statistics Korea).

Korea (South Korea), fisheries statistics, and is the source of all information in this section[1]. Landings of octopus for the period 1970–2015 were obtained, subdivided according to whether the fisheries source was "adjacent waters" or "distant waters" (Figure 49). No species categories are recognized, the statistics being for the blanket term "common octopus" only. This presumably includes the same species as are fished on the Japanese side of the Japan Sea, as deduced from Korean studies on *O. sinensis*, "*O.*" *minor*, *A. fangsiao* and "*Octopus*" *longispadiceus* (Sasaki, 1917); as the respective synonyms *O. vulgaris*, *O. minor*, *Octopus ocellatus* and "*O.*" *longispadiceus* (Yamamoto 1942b; Chang and Kim 2003; Kim, et al. 2008; Kang et al. 2009; Son et al. 2015; Kim, Yang, and Lee 2016). Chikuni (1985) notes that "*O.*" *conispadiceus* is captured in northern Korean waters, and Yamamoto (1942a) identified *E. dofleini* from waters off the Korean coast.

Interestingly, the data appear to show a fluctuating but clearly marked decline in octopus fished in "distant-waters" between 1970 and 1990, reaching insignificant proportions between the late 1980s and the present; replaced by a general increase in "adjacent-waters" landings (Figure 49). The reasons for this are unclear (direct enquiries to Statistics Korea and the Korea Overseas Fisheries Association) although the rise in catches from local Korean waters has been attributed to continuous increases in fishing efficiency (Chikuni 1985). The total octopus catch in recent years has declined to less than 10,000 t and is about half what it was in peak years in the late 1970s and early 1980s, when it briefly exceeded 20,000 t.

The major types of gear employed are traps, pots, and jigging with hand-operated lures composed of several hooks attached to a central object.

[1]Obtained as a brief answer to questions asked in an official application to the Civil Petition Office of Statistics Korea: Petition 1AA-1605-134269 made by IGG to kostatmw@korea.kr on 23 May, 2016

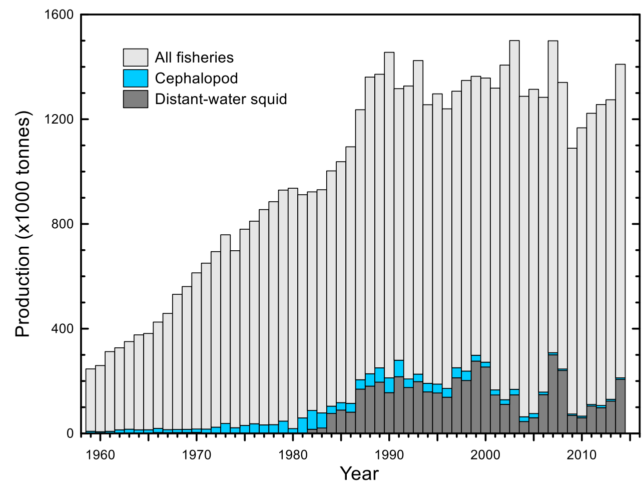

Figure 50. Annual production for all fisheries in comparison with catches of distant-water squid and other cephalopods.

Table 8. Octopus species fished from the seas around Taiwan.

	Off North Taiwan	Taiwan Straits	Off South Taiwan
Octopus sinensis	+	+	+
Octopus cyanea	+	+	+
Octopus minor	+	+	+
Amphioctopus aegina	+	+	+
Amphioctopus exannulatus	−	+	+
Amphioctopus fangsiao	+	+	+
Amphioctopus kagoshimensis	+	+	+
Amphioctopus marginatus	+	+	+
Callistoctopus luteus	+	+	+
Callistoctopus ornatus	−	−	+
Cistopus taiwanicus	+	+	+
Scaeurgus patagiatus	+	−	−
Enteroctopus sp.	+	−	−

Octopus is eaten parboiled, as sushi, stir-fried and in various kinds of stew. Par-boiled octopus is an important symbolic offering at wedding parties, especially for the communities of Gangwon and Gyeonsangbu islands (*fide* Statistics Korea, pers. comm. to IGG).

11.1.3. Taiwan

Typical of many countries, cephalopod catches off Taiwan are relatively small compared to the total catch for all fisheries, but nevertheless significant (Figure 50).

As with China and Korea, octopus fisheries production data for Taiwan are recorded under a single category "octopus" although at least 13 species have been collected and described from local fish markets (Lu 1998; Lu and Chung 2017), most of which are captured at all three major fishing areas (Table 8).

Octopus landings are a minor part of the total cephalopods fished off Taiwan (Figure 51). Annual cephalopod production is dominated by the distant-water squid jigging fishery, which has accounted for more than 70% of cephalopod production and

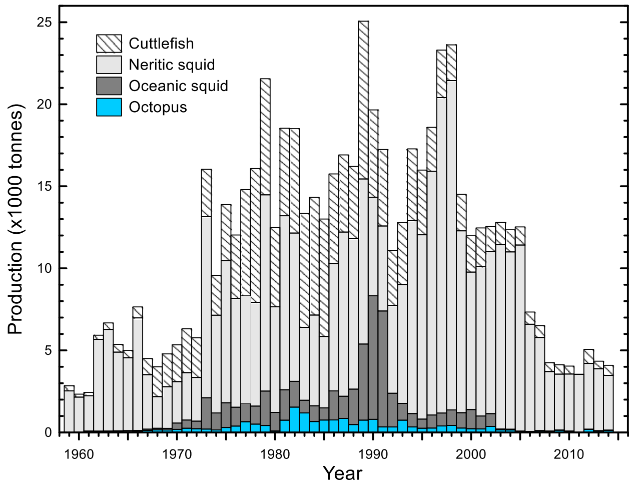

Figure 51. Comparison of octopus annual landings versus catch data for other cephalopods (excluding distant-water squid catches).

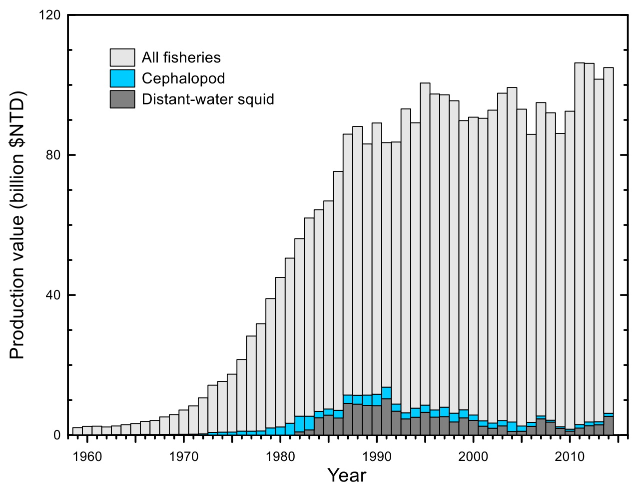

Figure 52. Annual production value of Taiwan fisheries for distant-water squid and locally-caught cephalopods in comparison with total fisheries production. Exchange rate approx. 30 New Taiwan Dollars ($NTD) to 1 $US (USD).

fisheries value since 1984 (Figure 52). Between 1959 and 2014 the annual cephalopod production for the neritic and coastal fisheries off Taiwan ranged from 2,300 t in 1960 to 25,000 t in 1982, with a mean of 5,600 t for the years 2005–2014 (Figure 51). For the same period, the annual octopus production ranged from 1.5 t in 2011 to 1,500 t in 1982. It was 20–30 t in the 1960s, increased during the 1970s, with a mean of 87 t for the years 2005–2014, accounting for 2% of local cephalopod production (Figure 51). Octopus production in recent years has dwindled and in 2014 was only 130 t.

11.1.3.1. Conservation and management measures.

All fishing vessels are required to operate under a license to fish in the waters around Taiwan. Trawling

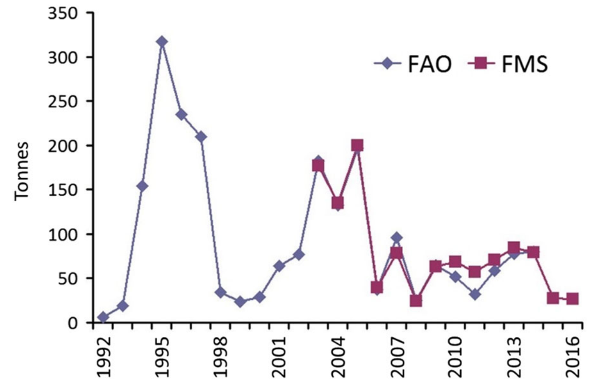

Figure 53. Annual landings of octopus in Russia, based on FAO statistics for 1992–2016 (www.fao.org/fishery/statistics/fishstatj/en).

has been prohibited within 3 nautical miles around Taiwan since 1999. Conservation and management regulations for fisheries resources, including octopus, within territorial waters are developed and established by local (city or county) and/or central governments (Fisheries Agencies) in Taiwan. For example, Peng-Hu county government announced a ban on harvesting an endemic octopus species for 45 days (from 29 March to 12 April) which has been in force since 2015.

11.1.4. Russia

The total commercial catch (targeted catch and bycatch) for octopus in the Russian EEZ shows significant annual variability, based on data submitted to the FAO beginning from the early 1990s (Figure 53). The annual catch reached its highest peak of 317 t in 1995, with subsequent smaller peaks, each of about 200 t, in 2003 and 2005, after which landings in Russia have been very low, at less than 30 t in 2015.

Catch statistics for specialized octopus trap fisheries in different geographic regions within the Russian EEZ are available from early this century (Figure 54). Annual catches of octopus in these specialized traps have fluctuated widely, and were at first much higher in the Pacific Ocean off the South Kuril Islands, but recently most of the harvest has been from the northwestern Japan Sea.

Considering all types of gear that catch octopus as a target, with octopus exceeding 50% of the total catch of all bottom species, the highest annual catches of the early 2000s were not accompanied by the highest catches per unit effort (CPUE), which were reported from fisheries off the South Kuril Islands (up to 5.6 t per day per vessel). Fisheries using specialized traps usually did not yield high CPUE values but they were consistent, unlike the high annual fluctuations seen in the total catch.

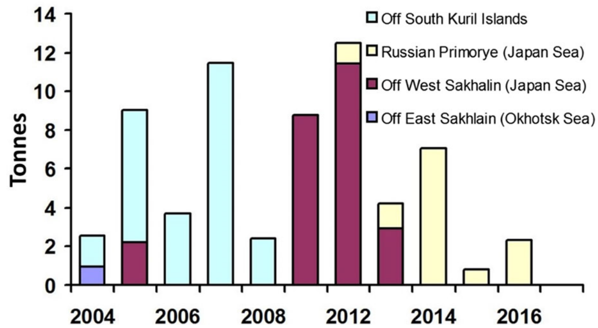

Figure 54. Annual landings of trap-caught octopus off different areas of eastern Russia.

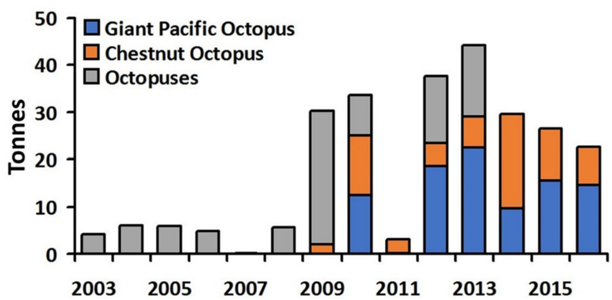

Figure 55. Annual landings of octopus off Primorye in the northwestern Japan Sea.

The octopuses presently fished in the Russian far eastern seas are primarily from the northwestern Japan Sea and comprise mostly two targeted species: *E. dofleini* and "*O.*" *conispadiceus*, both cold-water species. Unfortunately, prior to 2009, fishing companies did not specify target species in their reports, and only in the last three years have these two species been identified in statistics for the specialized octopus fishery of Primorye (Figure 55). In this region, the annual commercial harvest of octopus increased rapidly to 30 t in 2009, reached a maximum of 44 t in 2013, and subsequently decreased to 23 t in 2016. The share of the catch of *E. dofleini* has tended to increase, which could be attributable to the fact that, in the last three years, 75–94% of all octopuses were harvested from rocky substrate off the southern part of Primorye.

11.1.5. Japan

Consumption of octopus has occurred throughout Japan since pre-historic times. In recent times though, the more abundant squid are generally the most popular cephalopod seafood item, particularly with the modern advances in efficient capture last century using vessels carrying multiple automated jigging machines. The most valuable octopus commodities in Japan are *E. dofleini* (with "*O.*" *conispadiceus*), *O. sinensis* and *A. fangsiao*. Landings of small amounts of "*O.*" *longispadiceus* and "*O.*" *minor* in some prefectures are also

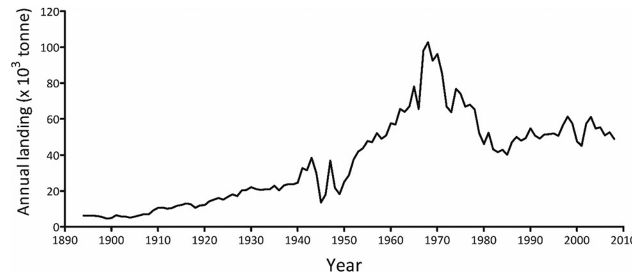

Figure 56. Annual catch of octopus off Japan since records began in 1894 (data source: Japan eStats national fishery data by catch group category "tako-rui").

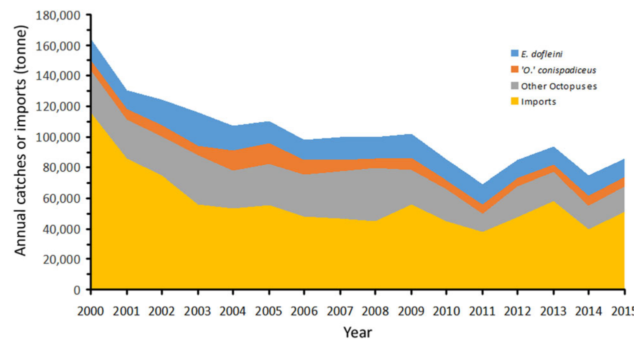

Figure 57. Consumption of octopus in Japan. Domestic fisheries production and imports of octopus during the early part of the 21st Century (data source: Japan Customs web site; see Appendix A). At least half of the imports are attributable to *Octopus vulgaris*, which is closely related to the East Asian endemic, *O. sinensis*. Note that a significant part of the fisheries catch for Japan is *Enteroctopus dofleini* (GPO) and "*O.*" *conispadiceus*. *Octopus sinensis* is a (large) component of the domestic category "other octopus species."

discussed below. Species not treated in detail in this review (e.g., some of those listed in Table 9; see also Appendix B) are not fished commercially or are present as minor bycatch and are included in catch statistics in the miscellaneous category "octopus."

The Japanese fast-food item known locally as "takoyaki" (grilled dough balls filled with a piece of octopus meat) has shown a dramatic rise in popularity this century, with restaurants opening in many countries world wide (Hotland plc, for example, now has branches in China, Hong Kong, South Korea, Malaysia, Taiwan and Thailand; advertising literature and K. Matsubara, pers. comm. to IGG). The East Asian common octopus, *O. sinensis*, is the preferred species for takoyaki. The consequent rise in domestic popularity of the common octopus group of species has increased the pressure on populations that are already acknowledged to be fully- or over-exploited (Hamabe et al. 1976; Chikuni 1985). Species very close to *O. sinensis* account for much of the octopus imported to Japan, most of which ends up as takoyaki. The species *E. dofleini* (along with "*O.*"

Table 9. Distribution of species included in catch data reported from the main coastal regions of Japan.[5]

	Hokkaido	NEP	Japan Sea	SCP	Seto	Kyushu	Okinawa
Enteroctopus dofleini	+	+	+	+	+	+	−
"Octopus" conispadiceus	+	+	+	+	+	−	−
Octopus sinensis	−	+	−	+	−	−	−
"Octopus" hongkongensis	−	+	−	−	−	−	−
"Octopus" longispadiceus	−	+	+	+		−	−
Amphioctopus fangsiao	−	+	+	+	+	+	−
"Octopus" minor	−	−	−	−	+	−	−
"Octopus" sasakii	−	−	−	+	+	−	−
Amphioctopus kagoshimensis	−	−	−	−	+	+	−
Amphioctopus sp.*	−	−	−	−	+	−	−
Octopus cyanea	−	−	−	−	−	−	+
"Octopus" ornatus	−	−	−	−	−	−	+
"Octopus" luteus	−	−	−	−	−	−	+

conispadiceus) is consumed mostly as sushi, and *A. fangsiao* is typically boiled whole as one of the components of a hot-pot dish known in Japanese as "oden" or "kantō-ni" and for special dishes focused on the rice-like egg content of ripe females, particularly during Spring.

Figure 56 indicates a steady increase in total octopus catches off Japan seen since records began in the late 19th century, presumably the effect of an increase in the number of fishing vessels along with improvements and innovations in gear (cf. Worms 1983). Superimposed on this increase is a declining trend in catches since a peak of over 100,000 t in the late 1960s. Over the last few decades, the total octopus catch off Japan has fluctuated between 40,000 and 60,000 t. Since the beginning of this century, catches are declining, and this is shown more clearly in Figure 57, which reveals that the decline applies to both local catches and imports. In Japan, certainly, this decline is now acute: in particular, *E. dofleini* is declining year upon year, particularly off the Pacific northeastern coast of Honshu; *A. fangsiao* is currently in unavailable off Okayama Pref. (T. Akiyama, pers. comm. to IGG, March 2018); and in Hokkaido the catch of "*O.*" *conispadiceus* has plummeted such that urgent research is in progress to try to raise juveniles from eggs in the hope of rejuvenating the fishery by restocking (N. Akiyama, pers. comm. to IGG, April 2018).

11.1.5.1. Imports to Japan. Taking the place of much of the demand for the overfished octopus in Japan, imports were over 100,000 t at the turn of the century (Figure 57) but are now only a fifth of that amount. In 2017, Japan imported 23,763 t of octopus: 9,034 t from Morocco, 8,118 t from Mauritania, 3,995 t from China, 1,338 t from Vietnam, 304 t from Senegal, 302 t from Mexico, 289 t from Thailand, 143 t from Chile; less than 100 t each from India, Indonesia, Malaysia, Peru and the Philippines; and less than 5 t each from Greece, Russia and Spain (data source: Japan Customs web site, details in Appendix A). Imports from Greece, Mauritania, Morocco, Senegal and Spain (56% of total imports for 2017) are *O. vulgaris* and (along with the country of origin) are labeled "madako" in Japanese supermarkets, which is the same name used for the local *O. sinensis*. It has been suggested (Gleadall 2016a) that the overwhelming amount of *O. vulgaris* imports (labeled "madako") has been masking the dramatic decline of the local *O. sinensis* (also labeled "madako"): compare the import tonnage with the total Japanese fisheries catch, comprising catches of *E. dofleini*, "*O.*" *conispadiceus* and "other" species, which includes Japanese "madako" *O. sinensis* (Figure 57). To draw consumer attention to this situation, the Japanese name "chichūkai madako" (literally "Mediterranean common octopus") has been proposed (Gleadall 2016b) with the aim of applying it to *O. vulgaris* imports to Japan.

Tariffs on imported octopus (as announced on the Foreign Ministry Trade Statistics Japan Customs web site) are generally 10% (WTO 7%; GSP 5%) but free for imports from less developed countries (LDC) and named regions and countries (ASEAN, Brunei, Chile, Indonesia, Malaysia, Mexico, Philippines, Singapore, Thailand).

11.1.5.2. Species distribution in Japan. The main commercial species are listed in Table 9. The most important species in the Japanese fishery is *E. dofleini* (which along with lesser amounts of "*O.*" *conispadiceus* is aimed at the sushi trade), followed by *O. sinensis* (Figure 58). They are important not only in terms of their abundance as common species, but also for

[5]Species listed top-down roughly in order of annual catch weight. Regions listed left-to-right from Northeast to Southwest (refer to map, Figure 59). NEP, combined prefectural coastal catches from the northeastern Pacific coast of Honshu (Aomori, Iwate, Miyagi, Fukushima, Ibaraki and Chiba); SCP, southern Central Pacific coast of Honshu (Tokyo, Kanagawa, Shizuoka, Aichi, Mie and Wakayama); Seto, Seto Sea and surrounding regions (Osaka, southern Hyogo, Okayama, Hiroshima, Yamaguchi and Shikoku). 'Japan Sea' includes combined prefectural catches for Akita, Yamagata, Niigata, Toyama, Ishikawa, Fukui, northern Hyogo, Tottori and Shimane. *Identification uncertain: an ocellate species sometimes misidentified as *Amphioctopus areolatus*.

Figure 58. *Enteroctopus dofleini* (left) and *Octopus sinensis* (right) of comparable size on the deck of a fishing vessel unloading octopuses taken in the same catch by an octopus-cage fisherman off Oura Port, Oshika Peninsula, Miyagi, in January, 2014. (Image: IGG).

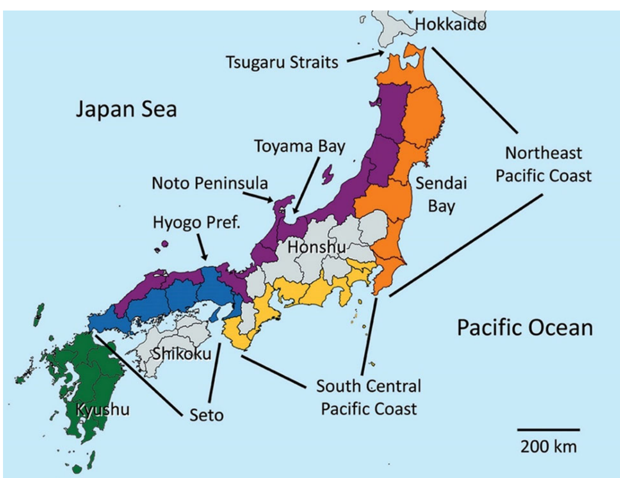

Figure 59. Map showing the larger islands of Japan with geographical features and divisions of the Japanese coastal regions of Honshu used in this review (cf. Figure 63). For the prefectural composition of these coastal regions, see notes with Table 9. Note that Hyogo Pref. has coasts on both the Seto and Japan Sea sides. The northern island of Hokkaido is discussed in more detail in section 11.3.2: Japanese fisheries.

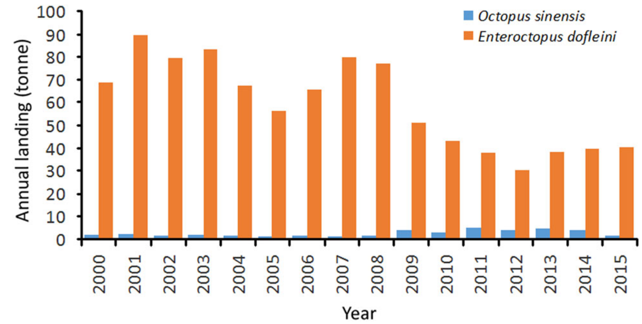

Figure 60. Annual landings of octopus for the Japan Sea coast of Hyogo Prefecture.

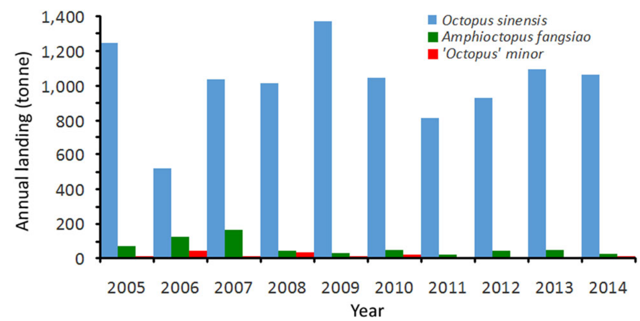

Figure 61. Annual landings of octopus for Akashi, on the Seto Sea coast of Hyogo Prefecture.

their wide distribution, the annual tonnage of each caught in Japanese waters, and their consequent economic importance. Both species occur among the catches of the Japan Sea and northeastern Pacific coasts of Honshu (NEP, Table 9), so their distributions overlap geographically, although they occur at different depths and temperatures, since *E. dofleini* is a cold-water species, while *O. sinensis* requires much warmer waters. In more southerly, shallow coastal seas, *O. sinensis* dominates. The species distribution shown in Table 9 is exemplified by catches off Hyogo, which is the only prefecture of Honshu (except for the northern and southern ends) with a coast on both the Japan Sea and Pacific sides (the latter in the Seto Sea). Octopus catches on the Japan Sea coast are relatively much smaller, at around 40 t per year, while on the Pacific (Seto) coast the annual catch usually exceeds 1,000 t (compare Figure 60 and Figure 61). Relatively small amounts of octopus are taken from the ocean off Okinawa (the Ryukyu Islands) and the species are very different from those present off the large Japanese islands from Kyushu northwards. The annual catch throughout the Ryukyu Islands is rarely more than 100 t, recently around 70 t, and is dominated by the Indo-West Pacific species *O. cyanea*, with very small amounts of "*Octopus*" *ornatus* Gould, 1852 and *C. luteus* (*O. luteus*) (Ohta and Uehara 2015).

Qualitatively, the catch composition is very different: note the absence of *E. dofleini* from the enclosed, warm, shallow Mediterranean-like Seto region (Figure 61), which instead has significant catches of *A. fangsiao* and "*O.*" *minor*. Both these latter species are present in the Japan Sea at least as far north as the Toyama region (see Sasaki 1929) but in amounts too small to appear on catch charts. Monthly catch data for the Japan Sea prefecture Ishikawa show clearly the temperature dependence and seasonality of *E. dofleini* and *O. sinensis*, the former taken only during cold winter months, while *O. sinensis* is taken year-round but mostly in the Spring and Autumn (Figure 62).

In terms of quantity, *E. dofleini* is taken in largest amounts around Hokkaido and off the NEP coast of Honshu, while the largest catches of *O. sinensis* are off the southern Central Pacific coast (SCP) and the Seto region.

Breaking down the total catch by region of capture, it can be deduced that the decline in catches since the late 1960s is due mostly to declines in the warm-water species (corresponding to the yellow and deep-blue solid portions of the graph in Figure 63). The catches of *E. dofleini* (the majority of the Hokkaido catches) seem reasonably stable at this level of resolution. In view of the dominance of *O. sinensis* in the SCP and Seto regions, this suggests strongly that the decline in the octopus catch has been borne mainly by *O. sinensis* (see also Gleadall 2016a), although there is evidence that the much smaller *A. fangsiao* also is heavily overfished. The reasons for this decline are not clear. Commercially important shellfish and kuruma prawn catches here have also slumped recently, and a fall in secondary production by macrobenthic communities generally has been detected in the Seto region (Tsujino 2018).

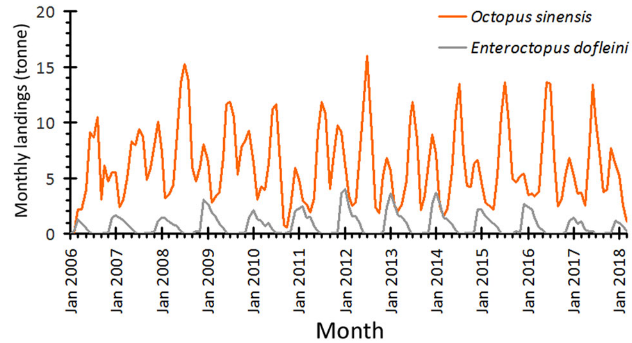

Figure 62. Ishikawa Prefecture monthly octopus landings. Compiled from monthly data for Toyama and Ishikawa downloaded from the Toyama Prefectural Fisheries Research Institute web site: the main Ishikawa ports are mostly at the western end of Toyama Bay, on the eastern side of the Noto Peninsula (refer to map, Figure 59).

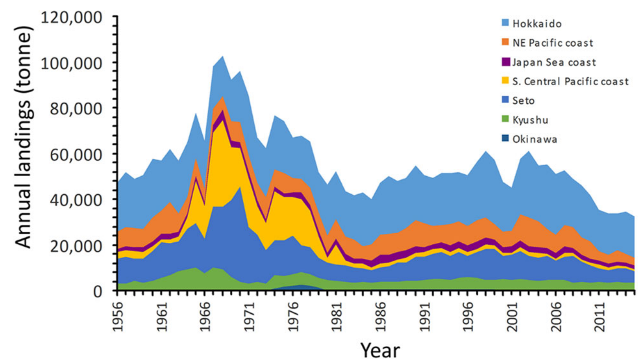

Figure 63. Total annual landings of octopus from Japanese waters by region (as indicated in Figure 59). See footnotes of Table 9 for prefectures comprising each region. Data for each prefecture downloaded from the eStats web site (see Appendix A).

11.1.5.3. Identification. A number of guides for Japanese cephalopods have been published which include octopuses (Okutani et al. 1987; Kubodera 2000, 2013; Tsuchiya et al. 2002) and these can be consulted for identifications not only for Japan but also for the Northwest Pacific region in general. Supplementary identification sources include Gleadall (1993, 1997, 2004, 2016a), Lu (1998), O'Shea (1999) and Lu and Chung (2017). As with many octopus species, once dead they can be very difficult to distinguish and many fisheries statistics list all octopuses together under blanket names such as "common octopus" (listed in Japan by the vernacular name "madako," usually in the sense of *O. sinensis*, but also including any species in the *O. vulgaris* complex of species) or even just "octopus" ("tako").

11.1.5.4. Fisheries management. Fishing effort off Japan is regulated through a strict licensing system (Chikuni 1985). Japanese coastal fisheries and aquaculture are overseen by some 934 local fisheries co-operatives and unions around the Japanese archipelago, with the number per prefecture reflecting the length of coastline available: for example, the coasts of the large island of Hokkaido are overseen by 70 different organizations; while on the relatively short coast of Miyagi Prefecture there are only five. These co-operatives maintain exclusive control of all fishing rights and activities in each local area, supported by quasi-governmental prefectural research stations.

The status of octopus stocks in Japanese waters varies by region. In some prefectures, landings show a steady seasonal pattern that is reasonably consistent (as for Ishikawa Pref., for example; Figure 62). It has long been recognized, however, that, in general, octopus is fully exploited in Japanese waters (see, for example, Itami 1976; Chikuni 1985). For octopus fishing, size limits are imposed (e.g., a 100 g legal minimum for *O. sinensis*; Itami, 1976) as well as seasonal closures in some prefectures (information available in Japanese on the web sites for individual prefectural marine research institutes). For example, the *O. sinensis* fishery off Kagawa Pref. is closed in September (Seto region); there is a limit on the size of fishing vessels that may offload during July and August at

Ishinomaki Port, Miyagi Pref. (IGG, pers. obs. and information obtained during port visits); and sales of octopus are prohibited in Miyagi Pref. during June through August.

11.2. *Enteroctopus dofleini*

In the Northwest Pacific, the giant Pacific octopus (GPO; "mizudako" in Japanese) occurs widely across the Subarctic Pacific Rim from the Japan Sea and coastal Asia northwards. It is very common along the shores of Japan and Korea, rarer in Russian waters (Akimushkin 1963, 1965). In Japanese waters, it occurs off the coasts of Hokkaido and Northeastern Honshu (Tohoku in Japanese) and in deeper waters further southwards (Sasaki 1920, 1929). There are however some uncertainties concerning its species composition.

Pickford (1964) identified three subspecies: *E. dofleini dofleini* in the Northwest Pacific; *E. dofleini martini* in the Northeast Pacific; and *E. dofleini apollyon* off the Aleutians. Gleadall (1993) discovered that Pickford's identification of the Japanese population included specimens of another species, "*Octopus*" *hongkongensis* (Hoyle, 1885), and concluded that the evidence presented by Pickford did not justify recognition of a subspecies complex of *E. dofleini* in the North Pacific (cf. also some past misidentifications of GPO using the species name *hongkongensis*: Kanamaru, 1964; Kanamaru and Yamashita 1968).

Nesis (1994) reported on a population in the Western Bering Sea that he identified as subspecies *apollyon* (although he was unfortunately unable to retain or preserve any of the specimens, which were obtained by him as a visiting researcher aboard a Japanese survey trawler). That population was sampled mainly in trawls between 100 and 750 m, mostly at 300–400 m depth. Recently, the presence of more than one species of GPO has been confirmed off Alaska, in the American Northeast Pacific (Toussaint et al. 2012; Hollenbeck and Scheel 2017), raising the possibility, also, that there may be more than one species of the *E. dofleini* complex in Russian and Japanese waters. The two Alaskan species, however, are very similar morphologically, especially when dead, so for fisheries purposes the identification *E. dofleini* (GPO) is appropriate at the present time.

If more than one species is present in the Northwest Pacific also, research on their distribution pattern and fisheries impact will be advisable in order to manage this important fishery effectively and sustainably, particularly in view of the recently observed decline in catches of this species in the population off northeastern Honshu, Japan. In shallower Russian waters, where it is harvested commercially, GPO seem to inhabit only shelf areas from the inter-tidal zone down to the shelf-break (Hartwick 1983; Nesis 1982, 1987; Sakamoto 1976; cf. Noro and Sakurai 2012), rarely in the bathyal zone (Akimushkin 1963, 1965; Kondakov 1941). The Albatross Expedition of 1906 collected four specimens from off Miyazaki, eastern Kyushu, at 800 m, marking the southern limit of its known distribution in the Northwest Pacific (Sasaki 1920; as "*O.*" *hongkongensis*), although there is no GPO fishery this far south.

Apart from its very large size, the living animal (Figure 58) is distinguished by a single, large, ear-shaped papilla above each eye; longitudinal stripes and grooves on the dorsal mantle, emphasized by raised, laterally-flattened papillae; and differential aggregations and/or expansions of chromatophores manifested as longitudinal lines, which on the skin of the arms and interbrachial membranes form an amorphous network. These features disappear soon after death, however, following which the main distinguishing features are the large body size, the very long, slim ligula of males (Gleadall 1993) and the presence of large numbers of very small eggs in mature females (38,000 to 94,000; Noro 1996). This species may live for up to 5 years, reaching a correspondingly very large size, with some individuals reaching more than 50 kg wet weight.

The GPO is a cold-water octopus with an optimal food conversion rate between 2.5 and 5 °C, decreasing at higher temperatures (Sano and Bando 2018). Daily growth rate is optimal at 10 °C, decreasing as the water temperature increases, until at 20 °C it becomes negative and weight is lost; the daily feeding rate decreases at temperatures above 15 °C (Sano and Bando 2018). The most abundant food items of GPO (in Japanese waters) include significant amounts of the echiuran "penis" worm *Urechis unicinctus*, various fish, crabs and octopus (Sano et al. 2017).

11.2.1. Russian fisheries

11.2.1.1. *Distribution and life history.* The main focus of Russian GPO catches in recent years is the northwestern Japan Sea, which is enclosed by two Regions (Krai) and one Area (Oblast) of the Russian Federation: Primorskyi Krai (Primorye) in the south, bordering China except for a short border with North Korea; further north, Khabarovskyi Krai lining the far northwestern Japan Sea; and, to the east, Sakhalin Oblast, which includes the island of Sakhalin, the

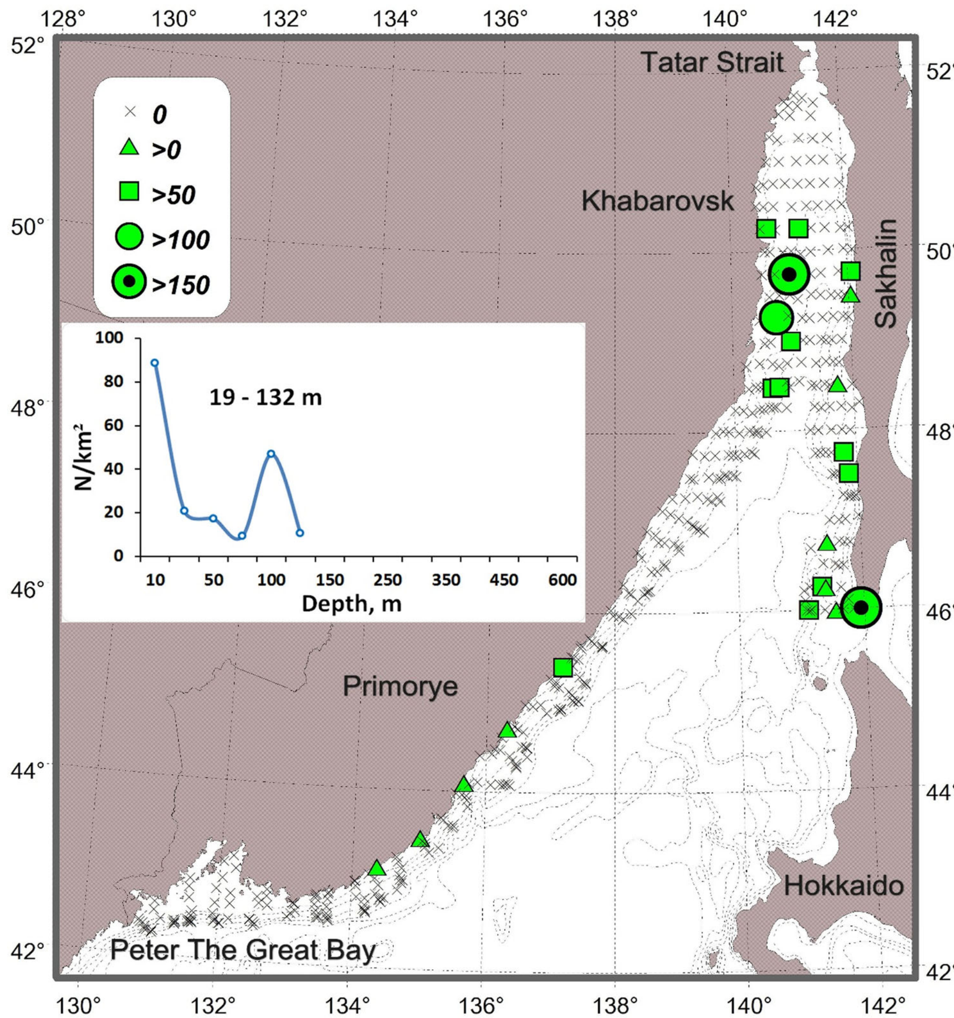

Figure 64. Distribution of *Enteroctopus dofleini* (GPO) in the northwestern Japan Sea in April-June, 2015 (symbols: no. of individual octopuses per square km in groups of 50). Inset graph: Distribution by depth, showing two main groups, at about 10 m and 100 m.

Kuril Islands, and the Tatar Strait between Khabarovskyi Krai and Sakhalin (Figure 64).

Data collected during trap-box surveys suggest that, off the Primorye region, GPO migrate seasonally up and down (and presumably also along) the shelf, largely associated with reproductive behavior and seasonal changes in habitat conditions (Golenkevich 1998). During the warm Summer–Autumn season, octopuses were captured at depths from 10–15 m down to 100 m, with the highest occurrence at depths 20–50 m and water temperatures near the bottom of 8–18 °C. During the cold Winter–Spring season, they were found sporadically from the inter-tidal zone down to 150 m depth, very occasionally down to 300 m depth, occurring mainly between 15 and 100 m. These octopuses therefore show at least two large-scale seasonal migrations: moving up the shelf and close to the coast in Summer; returning to deeper waters in the Autumn as the coastal waters cool (Golenkevich 1998).

Wide-scale patterns of geographic and bathymetric distribution of GPO in the northwestern Japan Sea were obtained during an extensive bottom trawl survey in the Spring of 2015 (Figure 64). Bottom hauls were made down to 600 m but GPO were encountered only on the shelf at depths of 19–132m, with the highest concentrations occurring in the shallow Tatar Strait (between Sakhalin Island and the mainland) and off the southwestern cape of Sakhalin Island.

GPO distribution patterns are related to the species life history features (Katugin et al. 2010). Octopuses mature at about 3 years and mate presumably in deep-water areas during Winter and Spring. Females then migrate to shallow waters (usually not deeper than 50 m) and occupy a den inside crevices with an overhanging surface on which they deposit up to 100,000 eggs per female. The eggs are relatively small, elongate-ovoid, 6–7 mm in length with a long (15 mm) thin stalk. As with all octopus species (e.g., Kaneko et al. 2006), females brood their eggs, blowing water over them for efficient aeration, cleaning them with the many suckers on the arms and protecting them from predators. Brooding usually lasts 5–7 months during Spring to Autumn, and after the eggs have hatched, the females die.

Newly hatched paralarvae are planktonic during the next 2–3 months, after which they settle on the sea-bed, where the benthic phase of their life cycle begins and will last for about the next 2 years. Once more than a year old, by late June to early July, the immature octopuses recruit into stocks which are harvested by the fishery. Therefore, on the shelf of Primorye, the early season (Winter and Spring) fishery is based upon two major groups of octopus with different size-at-maturity features: smaller immature and maturing animals; and larger mature and pre-spawning animals (Golenkevich 1998). Immature and maturing males weigh 5–13 kg (with a reproductive system of 60–450 g), and fully mature males weigh 8–24 kg (reproductive system 500–1,000 g, largest in November to December, dwindling to half that by early February; Akimushkin 1963, 1965). Immature and maturing females weigh 3–13 kg (reproductive system 20–450 g), and pre-spawning copulated females weigh 8.7–20.4 kg (reproductive system 520–1,400 g). As the season (early Summer) progresses, mature and ready-to-spawn animals migrate to spawning areas and disappear from the catches. Eggs are laid in Spring and early Summer (Akimushkin 1963, 1965). In Summer, catches are dominated by growing and maturing individuals, which will mature the following Spring.

There are two distinctive peaks of bathymetric occurrence of GPO in Spring, one close to the shore in shallow areas; and the other at depths of about 100 m (Figure 64), presumably related to their life-history stage.

11.2.1.2. Stock identification. No data on stock identification for GPO are available from Russian waters so far, other than the above-mentioned age- and depth-related cohorts.

11.2.1.3. Catch and landings. GPO catches on the Primorye shelf show a seasonal pattern and are associated with life history features such as maturation and migrations. After a winter drop in octopus abundance, there is a spring rise in catches of large octopus at 10–20 m depth. In April and May, large pre-spawning females occur which later disappear from catches. In the early Summer, relatively small immature animals weighing 3–8 kg dominate the trap-box catches. An increase in octopus catches then occurs from late August through October, during which up to 80% of trap-boxes are occupied when hauled in. At this time, actively foraging octopuses concentrate mainly within the depth range of 20–50 m, which could be associated with an increase in productivity of coastal waters due to upwelling of deep, nutrient-rich water (Zuenko 1998). This is the most favorable time for the octopus fishery over most of the entire shelf of Primorye, and the octopus harvest is based primarily upon immature and fast-growing individuals. Later in the season, when the water cools due to autumn wind-stress mixing and maturation of octopus progresses, first the pre-mature males and then large pre-mature females disappear from the catches. In December, GPO occurrence is at its minimum.

11.2.1.4. Fishing methods (vessels, gear). Methods for GPO fishing make use of information on specific features of the species behavior and distribution, particularly octopus occurrence on different types of sea-bed, and preference for certain biotopes. In the coastal zone, octopuses frequently utilize as a shelter various rocky areas with caves, boulders and crevices, so they tend to aggregate near rocky capes and occur less frequently in the central parts of sandy bays. Farther offshore, octopuses do not seem to have any substrate preference and may occur on gravel and shelly ground, as well as on sand and silt (Golenkevich 1998).

Close to the rocky shores of Primorye, fishing for octopuses is begun by scuba divers. Such a harvest of octopuses traditionally occurs at depths of 12–28 m along the crenelated shoreline of the mainland, as well as near large islands (such as Ascold and Putyatin), small islands, and steep conical rocks, some of which emerge above the sea surface. Large mature octopuses usually migrate to these areas during the period between early May and late July, where they find a den suitable for egg laying. Observer data suggests that during this short-term fishing season (which lasted only 17 days in June–July of 2008) octopus catches per diver were up to 40 kg per individual diving operation and total daily catches ranged from 100 to 350 kg per boat, peaking at 480 kg. A total of about 4,000 kg of octopus was taken aboard a fishing boat by scuba divers, with the catch consisting of males weighing 4–24 kg and females 5–20 kg.

In areas where there are no natural dens, fishing for octopus is conducted using longlines and traps. Along the Kuril Islands, small conical crab traps, Russian whelk traps and Japanese unbaited longlines are used to capture octopuses. The latter gear appeared the most successful with a catch per longline of 6 thousand hooks peaking at 2.5 t per fishing operation. In the northeastern Japan Sea, octopuses are harvested mainly using specially designed boxes made of wooden boards with a hole in one side (trap-boxes). The holes may have different shapes: oval, rectangular, or rhomboid. These traps are attached to the longline and deposited on the bottom.

11.2.1.5. Fishery management. GPO fishery management is based on existing general knowledge of the species abundance and distribution patterns, and reflects the demands and abilities of the fishing industry. In view of the habits specific to octopuses (solitary lifestyle associated with the seabed and frequent use of hiding shelters) it is difficult to collect reliable information on distribution and abundance.

Trawl research surveys conducted in Peter The Great Bay (the largest gulf of the Japan Sea, at Vladivostok in Primorye, just north of the short border with North Korea; Figure 64) have provided some information about GPO abundance. Over a research area of 9–11,000 km^2 in the bay, GPO biomass was estimated at 437 t (distribution density 21–22 individuals per km^2) in 2011; and 170 t (3–4 individuals per km^2) in 2012. Over a much smaller area of 151 km^2, the survey in 2013 covered a rather dense aggregation of GPO, for which the biomass was estimated as 68.1 t (76 individuals per km^2). This may reflect patchiness in the distribution as well as shifts in the timing of migration, and annual changes in abundance. Estimation of the recommended annual harvest rate is difficult, and the demands by the local fishery are low, so the catch quota for GPO is set at only 15 t on the Primorye coast.

In the Tatar Strait off the Sakhalin coast, GPO distribution density was calculated at the turn of the century based upon trap-box surveys. No sharp annual changes in abundance have been observed in the region: stock size of large mature animals weighing more than 5 kg was estimated to be about 200 t; and the annual quota for this species was set at 60 t. Each year, however, the annual catch is very low due to the low demands of the fishery. Around the south Kuril Islands, where the commercial GPO catch is based on at least two aggregations near Kunashir and Shikotan islands, the annual catch quota is set at 240 t, based on the minimum mature octopus abundance, estimated to be about 800 t.

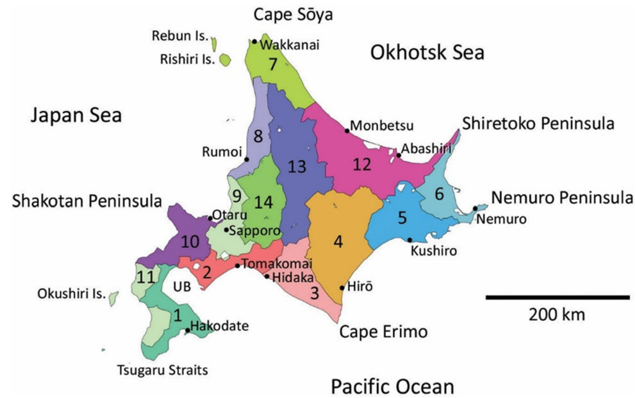

Figure 65. Map of Hokkaido to illustrate some of the major ports and features mentioned in the text and fisheries literature. UB, Uchiura Bay (commonly known also as Funka Bay, = Eruption Bay). Key to Hokkaido subprefectures (also the names of towns in some instances): 1, Oshima; 2, Iburi; 3, Hidaka (now part of Iburi); 4, Tokachi (main port Hirō); 5, Kushiro; 6, Nemuro (now part of Kushiro); 7, Sōya; 8, Rumoi (now part of Kamikawa); 9, Ishikari (now part of Sorachi; Ishikari town is not far from Otaru); 10, Shiribeshi; 11, Hiyama (now part of Oshima); 12, Okhotsk (name changed from Abashiri Subprefecture in 2010; main port Abashiri); 13, Kamikawa; 14, Sorachi. Note that, since 2010, five of the former coastal subprefectures are no longer official names but have been commonly used in the fisheries literature. (Annotated by IGG from a base map with a Creative Commons license attributed to Kolya).

11.2.1.6. Economic importance. Since catches of GPO are very low and there is low demand, GPO currently are not economically important in Russia.

11.2.2. Japanese fisheries

In contrast to the relatively low levels of GPO exploitation in the NE Pacific and off Russia, the GPO fisheries of Japan are at least an order of magnitude larger, with an annual fishery of around 20,000 t. Most landings are from around the coast of the northern island of Hokkaido (Figures 65–67) with more modest amounts fished off the northeastern Pacific and Japan Sea coasts of northern Honshu (Figure 67; ref. Figure 59).

11.2.2.1. Distribution and life history. Seasonal changes in the vertical distribution of GPO have been investigated off the Rumoi coast of northwestern Hokkaido (Kanamaru 1964; Sano et al. 2017). Most GPO sampled were immature with a body weight of 2.5–10.0 kg (mean 5.7 kg). Immature octopuses in this fishery appear to undertake two sets of seasonal migrations per year: into shallower waters during

Autumn (October–December) and Spring (April–May); and into deeper water during Winter (January–February) and Summer (June–September). Sea bottom temperatures off Rumoi show an annual cycle, with a broad minimum of 2 °C in Winter (around March) and 22 °C in Summer (peaking sharply in September–October).

GPO are found mostly on the shelf region down to 200 m, particularly in regions of rocky substrate (Sano 2017). Their seasonal migrations were investigated in and near the Sōya Straits (the restricted seaway, also called the La Pérouse Straits, or Proliv Laperuza in Russian, passing between the islands of Hokkaido and Sakhalin at Cape Sōya on the Japanese side and Cape Krilon on the Russian side). The location of octopus catches by drift fishery boats was monitored by GPS. Immature octopuses were found at 40–60 m in Summer; 10–30 m in Autumn to Spring. Mature male and female octopuses were observed over similar ranges but in June–July they migrated to deeper areas just before spawning. Most fished specimens are pre-mated individuals (Sano 2017). GPO spawning off Hokkaido is estimated to occur between May and July (Yamashita 1974). It was deduced that they migrate to deeper areas to avoid sea temperatures above 18 °C (Sano and Bando 2015). Eggs have been recorded at depths of 7–73 m in various localities (Sano et al. 2011; Sano 2017).

Immature octopuses have the following mean weights in December: 40 g (at 1 year old); 1 kg (2 years); 1–10 kg (3 years); 4–12 kg (4 years). Mature octopuses weigh more than 7 kg and are of age 3 or 4 years (Sano et al. 2011; Sano 2017). Mating takes place during October to December, with eggs laid in the following June and July. A captive female at Iwanai in Hokkaido (at the southwestern base of the Shakotan Peninsula in Shiribeshi Subprefecture) laid eggs in June. These took 181 days (just over 2,600 degree days) of incubation, hatching the following December (Yamashita 1974). In colder waters off the Pacific coast (under the direct influence of the cold boreal Oyashio Current, at temperatures of 2.6 °C to barely above 10 °C), it is estimated that incubation lasts about 1 year (Yamashita and Torisawa 1983). Paralarvae remain in the plankton for 1–2 months (Sano 2017).

In the Tsugaru Straits region, sampling shows that immature octopuses of both sexes are present throughout the year (Noro and Sakurai 2014). Maturing males appear from March through December and mature males from November to May. Mature testis size peaks in November, overall gonad size in January, and mature males have a mean of 6

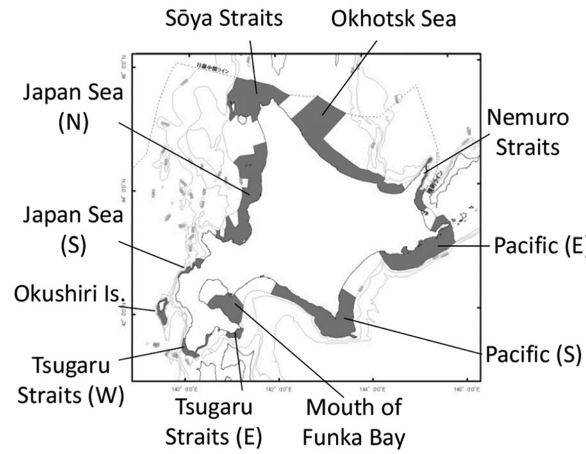

Figure 66. Map showing the geographical distribution of the 11 main fishing regions for *Enteroctopus dofleini* (GPO) around Hokkaido, as determined by Sano (2010) based on annual catch abundance in licensed fishing grounds, and changes in annual catch between 1985 and 2004 (modified from Sano 2010). The Tsugaru Straits (east and west) and waters off Aomori (northern Honshu), resolve into a single fishery (see text), resulting in a total of just 10 Hokkaido fishery regions.

(range 1–12) spermatophores of about 1 m in length from December through April. Mature females are caught from December to May and weigh upwards of 8.5 kg, copulated females more than 10.6 kg. Maximum ovary size occurs in April–May (Sato 1994, 1996; Noro and Sakurai 2014). Mating takes place between January and May and eggs are laid in Spring. Maximum body weight is 37 kg for males, 36 kg for females; and maximum life span 4.4 years for males, 5 years for females. Tsugaru GPO were found deeper during Summer, shallower in Autumn and Winter, and the population was limited mostly to within the straits (Noro and Sakurai 2012).

11.2.2.2. Stock identification. The geographical distribution of GPO fisheries was assessed for fisheries management by Sano (2010), based on the abundance of annual catch in licensed fishing grounds and changes in annual catch from 1985 to 2004. This information was used to classify Hokkaido fisheries into 11 regions (Figure 66), which are as follows: the Sōya Straits including the coastal area around Rishiri and Rebun islands; the Okhotsk Sea coastal region; the Nemuro Straits; the eastern and southern Pacific Ocean coasts of Hokkaido; the area near the mouth of Funka Bay; the eastern and western Tsugaru Straits; the coastal area around Okushiri Island; and the northern and southern Japan Sea coasts of western Hokkaido. The catch trends in these regions differ, so the disposition of these local octopus fisheries regions is well suited to fisheries management (Sano 2017).

Concerning the Tsugaru Straits regions, tag and recapture research has shown that GPO migrate long distances, including between the eastern and western sides, as well as across the straits between Aomori (the most northern prefecture of Honshu) and Hokkaido (Sato and Yorita 1999; Noro and Sakurai 2012). This presumably explains the correlation of catches between the Hokkaido and Aomori sides of the straits (Sato and Yorita 1999), so Aomori and the Hokkaido eastern and western regions of the Tsugaru Straits can be combined as a single fishery, resulting in a total of no more than 10 Hokkaido fishery regions.

11.2.2.3. Catches/landings. During the 32-year period from 1985 to 2016, the mean catch for Hokkaido was 15,300 t. The lowest annual catch during this period was in 2013 (11,338 t) and the highest was 21,653 t in 2003. The annual catch for Hokkaido is therefore mostly sustained, and in 2016 was 15,722 t, which is just above the mean. There is, however, no predictable trend.

The different regions show local differences, with the Okushiri and Tsugaru catches (both East and West regions) showing a steady and disconcerting decline over the last eight years, each to very low levels of 70 t for the former and just 20 t for each of the latter (Sano 2017). A similar trend has also been noted for the northeastern Pacific region of Honshu (NEP as defined in the footnotes to Table 9), stimulating a joint meeting of researchers and fishermen, which took place in Morioka, Iwate Pref., on 28 February 2015 ("Iwate Prefecture Mizudako Forum"). Catches since 2011 for Fukushima have been artificially low because of the suspension of fishing activity since the radioactive contamination of the coast in that area resulting from the multiple large-scale disasters on 11th March of that year. Consequent destruction of fishing vessels and equipment on the NEP coast has also, of course, depressed fishing activity, but this is now recovering.

11.2.2.4. Fisheries/fishing methods/fleet. The majority of the GPO catch is attributed to floating-barrel drift lines (Sano 2017; Taka and Wada 2018). This method is used off the Hokkaido subprefectures of Sōya, Rumoi, Ishikari, Shiribeshi, Hiyama, and Oshima (ref. Figure 65). Also efficient are octopus cages and baskets. The octopus cage method involves 35–40 box cages tied to a main rope attached to a buoy, leaving the cages on the seabed until they are occupied by octopuses. This method is used off

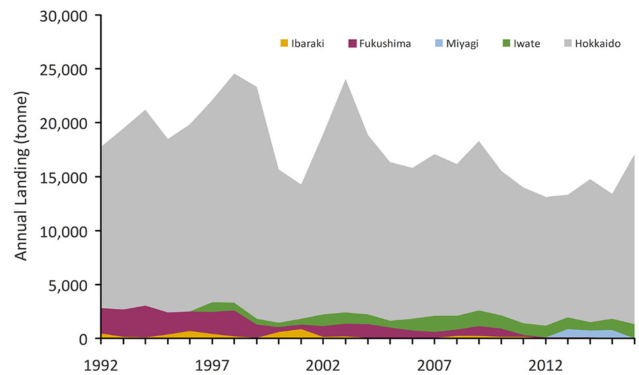

Figure 67. Annual landings for *Enteroctopus dofleini* (GPO) in Japan by prefecture. Compiled from data supplied by individual Prefectural Fisheries Research Institutes, where separate figures for different species were made available. Aomori Pref. data (incomplete, so not included) constitute an additional 1,500 to 2,000 t per annum, comprising about 10% of the current total Japanese GPO catch.

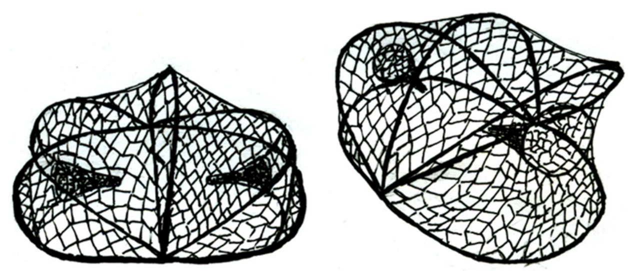

Figure 68. Octopus baskets: baited traps used to catch octopus. The traps are collapsible for easy storage. At setting, there are two entrances, which tend to stay closed at the inside and octopuses cannot return after once entering. The mesh size is designed to retain octopuses of large size. Smaller octopuses can squeeze through the mesh (Drawing: DP).

southern Hokkaido, the East Pacific coast, Okushiri Is., and all other areas of Hokkaido except Rebun Is. The octopus-basket method involves a main rope attached to baited round baskets (Figure 68), mostly off Sōya Subprefecture. Other fishing methods specialized for GPO include unbaited longlines, set nets, bottom set nets and inshore and offshore bottom trawls (Noro 2013; Sano 2017).

By method (for the areas where statistics are available: the area of the Sōya Straits and nearby Rishiri and Rebun Islands), fishing effort (as number of outings per year) reveals stable, fairly constant but relatively low levels of fishing by unbaited longline, octopus cage and octopus basket (Sano 2017).

Use of the floating-barrel drift line method has declined dramatically off Rebun Is. since the turn of the century (from more than 10,000 outings per year in 1992 to the same basal levels as the other fishing methods by 2015). Off the Sōya Straits and Rishiri Is., there is much more activity, although outings per year have declined somewhat: in the Sōya Straits, from a peak of nearly 20,000 outings in 2003 to around 10,000 per year since 2004; and off Rishiri, after peaking at just over 4,000 outings in 1996, declining gradually to around 1,500 outings in 2016. The annual CPUE for this method, however, reveals a fluctuating but steadily increasing trend since 1982, peaking at just over 200% of 1982 levels in 2014, and in 2016 at around 160% (Sano 2017).

For the 11 fisheries regions of Hokkaido, annual CPUE data were calculated based on representative floating-barrel drift lines for Sōya (for the Sōya/Rebun/Rishiri region), unbaited longlines for Mashike Port (Japan Sea north region), and the rest based on figures reported by the respective fisheries organizations. These figures reveal CPUEs fluctuating around 100% of 1982 levels for most regions, with the Okhotsk Sea and northern Japan Sea fisheries consistently showing the best performance with over 160% in 2016. The Tsugaru Straits East and West CPUEs have steadily fallen to around 20% in 2016, and Okushiri Island annual CPUE has declined to around 50% (Sano 2017).

11.2.2.5. Fishery management and stock assessment. Of the 11 Hokkaido fisheries regions recognized by Sano, for 2016 they were assessed as developing as expected but with resource sustainability uncertain (Sano 2017). The regions on either side of the Tsugaru Straits showed lower than average catches but this is considered to be an effect of the declining number of fishers rather than a problem with the resource.

Since GPO growth is very fast, in most regions a limit is placed on octopus size, which is set independently in each fishing region (Sano 2017): 3 kg for Hiyama, Oshima (except Toi-machi Fishing Cooperative), Iburi and Hidaka; 2.5 kg for Sōya, Rumoi, Ishikari, Shiribeshi and the Toi-machi region of Oshima; 2 kg for Okhotsk; and no limits for Tokachi, Kushiro and Nemuro. In some regions and for some methods, non-fishing periods are imposed (Sano 2017).

Statistics on fishing licenses for octopus are available as a measure of fishing effort: the number of local government fishing permits for octopus (Figure 69) and the number of people and co-operatives actively holding a fishing license (Figure 70), along with new entrants in these categories (Sano 2017). Numbers have fluctuated but remained fairly stable for most regions of Hokkaido except the Sōya Straits region, which has seen a steady decline since the year 2000: from around 1,400 to 600 co-operative license holders and from around 500 to around 300 governor's permit holders (Sano 2017).

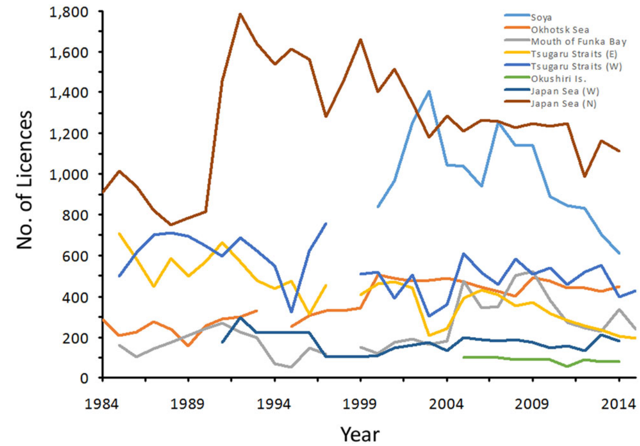

Figure 69. Changes in the number of active local government fishing permits for octopus in Hokkaido (data from Sano 2017).

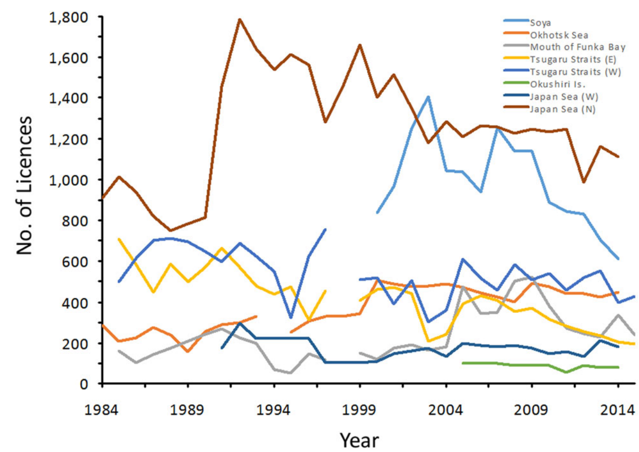

Figure 70. Changes in the number of active co-operative fishing licenses for octopus in Hokkaido (data from Sano 2017).

The CPUE for the Sōya region floating-barrel drift lines shows a gradual rise to around 171% for 2016 compared with 1982 (Sano 2017). A comparison of catches for all 11 regions of Hokkaido reveals that, since 1985, all regions show fluctuations but there is no overall upward or downward trend. Okushiri Island and the eastern and western Tsugaru Straits regions, however, have shown a steady decline: the catches in these regions were each in excess of 180 t in 1988, but by 2016 the Okushiri catch was less than 80 t; and for the Tsugaru Straits regions the catches had fallen to barely 20 t. The outlook for Hokkaido as a whole is uncertain but it is considered that there will be no particularly large fluctuations (other than off the Tsugaru region). Off the Sōya Straits and the northern Japan Sea region of Hokkaido, the catches are expected to remain at around the same amounts (Sano 2017).

11.2.2.6. Economic importance. With annual GPO catches off Hokkaido exceeding 20,000 t, this is an important fishery economically, earning some JPY 7 billion per year (Sano et al. 2017; ≈USD 70 million). The fishery off Cape Sōya, at 2,400–5,200 t per year, comprises between 12 and 26% of the total landings of Hokkaido and is worth JPY 0.9–1.6 billion (≈USD 9–16 million). Wholesale prices for GPO have remained stable over the last 5 years (Figure 71), fluctuating between JPY. kg^{-1} 400 and 500 (roughly USD 4–5), despite a declining trend in catches in Japanese waters (Figure 67). This price stability might be explained by the simultaneous complementary rise in world catches of the NE Pacific GPO fishery, development of which has begun only recently (see section 12). Much of the GPO product is par-boiled soon after landing (IGG pers. obs. of GPO landings at Rishiri) and is used mainly within Japan for the sushi trade (T. Gotō, M. Sano and A. Takanashi, pers. comm. to IGG).

11.3. "Octopus" conispadiceus

Also known as the chestnut or sandy octopus ("yanagidako" in Japanese; Okutani et al. 1987; Gleadall 1993), "*O.*" *conispadiceus* (Sasaki, 1917) is a cold-water species inhabiting the northwestern Pacific Ocean and adjacent marginal seas, from off southern Sakhalin Island and southern Kuril Islands to Korea and Japan, including the coasts of Hokkaido and northern Honshu (Sasaki 1929; Kondakov 1941; Akimushkin 1963, 1965; Nesis 1982, 1987; Okutani et al. 1987; Gleadall 1993; Katugin et al. 2010; Katugin and Shevtsov 2012). It is much smaller than *E. dofleini*: mature octopuses weighing from 1.5 to 7 kg (Golenkevich 1998; Hoshino 2017), with a different life history. The ripe eggs are much larger than those of *E. dofleini*, about 15 mm long and 6 mm wide, and during the incubation period of 10–11 months, the eggs triple their weight and reach 19 by 9 mm. The fecundity is much lower than for *E. dofleini*, at about 700–1200 eggs per female, and newly hatched individuals begin life on the seabed immediately after hatching, taking refuge inside empty whelk and clam shells (Sakamoto 1976; Katugin et al. 2010). Complete mitochondrial genome sequencing by Ma et al. (2014) showed remarkable similarity to that of *O. vulgaris*, *A. fangsiao*, *C. chinensis* and *C. taiwanicus*.

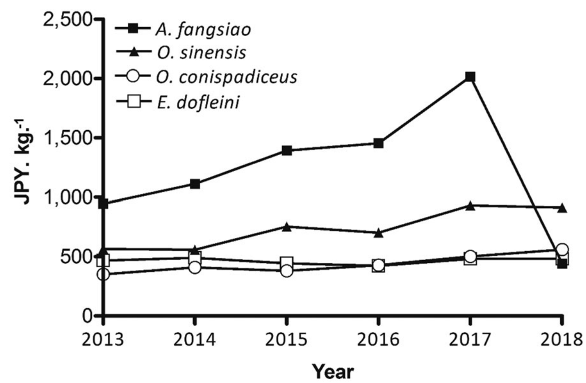

Figure 71. Mean annual wholesale price of Japanese octopuses by species (JPY kg^{-1}).

This moderately large species has a superficial resemblance to *E. dofleini*, with which it is often confused and consequently included in GPO catch and landing statistics for some regions of both Japan and Russia. When alive, it is very different from the GPO, with a much broader head, across which there is a thin pale head bar (Okutani et al. 1987; Gleadall 1993), and there are no longitudinal grooves and ridges characteristic of *E. dofleini* (cf. Figure 58). The distinguishing features of both species, however, disappear with death and relaxation of the skin and (presumably since in Japan both species are sold to the sushi trade) they are often processed together.

11.3.1. Russian fisheries

11.3.1.1. Distribution and life history. Similar to *E. dofleini*, most information on the distribution of "*O.*" *conispadiceus* within the Russian EEZ was obtained from waters off the coast of Primorye. In that particular area, "*O.*" *conispadiceus* occurs almost all year round at depths of 20–530 m, and concentrated in off-shore areas at depths of 50–100 m down to 300–400 m (Golenkevich 1998). These octopuses may live on all types of seabed substrate. Most frequently their distribution density is higher in regions of gravel, sand and silt, and much lower in rocky areas. Seasonal features in bathymetric distribution of "*O.*" *conispadiceus* have been observed but were much less clear than for *E. dofleini*.

Wide-scale patterns of geographic and bathymetric distribution of "*O.*" *conispadiceus* in the northwestern Japan Sea were obtained during a bottom trawl survey in Spring 2015 (Figure 72). Bottom hauls were made down to 600 m and, contrary to *E. dofleini* (which aggregated at shallow depths), "*O.*" *conispadiceus* occurred over a wide depth range from the intertidal zone down to 600 m, and was found throughout the entire research area.

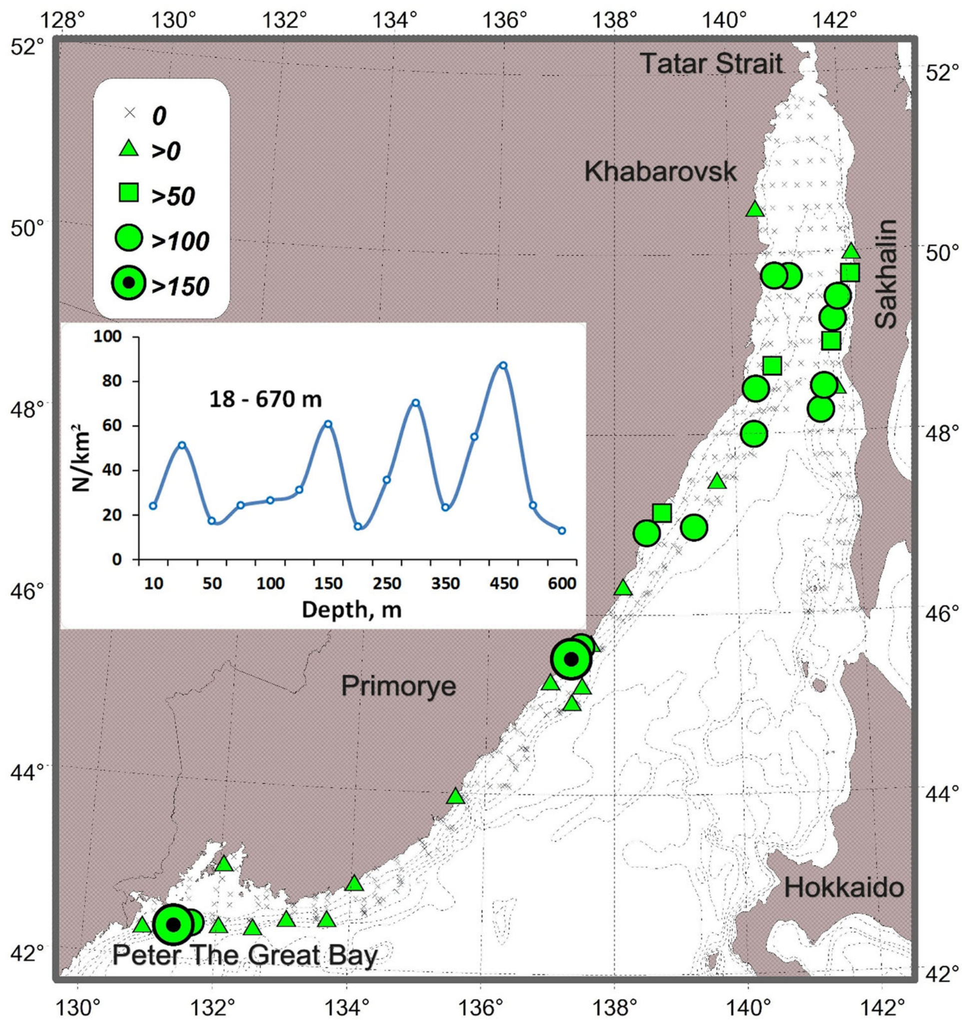

Figure 72. Distribution of "*Octopus*" *conispadiceus* in the northwestern Japan Sea in April–June, 2015 (symbols: no. of individual octopuses per square km in groups of 50). Inset: Distribution by depth. Note the much larger depth range compared with *E. dofleini* (Figure 64).

In Summer, octopuses usually occur at depths from 30 to over 300 m and concentrate in relatively cold bottom areas influenced by deep shelf and cold intermediate water (Zuenko 1998). In Winter, when thermal water structure transforms from the summer type into a cold relatively homogeneous water layer, octopuses tend to occur at shallower depths. In Spring, when the water is still cold, dense concentrations of "*O.*" *conispadiceus* occasionally occur close to the shore at depths of 15–20 m. These observations suggest that this species has a generally wider bathymetric distribution, compared to *E. dofleini*, and tends to live deeper and at lower near-bottom water temperature (Golenkevich 1998).

Information on the life history of "*O.*" *conispadiceus* is scarce (Golenkevich 1998). Mature and pre-spawning individuals occur almost throughout the year, and though a female brooding her egg-clutch was captured at 70 m depth only once in November, spawning is thought to be extended over most of the year. Individuals at the earliest known stages, and weighing about 5 g, occasionally occur in the mid- to late Summer at shallow depths of 5–15 m, with larger animals up to 17.6 g occurring during the late Summer and Autumn within the depth range of 10–70 m; young octopuses weighing 200–300 g occur at 100–200 m. These observations seem to indicate that this species gradually migrates offshore with growth, with larger mature individuals concentrating in deeper areas below the shelf-break. After sexual maturity and copulation, females move back shoreward to lay their eggs. After mating, males apparently remain in deep areas, judging by the observations that males are much more numerous there than females (Golenkevich 1998).

11.3.1.2. Stock identification. No data on stock identification of "*O.*" *conispadiceus* are available from Russian waters so far.

11.3.1.3. Catch and landings. Catches of "*O.*" *conispadiceus* from the shelf of Primorye are associated with the bathymetric distribution of this species. It is not yet possible, however, to provide a reliable analysis of catches for "*O.*" *conispadiceus* because most of the catch statistics at hand relate to unidentified octopus, and subdivision of the catch by species in fishery reports was inconsistent until recently.

11.3.1.4. Fishing methods (vessels, gear). Fishing for "*O.*" *conispadiceus* is with trap-boxes similar to those used for GPO, and it is also harvested as a bycatch during fishing for whelk and shrimp. During experimental fishing with whelk traps in April–June 1996 in Peter The Great Bay, "*O.*" *conispadiceus* regularly occurred in trap catches at depths of 100–300 m. Octopus catches were, however, low; with a mean of 9 individuals (maximum 32 individuals) per line, which consisted of either 400 or 800 traps. During 301 sets of line traps, 88 t of whelk and only 569 kg of octopus were captured. Most of the captured octopuses were identified as "*O.*" *conispadiceus*; however, GPO were taken occasionally (one individual per 10–20 trap lines), as well as "*Octopus*" cf. *yendoi* (Sasaki 1920).

Aggregations of "*O.*" *conispadiceus* were also found during shrimp fishing at the shelf break along the coast of Primorye. Catches of octopus peaked at 500–600 kg per line of 650 shrimp traps deposited at depths of 250–300 m off southern Primorye in 1994; and 200–400 kg per trap line in the Tatar Straits in 1995.

11.3.1.5. Fishery management. Advice for "*O.*" *conispadiceus* management to the fishing industry is based upon existing knowledge of the species abundance, distribution patterns and the demands and abilities of the fishing industry. The effectiveness of such advice, however, is difficult to estimate, since most of the catch reports until recently provided octopus catch statistics without species identification, and catches including both *E. dofleini* and "*O.*" *conispadiceus* were reported as "*Octopus* spp."

11.3.1.6. Economic importance. Presently, "*O.*" *conispadiceus* in Russia waters is not of significant economic importance.

11.3.2. Japanese fisheries

11.3.2.1. Distribution and life history. Off Japan, this species is fished from 100–400 m, mainly off Hokkaido, with small amounts taken off the NEP coast. Mature individuals appear at a body weight of about 3 kg. The maximum wet weight is around 7 kg. Off Hokkaido, eggs are laid during May–June at 120–180 m on the Japan Sea coast, and at around 70 m during Winter on the Pacific eastern coast. There are some seasonal movements to different depths but, since there is no planktonic larval stage, there are no known long-distance migrations and it is considered that the young begin a benthic life directly in the region where they hatch. Juveniles are found at around 30 m (Hoshino 2017).

11.3.2.2. Stock identification. There is no reported stock identification for "*O.*" *conispadiceus* but since it is a large-egged form with probably no significant migration (other than depth migrations), the fisheries regions recognized from catch statistics by Sano (2017) might be considered to form a proxy for stock identification. The totals for Hokkaido were divided into four sea regions, according to data from the following subprefectures (in parentheses) for each region (see Figure 65): Japan Sea (Sōya, Rumoi, Ishikari, Shiribeshi and Hiyama); Erimo West (Oshima, Iburi and Hidaka); Erimo East (Tokachi, Kushiro and Nemuro); and Okhotsk Sea (Okhotsk). In the main production region of the Pacific coast, the fishing season for "*O.*" *conispadiceus* begins from October and continues until the following Spring, making allowances for depth migrations.

11.3.2.3. Catches/landings. The Pacific regions comprise almost 90% of the catches of "*O.*" *conispadiceus* for the whole of Hokkaido, based on years from September to August.[2] For Hokkaido as a whole, catches were 8,000–9,000 t between 1985 and 1990, falling to 4,000–5,000 t between 1991 and 1995, rising again to about 7,000 t, then to 12,000 t in 2004–2005. After 2007, the catch was again 5,000–7,000 t, and in 2015 was about the same at 6,408 t. (Hoshino 2017).

By region, Japan Sea catches were around 1,000 t in the 1990s, falling to just 400 t in 2011, recovering to 701 t in 2015. The Erimo western Pacific region in 1995 showed low catches, following which 3,000–4,000 t has been the level at which catches have fluctuated, and was 2,951 t in 2015 (around 110% of the yearly mean since 1985). East of Erimo, similar to the Japan Sea, the early 1990s were a time of low catches, following which the annual catch gradually

[2]Note that, until 2015, data were for normal calendar years but because of the working dates of the unbaited longline fisheries businesses of Hidaka Subprefecture, data compiled for 2015 onwards are based on years from September to August, so 2015 runs from Sept. 2015 to August 2016 (Hoshino, 2017).

increased, with a sudden increase in 2004–2005 when more than 7,500 t were taken in the Nemuro region. Although the catch fell significantly in 2012, it recovered, reaching 3,054 t in 2014 and 2,682 t in 2015. The catch off the Japan Sea coast is generally much lower, with 100–300 t taken in the 1990s, since which there has been a low mean annual catch of around 100 t only (Hoshino 2017).

The peaks of catches (monthly means for 2011–2015) occur in January to February (400 t) to the east of Cape Erimo, and March to April (700 t) to the west. Peak catches for the Japan Sea region are in October–November (60 t) and May–June (80 t); and September (12 t) for the Okhotsk region (Hoshino 2017).

11.3.2.4. Fisheries/fishing methods/fleet. A number of different kinds of gear are used to catch "*O.*" *conispadiceus*, including unbaited longline for octopus, octopus box, various types of octopus basket and cage, offshore bottom trawl, and gill net. Mostly prawn cage and offshore bottom trawl are used along the extent of the Japan Sea coasts; unbaited longline for octopus and octopus cages are used on the Pacific coasts either side of Cape Erimo; and offshore bottom trawl is used on the coast of Okhotsk (Hoshino 2017).

11.3.2.5. Fishery management and stock assessment. The highest catches are taken off the Pacific coasts of Hokkaido: 55% (based on the mean catches of 2011–2015) to the west of Cape Erimo (between Oshima and Hidaka Subprefectures); and 33% to the east (Tokachi to Nemuro). In 2015, 6408 t were landed, which is similar to the previous year catch: there seems to be no particular trend for catch increase or decrease (Hoshino 2017). The number of local governor-licensed octopus fishing businesses for "*O.*" *conispadiceus* catches of 3 Pacific-coast subprefectures (Hidaka, Kushiro and Nemuro) have been used to compile a measure of fishing effort (Hoshino 2017). In Nemuro Subprefecture there are around 140–160 local government permits (octopus box and unbaited longline) and 150–170 are registered with the Kushiro authorities (unbaited longline), fluctuating by around 70–80. The effects on the resource depend on a variety of different fishing measures and season times. No major changes are expected during the next few years (Hoshino 2017).

Considering the catches since species-specific records were begun in 1985, the 1990s level of around 4,000 t was a low period, while the annual catch recently has fluctuated mostly between 5,000 and 8,000 t, so it is not possible to predict any large rises or falls over the coming years (Hoshino 2017). On the Pacific coasts, the region east of Erimo has shown the largest fluctuations, accounting for the largest and smallest annual catches of the whole of Hokkaido over the years. Since (apart from these exceptional years) it seems unlikely that there will be a future reduction in catches in this region, it is considered that the kind of fluctuations seen will be repeated in the future, presumably with no long-term deleterious effects.

On the Japan Sea coast since the 1990s, the catches have gradually dwindled, apparently due to the decline in the number of fisheries businesses in recent years, so it is considered unlikely that the resource is declining and that it will show similar fluctuations as the Pacific side of Hokkaido. Although the Okhotsk region showed high catches during the 1990s, the trend seems to be repeated fluctuations superimposed upon a general decline.

Overall, it is considered that the long-term pattern observed in past catch records will continue with small annual fluctuations (Hoshino 2017). Considering the changes in annual catch during the 20-year period 1995–2014, and taking the mean annual catch as representing 100, fluctuations outside 60–140% are considered "high" and below this as "low." For 2015, the resource level was 91%, which is therefore judged to be "average" (Hoshino 2017).

The above-mentioned large fluctuations in the overall resource for Hokkaido are similar to the changes occurring in the eastern Erimo population, so such fluctuations will presumably continue. Observing the sudden decline in catches during the 1990s and sudden rise during the early part of the first decade of this century, the annual catches show sudden and unpredictable changes, providing an uncertain basis for predicting future trends. Therefore, the future outlook is classified as "uncertain" (Hoshino 2017).

Although it is not possible to predict long-term trends, the present usage of this resource seems to be appropriate. Since changes in the resource are presumably reflected in the catch taken, it will be necessary to continue to monitor catch trends for each region (Hoshino 2017).

11.3.2.6. Economic importance. From 2013 to 2016, the price of "*O.*" *conispadiceus* has fluctuated around JPY kg.$^{-1}$ 400–500, more recently closer to JPY 600, similar to that for *E. dofleini* (Figure 71). This reflects its similar usage since for the consumer typically it is not distinguished from *E. dofleini*.

11.4. *Octopus sinensis*

This is the East Asian common octopus (“Zhangyu” or “Muzhuzhang” in Chinese; “madako” in Japanese) and, setting aside the large catches of *E. dofleini* (and “*O.*” *conispadiceus*), it is the most important species in the local Japanese fisheries. It is found from northern Honshu (Aomori and the Tsugaru Straits) and Taiwan (Sasaki 1929; Gleadall 2016a; Noro 2017) to the South China Sea (Lu et al. 2012).[3] It is in high demand in Japan for its superior taste along with closely similar species *O. vulgaris*. The latter is imported to Japan particularly from western Africa and the Mediterranean and supplements dwindling catches of *O. sinensis*.

It was identified until recently as *O. vulgaris* (Amor et al. 2017; Gleadall 2016a, 2016b) and data from the latter have often been mixed with those obtained from Japanese populations of “madako” (see, for example, reviews by Mangold 1983, and Takeda 1990).

This is a warm-water species apparently preferring temperatures around 25–26 °C (for spawning at least; Itami 1976). It shows reduced feeding below 12 °C and stops feeding completely at 7 °C. It can survive at 6 °C but dies if the temperature remains at 5 °C (Itami 1976).

11.4.1. Distribution and life history

Although found as far north as the Tsugaru Straits and the waters of NEP (Tohoku) and the Japan Sea coast of Honshu (Gleadall 2016a; Noro 2017), it is found much more abundantly in the Seto and Kyushu regions southwards and westwards (Figure 63). It is not present in the seas around Okinawa (cf. Ohta and Uehara 2015), emphasizing the association of this species with warm seas over the East Asian continental shelf.

In the Kanmon region of northern Fukuoka Pref. (waters between Kyushu and Honshu) the times of year when most (>60%) females are mature with eggs are during March–April (Spring) and August–September (Autumn) each year. These females mature from a ML of about 70 mm (Ueda 2010).

In the Seto region, *O. sinensis* females mature at 144 g (Takeda 1990) and the number of eggs laid is estimated to vary according to size of the female at laying: 64,000 eggs for a female of 500 g; 120,000 at 1 kg; and 170,000 at 1.5 kg (Itami 1976; Takeda 1990). Eggs are laid in festoons of 70–80 mm length, each containing about 500 eggs, over a period of about 5–6 days in Spring (April to May) or Autumn (September to November), and require incubation for about 24–25 days before hatching (600–800 degree days; Itami 1976; Takeda 1990). They hatch at a mean ML of 1.7 mm, with 3 suckers on each arm. They will then grow to a ML of around 4–6 mm and arms with 21–23 suckers just before settling, which takes about 40 days at 25 °C (Takeda 1990). Off Akashi and in Osaka Bay (eastern Seto region), sampling detected paralarvae only during August to December (with a peak in October; Sakaguchi et al. 1999), and newly settled young between December and June. Based on these observations, Takeda (1990) concluded that *O. sinensis* reaches 400 g in about 9 months and lives about 1 year, 1.5 years at most (cf. also Itami 1976; Sakaguchi et al. 2000). The young reach 40 g in about 90 days after hatching, 740 g in about 150 days and 1 kg after 180 days, although they can reach 1.6 kg within five months (Itami 1976). They become mature around 140 days (Itami 1976).

The NEP coast of Honshu (Figure 59; Table 9) shows wide variations in annual catch (Figure 73) but from the surveys conducted it is concluded that the fishery is a local one. Considering maturity, catch, migration and size characteristics of the population found in Fukushima waters, a cohort lays eggs there during May–September, and another group arrives from Ibaraki after traveling north during May–August. Octopuses hatching during March–June off Ibaraki and Chiba are captured off Fukushima during the following October–January. Those octopuses spawning in the Fukushima area during May–September seem to be

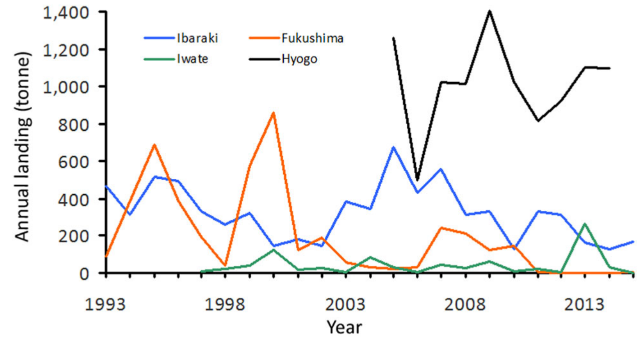

Figure 73. *Octopus sinensis* annual landings in Hyogo Pref. (Akashi, Seto Inland Sea side, southern Hyogo Pref.) in comparison with three prefectures on the northeastern Pacific (NEP) coast. The data are incomplete but illustrate the large catch fluctuations for this species, and the differences in annual catches between the NEP and Seto regions (see Figure 59 and Table 9 for the location of these regions).

[3]Based on similarity of mitochondrial DNA sequences, *O. sinensis* has been reported also from the Kermadec Islands in the southern hemisphere, to the north of New Zealand (Amor et al., 2017; cf.*O. jollyorum* Reid and Wilson, 2015), although morphological differences are detectable among males of the Japanese and Kermadec populations (compare data of Reid and Wilson, 2015, with Gleadall, 2016a).

those that hatched off Ibaraki and Chiba during the previous May–August and subsequently have migrated northwards. The large number of octopuses taken in Fukushima waters during November–January do not lay eggs there but instead are thought to migrate southwards to lay eggs off Ibaraki and Chiba during March–June and September–October (Tanaka 1958). Considering the large fluctuations in size and timing of capture, however, those distributed during March–June are important. The status of the coastal and offshore waters affects egg laying and paralarvae during March–July in the NEP coastal region and this depends on the relative strengths of the Kuroshio and Oyashio currents, which collide in this area producing conditions which vary greatly from year to year, particularly temperature (Akimoto and Sato 1980).

In the Tsugaru Straits fishery off Aomori, *O. sinensis* females mature from 500 g body weight, males from 100 g (Noro 2017). Mating takes place throughout the year, the males possessing 34–389 spermatophores measuring 31–92 mm in length. Egg laying occurs mostly in Summer. Males weigh up to 3.7 kg, females to 3.8 kg, and life span is estimated to be about 1 year (Noro 2017). Based on correlations of seasonal occurrence, state of maturation and body size, two different populations have been detected in this area: one is a group of larger-bodied octopuses caught during Autumn and Winter and considered migratory; and the other a locally-based group of smaller-bodied individuals caught in Spring and Summer (Noro 2017).

Off the northwestern coast of Hokkaido, bottom temperatures rise above 20 °C during the summer (Sano 2017), providing potentially suitable conditions for *O. sinensis*, at least for part of the year (cf. the seasonal patterns of migratory movements of *O. sinensis* documented below). It is thus not unreasonable to speculate that the distribution of this species may extend further northwards in future as global warming progresses (cf., for example, Doubleday et al. 2016).

In Chinese waters, the fecundity of *O. sinensis* is around 95,000 eggs per female, with time from laying to hatching of 25–35 days at 20.4–23.6°C and a mean hatchling length of 3.08 mm (Lin et al. 2006, Cai et al. 2009, Zheng et al. 2011).

11.4.2. Stock identification

There is no information on stocks of *O. sinensis* but it is clear from section 11.4.1 that some populations seem to feed and reproduce within certain of the main fishery regions (such as the population which lays eggs on the coast off Chiba, Ibaraki and Fukushima and forms the *O. sinensis* fisheries within much of the NEP region; the population found mainly within the Seto region; and a local population detected in the Tsugaru Straits off Aomori; Akimoto and Sato 1980; Takeda 1990; Noro 2017). There is some evidence, though, that individuals can and do travel for long distances: a mark, release and recapture study in the eastern Seto region recorded recapture distances and times of 21 km in 3 days, and 48 km in 9 days (Itami 1964)[4] and there are no obvious barriers to gene flow.

11.4.3. Catches/landings

Exact figures for the total catch of *O. sinensis* are difficult to assess. Some prefectures record catches by species (using Japanese vernacular names) but others lump together all catches under the category "tako" (octopus). While the latter often refers mainly to *O. sinensis* this is not always so, therefore if the name "madako" has not been used, catch data have not been included here. A selection of catch data involving *O. sinensis* is presented in Figure 60, Figure 61, Figure 62 and Figure 73. These data show that annual catches of *O. sinensis* are erratic and unpredictable. Fishing off Fukushima, for example, has produced bumper years of 700–1,000 t but others where catches have been close to zero. There seems to be little correlation with catches off other prefectures (Figure 73), even in the same region. Catches in the Seto region (Figure 61, Figure 73, and Figure 75) tend to be much higher than in the Japan Sea (Figure 60 and Figure 62) or the NEP region (Fukushima, Ibaraki and Iwate in Figure 73).

This species is taken all year round in the Seto region, with a peak in Summer (40% of the annual catch between June and August), and more than 10% of the catch taken between May and September. In the NEP region, there are two catch peaks: August to September and December to April, each occurring about 2–3 months before spawning is due. It is also taken as significant bycatch in commercial Japanese offshore trawls on the continental shelf of the East China Sea, where it has been recorded as widely abundant (Chikuni 1985).

Where monthly data are available, the seasonality of catches of *O. sinensis* and *E. dofleini* can be clearly seen. Off Ishikawa, a small number of *E. dofleini* are taken in Winter each year, while *O. sinensis* shows two peaks of abundance: a larger amount being taken

[4]Note, however, that (as Itami himself pointed out) the octopuses in this study had been transported from the East China Sea coast of Kyushu (see section 12.4.5) and had survived being hot-iron branded before release.

Figure 74. Culture in the coastal waters of Fujian and Zhejiang (image: XZ) A, In net cages in coastal waters; B, In indoor tanks.

in Spring–Summer, and a lesser peak of abundance appearing every Autumn (Figure 62).

11.4.4. Fisheries/fishing methods/fleet

The species *O. sinensis* is captured by octopus pot, basket or by hand line with an unbaited lure (see, for example, Ueda 2010). Itami (1976) noted that, in the Seto region, fishing for *O. sinensis* is typically close to rocky shores and best where the tidal current is strong. Gear is used seasonally and includes octopus pots (June to the end of September), trawling and angling (May to September) and driftline (October to November). Fishing was originally at 20–30 m but extended to 100 m in the 1970s and 1980s with improvements in gear, when trawling gathered 65% of the catches and pot fishing about 15% (Itami 1976). Bottom trawls were towed by small vessels of 5 t and under 11 m in length. Chikuni (1985) considered the majority of warm-water octopus catches (most of which is *O. sinensis*) to be taken in the Seto region, attributing 15% to traps, 20% to hook-and-line and 60% to bycatch of small-scale dragnet fishing.

Seabed substrates where *O. sinensis* is fished are typically sand or small stones, occasionally mud (reviewed by Takeda 1990, for the Seto region, Tokyo Bay of the southern Pacific regions, and Ibaraki and Fukushima of the NEP region).

Ranching of small octopuses during times of cheap prices was recorded as taking place during the 1960s and 1970s off Hyogo in the Seto region by Takeda (1990), exceeding 500 t around 1965 (when trawling for octopus yielded more than 60,000 t), then declining below 10 t (trawl catches falling to less than 1,000 t) by 1981.

In recent years, rising prices and worries about sustainability of stocks have encouraged increased research efforts to raise *O. sinensis* as an aquaculture species in Japan, with financial support from the Japan Science and Technology Agency and the

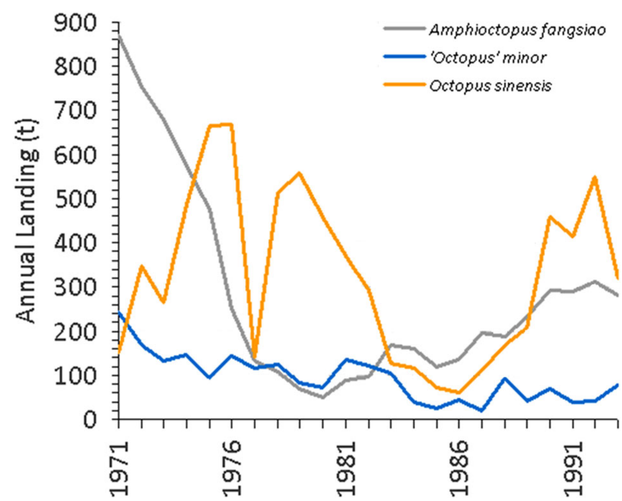

Figure 75. Okayama Prefecture annual landings of octopus.

Ministry of Agriculture, Forestry and Fisheries. In China, *O. sinensis* is an important export species, ongrown from juveniles mainly in the coastal waters of Fujian and Zhejiang (Figure 74).

11.4.5. Fishery management and stock assessment

Fishing pressure on *O. sinensis* is likely to continue into the future and attention will need to be paid to managing the fisheries for this species, to ensure its sustainability. The population of *O. sinensis* in the Seto region has long been recognized as "fully exploited" (Hamabe et al. 1976) but there are clear regional differences in the sustainable populations. Note, for example, the clear difference in abundance for Hyogo Prefecture (which has coasts on both the Seto Sea and Japan Sea; Figure 60 and Figure 61,) compared with the northeastern prefectures of the Pacific coast (Iwate, Fukushima and Ibaraki; Figure 73). There are also erratic changes from year to year in some fisheries (Figure 73 and Figure 75).

The exceptionally cold winter of 1963 decimated the *O. sinensis* population in the Seto Region, so in the following July the eastern part of the local population was supplemented with around 40,000 young octopuses (10.5 t in total wet weight) trucked in from the East China Sea coast of Kumamoto, Kyushu (Itami 1964, 1976). Fishing for *O. sinensis* was prohibited in the Seto region and empty concrete pots were provided for the octopuses to spawn (a practice used since the 1930s; Itami 1976). It was recognized, however, that the presence of sufficient live feed is likely to be a limiting factor, and trawling and pollution have also been cited as causes of decreases in catches of *O. sinensis* (Itami 1976).

Multi-annual cycles in abundance have long been recognized in northern waters, and this is shown in long-term data such as those for Fukushima: note the peaks in the early 1970s and at the turn of the millennium in Figure 73. Wide variation in catches has also been noted for Aomori (the most northern prefecture of Honshu; Noro 2017): *O. sinensis* here is caught mainly inshore, particularly off the most southern part of the Pacific coast of Aomori.

From a population analysis in the Akashi area (Seto region), Takeda (1990) concluded that the population of *O. sinensis* is overfished and suggested that the best way to control the size of octopus caught is by fixing the size of octopus pots.

Beginning in the 1930s and into the 1980s, there have been several efforts to encourage and protect spawning octopuses in the Seto region (off Hyogo) and off the Nagasaki coast of Kyushu (Itami 1976; Takeda 1990). Such efforts are ongoing (NPO activity in the region of Okayama and Kurashiki in the Seto region; IGG and K. Matsubara, personal observations), with activities including the distribution of loose octopus pots, often embedded in concrete to discourage movement by currents; laying large stone ballast over sandy and gravel areas; and sinking large stones and concrete blocks of around 1 t to deter trawling activity (Itami 1976; Takeda 1990).

11.4.6. Economic importance

The wholesale market price of *O. sinensis* has doubled over the last 5 y, from JPY 500 to 1,000 kg^{-1} (Figure 71). This reflects the importance of this species, especially amid the currently limited catches and increasing demand for this highly prized commodity, based on the availability not only of *O. sinensis* but also of closely similar imported species in the *O. vulgaris* species group (cf. Figure 57).

11.5. Amphioctopus fangsiao (and other species of Amphioctopus)

This is a small species with a mature ML typically around 50 mm and arms of subequal length except for arms 1, which are conspicuously shorter; arms 4 are the longest by a small margin over arms 2 and 3. It is one of the easiest octopuses to identify when alive or freshly dead because of the presence of a distinctive golden iridescent ring on the outer surface of the interbrachial membrane between arms 2 and 3 of the right and left sides, and a broad pale-colored bar across the dorsal surface of the head (Figure 76; Sasaki 1929; Gleadall and Naggs 1991; Gleadall 1997). The iridescent rings are components of each of a pair of ocelli (false eyespots), which the living octopus uses to surprise and distract potential predators. After the octopus has died, however, the rings may appear only in rather vague form (as shown on the octopus labeled "O" in Figure 76), or may disappear altogether (as for the three animals accompanying the specimen with the "O" label; Figure 76). Similarly, the pale head bar can be obvious ("B" in Figure 76), or (after death) apparently absent (other animals in Figure 76). Several other species in this genus (including *A. aegina*, *A. ovulum*, *A. kagoshimensis* and *A. marginatus*), both domestic and imported, and with or without ocelli, all tend to be identified in Japanese markets using the vernacular name for *A. fangsiao*: "iidako."

Figure 76. Commercially packed *Amphioctopus fangsiao* imported from Hyogo Pref., obtained in Naha market, Okinawa (image: C. Timmons). B: bar, broad and pale in color, across the dorsal surface of the head, between the eyes; O: gold-colored iridescent ring component of an ocellus (false eyespot).

11.5.1. Distribution and life history

The distribution of *A. fangsiao* is apparently similar to that of *O. sinensis*, since it has been confirmed as present in continental shelf seas from Hong Kong (Gleadall 1997) to northern Japan (Segawa and Nomoto 2002; Gleadall 2003). It is commonly found on sandy and gravel substrates and has been described as "one of the most commercially important edible cephalopods" of southern and western Korea (Son et al. 2015).

This species (sometimes identified by a junior synonym, *O. ocellatus*) has been maintained in laboratory

Figure 77. Small octopus pots (left and middle) and shells of *Rapana venosa* (right) for *Amphioctopus fangsiao* off the coast of China being hauled aboard. (Image: Zheng XD).

aquaria, where it has been shown to have a life span of six months to one year (Segawa and Nomoto 2002; Son et al. 2015). Eggs are laid shortly after mating takes place in Spring or Autumn: Spring confirmed for the Seto region (Segawa and Nomoto 2002) and Korea (Son et al. 2015); and Autumn confirmed for Tokyo Bay (IGG, LJC, DP, unpublished observations) and Aomori, northern Honshu (IGG, unpublished observations). Females lay around 300–600 large eggs (length 10–13 mm in the ovary, 7 mm after ovulation and laying) which develop directly into benthic octopuses with no planktonic paralarval stage (Segawa and Nomoto 2002).

11.5.2. Stock identification

Gao et al. (2013) used polymorphic microsatellite loci to investigate the population structure and conservation genetics of *A. fangsiao*. Cryptic species have been detected but further research is required to clarify this species complex (Zhang et al., unpublished data).

11.5.3. Catches/landings

Catch data specific to *A. fangsiao* are sparse. At the present time, this species appears to have been heavily or over exploited and numbers are very low (Figure 61). The Seto region appears to have (or used to have) the largest population of this species and catches in other regions are of the order of a few hundred kg at most (e.g., 30 kg annual catch for the whole of Toyama Pref. in 2016). As an example of a prefecture from the Seto region, annual landings in Okayama Pref. were several hundred tonnes in the 1970s, sometimes surpassing catches of *O. sinensis* (Figure 75).

11.5.4. Fisheries/fishing methods/fleet

In Japan, *A. fangsiao* has been caught in largest quantities in the Seto region (e.g., Hyogo and Okayama Prefs.; Figure 61 and Figure 75), apparently taken in trawls aimed at *O. sinensis*. It is available (but apparently not in commercially exploitable quantities) in Mutsu Bay, Aomori Pref., and Sendai Bay, Miyagi Pref. (IGG, pers. obs.). In Tokyo Bay at Futtsu, Chiba Pref., there are several vessels operating a small commercial recreational fishery (rod and line with unbaited lure) for a limited season usually restricted to October and November each year (IGG, LJC, DP, pers. obs.).

Off the coast of Haizhou Bay, China, *A. fangsiao* is taken using octopus pots and shells of *Rapana venosa* (Figures 77 and 78).

11.5.5. Fishery management and stock assessment

No information has been obtained on fishery management and stock assessment for *A. fangsiao*. Erratic catch statistics for Japan, however, suggest that stocks are overfished (Figures 61 and75), probably in the Seto region in particular (cf. Figure 63; and failure recently to obtain specimens of *A. fangsiao* in the Okayama area of the Seto region; T. Akiyama, pers. comm. to IGG). There is geographic isolation among different local populations, since this is a large-egged species with no planktonic dispersal: seven distinct local stocks have been identified in the populations of Chinese coastal waters (Lü et al., 2010, who used the *A. fangsiao* synonym *Octopus ocellatus*). The only fishery management measure applied in the East China Sea is a summer fishing moratorium from May to August (Lin and Cheng 2009).

Figure 78. Close-up of an octopus pot and shells of *Rapana venosa* containing a captured specimen of *Amphioctopus fangsiao* caught off the coast of China. (Image: Zheng XD).

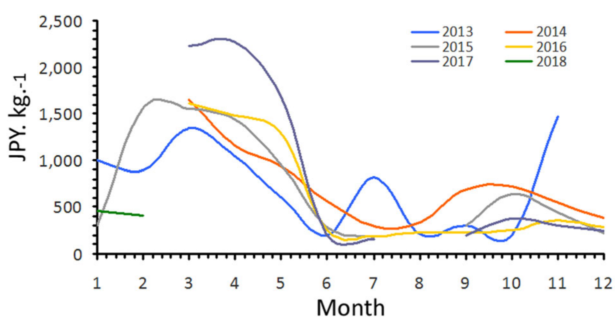

Figure 79. Monthly wholesale price for *Amphioctopus fangsiao* during the last 5 years or so.

11.5.6. Economic importance

Seasons when most females are ripe with eggs govern the pricing of this species which fluctuates erratically throughout the year (Figure 79), being much more expensive in the Spring when the price per kg may rise by more than JPY 1,000 compared with other seasons. A smaller rise from the basic price is also seen in Autumn (Figure 79), when females with eggs are again briefly available. The added value of female *A. fangsiao* with (rice grain-size) eggs as a gourmet item partly explains the large differences observed also for mean annual prices (Figure 71).

11.6. "Octopus" longispadiceus

This species ("kumodako" in Japanese; Okutani et al. 1987; Gleadall 1993) is a small, cold-water, boreal form, taken at 100–300 m at temperatures to around 4 °C (though not usually above 1.5 °C; Akimushkin 1963, 1965), endemic to the Japan Sea, Okhotsk Sea and the Kuril Islands (Kondakov 1941; Akimushkin 1963, 1965). It has also been reported from the Pacific coast of Hokkaido off Kushiro (Takeda 2003). Landings in Japan are mostly from the Japan Sea, as exemplified by figures for Niigata and Tottori Prefs (Figure 80). Little has been written about "*O.*" *longispadiceus* since its original description (based on 4 male specimens from deep waters off Miyagi Pref. on the NEP coast of Honshu), except for the surveys and review by Takeda (2003) concerning specimens taken off northern Hyogo Pref. (which is just east of Tottori Pref., on the Japan Sea coast) and by Gleadall (1993, 2004), who demonstrated morphological affinities of this species with genus *Muusoctopus*. It is a large-egged species which probably does not have a planktonic paralarval stage (Takeda 2003).

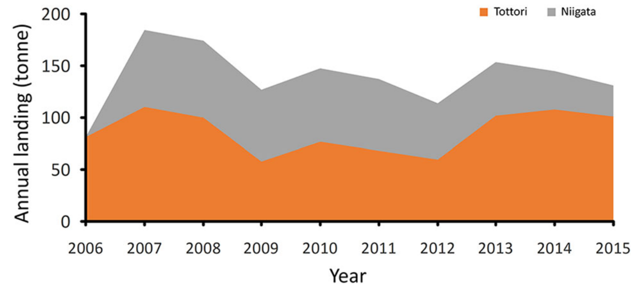

Figure 80. "*Octopus*" *longispadiceus* landings for Niigata and Tottori Prefectures.

Males of this species are easily recognized by the right third arm being as long as, or longer than, the third left arm (in males of most octopus species, the third right arm is very much shorter than the third left). The end of the third right arm of this species terminates with an obvious, long, slim ligula (sucker-free end of the third right arm of males), typically 2 or 3 cm in length (Sasaki 1929; Gleadall 1993; Takeda 2003). It has been reported also in Korean waters (Kim, Yang, and Lee 2016).

The catches of "*O.*" *longispadiceus* are relatively minor and no information has been acquired about its distribution, life history, stock identification, fishing methods, gear, fisheries management or stock assessment. In view of the relatively small catch size, it is of minor economic importance compared with other octopus species available in Japanese waters.

11.7. "Octopus" minor

This name ("changtuishao" or "mashao" in Chinese, and "tenagadako" in Japanese) is used for octopuses from East Asian waters distinguished by conspicuously long first arms, with arms 2, 3 and 4 of consecutively decreasing length (very different from the other species of octopus mentioned above, none of which have conspicuously longer first arms). The number of species involved is uncertain and the taxonomy of the group to which they belong requires further research. Larger specimens with similar morphology have been described as "*Octopus*" *variabilis* (Sasaki 1929) and "*Octopus*" *pardalis* (Sasaki 1929). Males have a markedly short right third arm with a conspicuous, cylindrical, club-like termination. The females lay large eggs. Off Japan they are fished much less frequently than the other octopus species, and are regarded as less tasty and consequently of lesser importance, typically obtained as bycatch in trawls aimed at *O. sinensis* and *A. fangsiao*.

It is also widely distributed along the coastal waters of China, Korea and Japan. It is nocturnal (Chang and Kim, 2003) and one of the most well studied octopuses in China due to its economic and ecological value (Zheng et al. 2014; Gao et al. 2016; Wang and Zheng, 2017, 2018; Song et al., 2019). It is a large-egg species, producing relative fewer eggs than other species, so it is not surprising to find that, like *A. fangsiao*, it shows substantial differentiation among geographical populations (Wang and Zheng, 2017, 2018). Multiple paternity and batch spawning have been observed. Development is direct with eggs hatching to release crawl-away young after an embryonic phase of 72–89 days (Zheng et al. 2014). The distribution of this species extends from Hainan Island in the south, along the coastal shelf of China and Korea to the Primorye coast of Russia and southern Sakhalin, and the main Japanese islands including Hokkaido (Sasaki 1929; Okutani et al. 1987; Zheng et al. 2014). Small numbers of *"O." minor* are reported to be present in Mutsu Bay, Honshu, which opens into the Tsugaru Straits (KN, pers. obs.).

Yamamoto (1942b) provides an account of an apparently similar species in Korean waters which he identified as *O. variabilis typicus* (Sasaki 1929), describing it as a mud-dweller in shallow, sheltered bays, where it digs deep into the mud (see also Zheng et al. 2014). It is harvested at low tide during Spring and Autumn, using a spade-like implement or a small hand-held plow to dig the octopuses out of the mud. The breeding season is May–June, sometimes extending into the Autumn. Females lay 120–130 large aubergine-shaped eggs of length 21–22 mm (Yamamoto 1942b; Zheng et al. 2014). Hatchlings develop directly over 72–89 days (at 21–25 °C; Zheng et al. 2014; Song et al. 2018) and show the adult-like burrowing habit soon after hatching, the adults eventually reaching a total length of up to 700 mm (Yamamoto 1942b). There is also a trap fishery for "*O.*" *minor* off the southwestern coast of the Korean Peninsula (Kim, An, et al 2008).

Said to be a popular seafood item in East Asia, "*O.*" *minor* is cultured on the NE coast of China (Zheng et al. 2014), originally for release of young octopuses as a resource stock enhancement strategy to boost the local "*O.*" *minor* population around Shandong Province.

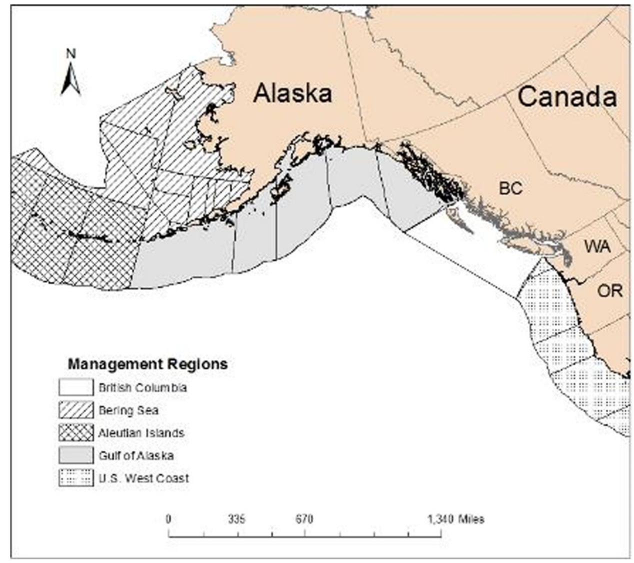

Figure 81. Fishery management regions of the north-east Pacific.

12. North-Eastern Pacific

The coastline of FAO Statistical Area 67 (Northeast Pacific) extends from northern California through Oregon, Washington, British Columbia, Alaska and the Bering Sea to eastern Russia. For this review landings from northern California are included in the Central East Pacific section and those from Russia in the Northwest Pacific section. Fishery management of the Northeast Pacific is conducted for four regions: the United States Pacific Northwest (waters off the coast of Oregon and Washington states), Canadian waters off the coast of British Columbia, the Gulf of Alaska (GOA), and the Bering Sea and Aleutian Islands (BSAI) (Figure 81). In the U.S., waters within 3 nm of the coast are managed by state fisheries agencies, while waters from 3–200 nm offshore are considered federal fisheries and are managed by regional Fishery Management Councils. In Canada, all marine waters are managed by Fisheries and Oceans Canada (DFO).

More than 19 species of octopods (two Orders, six Families) are found in the northeast Pacific in coastal waters from the U.S. and Canadian west coast through Alaska to the Bering Sea and Aleutian Islands chain (Jorgensen 2009; Jereb et al. 2013). These species range from open-ocean pelagic species through deep-water benthic species to species found in the shallow intertidal. While most of these species are small (100 g at maturity), the northern Pacific is home to the largest species of octopus in the world, *E. dofleini* (formerly *Octopus dofleini*), which grows to 15–25 kg at maturity. The total abundance of octopods and the relative species composition is unknown, as there is no effective way to census either pelagic or benthic populations. Octopus are occasionally taken in tribal, recreational, research, and commercial fisheries, but the size and species caught depends strongly on the type of fishing gear used and the depth of fishing. The species most commonly observed are red octopus (*Octopus rubescens* Berry, 1953), North Pacific giant octopus (*E. dofleini*), and flapjack devilfish (*Opistoteuthis californiana* Berry, 1949). Deepwater and pelagic species are rarely seen except in research surveys. The only species harvested commercially in the northeastern Pacific is *E. dofleini*. This species has a long history of artisanal fisheries by various Pacific Northwest tribes and Canadian First Nations, but was not commercially exploited prior to 1950, and has been harvested sporadically and at low levels since then. Commercial harvest in British Columbia historically included a directed dive fishery but currently consists of bycatch in trawl (shrimp and groundfish) and trap (shrimp and crab) fisheries. Octopus stocks off British Columbia are not assessed. There is no directed commercial fishery for octopus in U.S. waters, but octopus taken incidentally in commercial groundfish fisheries are sometimes retained and sold. Because of the size of the Alaskan groundfish industry, incidental catch of octopus in the two regions off Alaska is substantial. The North Pacific Fishery Management Council began tracking catch of octopus from federal and state waters off Alaska in 2003, and has set annual catch limits for an octopus assemblage since 2011. An annual assessment is conducted for octopus in Alaska, but this assessment is considered data-poor, most notably because of the inability to estimate total biomass for the stocks.

The geographic range and principal habitat of octopus species in the northeast Pacific are described in Jorgensen (2009) and Jereb et al. (2013) and are summarized in Table 10. Both *O. rubescens* and *E. dofleini* are widely distributed geographically and common in coastal shelf waters. Other species are largely limited to greater depths (*Muusoctopus leioderma* Berry, 1911, *Opisthoteuthis californiana*) or offshore pelagic habitat (*J. diaphana*).

12.1. *Enteroctopus dofleini*

This species is found throughout the northern Pacific Ocean from northern Japanese waters, throughout the Aleutian Islands, the Bering Sea and the Gulf of Alaska down the Pacific coast to southern California and Baja California, Mexico (Kubodera 1991; Jorgensen 2009; Jereb et al. 2013).

It has been studied extensively in Alaskan, Japanese and Canadian waters, but the dynamics of natural populations are still largely unknown. Unlike other octopus species, *E. dofleini* may live up to 5–6 years, although Hartwick et al. (1981) and Hartwick and Barriga (1997) suggested that growth rates were more consistent with a 2–3 year life span in the wild. It has been found to mature between 10 to 20 kg, with size at 50% maturity values in the Gulf of Alaska of 13.7 kg for females and 14.5 kg for males (Conrath and Conners 2014). Similar work in the southeast Bering Sea (Brewer et al. 2013) found a weight at 50% maturity of 12.8 kg for females and 10.8 kg for males. They are problematic to age due to a lack of documented beak growth checks and soft chalky statoliths (Robinson and Hartwick 1986), therefore determination of age at maturity is difficult for this species. In Japan this species is estimated to mature at 1.5 to 3 years and at similar but smaller size ranges (Kanamaru and Yamashita 1967; Mottet 1975). Hochberg and Fields (1980) documented maximum size at 272 kg, for an individual with an arm span of 9.6 m; Cosgrove and McDaniel (2009) discussed the provenance and validity of this, and other size records.

It is semelparous, with a planktonic paralarval stage lasting weeks to months after hatching. Within the Gulf of Alaska this species has a protracted reproductive cycle with a peak in spawning in the winter to early spring months (Conrath and Conners 2014). A similar pattern was observed in the southeast Bering Sea, with *E. dofleini* reproductively active in the fall with peak spawning occurring in the winter to early spring months (Brewer et al. 2013; Brewer 2016). It appears that reproduction in this species is not fully synchronous, as mature adults of both sexes were observed throughout the year in both regions. Due to

Table 10. Octopus species found in the northeastern Pacific Ocean and eastern Bering Sea.

	General distribution								
Scientific name	US	BC	GOA	BS	AI	Habitat	Depth range	Max length Mantle/total	Reproduction
Order Octopoda									
Family Opisthoteuthidae									
Opisthoteuthis californiana	*X*	*X*	*X*	*X*	*X*	Demersal	250–1,000 m	/50 cm	Iteroparous
Family Alloposidae									
Haliphron atlanticus	*X*	*X*				Pelagic	0–1,260+ m	69/400 cm	Unknown
Family Amphitretidae									
Bolitaena pygmaea	*X*					Pelagic	100–1,500 m	60/ cm	Planktonic
Japetella diaphana	*X*	*X*	*X*	*X*	*X*	Pelagic	200–1,500 m	85/160 cm	Planktonic
Family Enteroctopodidae									
Enteroctopus dofleini	*X*	*X*	*X*	*X*	*X*	Epibenthic	0–1,000 m	/250 cm	Planktonic
Muusoctopus canthylus	*X*	*X*				Epibenthic	2,795–3,000 m	8/25 cm	Unknown
Muusoctopus hokkaidensis	*X*					Epibenthic	130–1,000 m	6/24 cm	Unknown
Muusoctopus leioderma	*X*	*X*	*X*	*X*	*X*	Epibenthic	90–500 m	7/27 cm	Benthic
Muusoctopus oregonensis	*X*	*?*	*?*	*X*		Epibenthic	>1,000 m	18/78 cm	Unknown
Muusoctopus profundorum	*?*	*?*	*X*	*?*	*?*	Epibenthic	150–3,400 m	/29 cm	Unknown
Muusoctopus robustus	*X*					Epibenthic	1,200–3,850 m	14/ cm	Unknown
Muusoctopus sibiricus				*X*		Epibenthic	30–220 m	16/ cm	Unknown
Muusoctopus yaquinae	*X*					Epibenthic	1000–3000 m	8/ cm	Unknown
Muusoctopus unid.		*X*				Epibenthic	>500 m		Unknown
Sasakiopus salebrosus				*X*	*X*	Epibenthic	200–1200 m	10/25 cm	Unknown
Family Megaeledonidae									
Graneledone boreopacifica	*X*	*X*	*?*	*X*		Epibenthic	700–1,500 m	16/ cm	Unknown
Family Octopodidae									
Octopus californicus	*X*	*?*	*X*			Epibenthic	100–1,000 m	10/ cm	Benthic
Octopus rubescens	*X*	*X*	*X*			Epibenthic	0–100 m	10/25 cm	Planktonic
Octopus unid.			*X*			Epibenthic	10–300 m		Benthic
Family Ocythoidae									
Ocythoe tuberculata	*X*	*X*	*X*	*X*	*X*	Pelagic	0–200 m	31/96 cm	Unknown
Order Vampyromorpha									
Family Vampyroteuthidae									
Vampyroteuthis infernalis	*X*	*X*	*X*	*X*	*X*	Pelagic	300–1,500 m	8/13 cm	Unknown

differences in the timing of peak gonad development between males and females, it is likely that females have the capability to store sperm. This phenomenon has been documented in aquarium studies of octopus in Alaska (Jared Gutheridge, pers. comm.) and British Columbia (Gabe 1975). Larson et al. (2015) provided molecular genetic evidence supporting multiple paternity and suggested contribution by two to four males in single clutches of eggs. Fecundity for this species in the GOA ranged from 40,000 to 240,000 eggs per female with an average fecundity of 106,800 eggs per female. Fecundity was significantly and positively related to the size of the female (Conrath and Conners 2014). Fecundity of *E. dofleini* within this region is higher than that reported for other regions. Fecundity of this species in Japanese waters has been estimated at 30,000 to 100,000 eggs per female (Kanamaru 1964; Mottet 1975; Sato 1996). Gabe (1975) estimated a female in captivity in British Columbia laid 35,000 eggs. Eggs are suspended in long strings from the ceiling of a rocky den and are protected and aerated by the female for 5.5–6.5 months before hatching, depending on water temperature (Gabe 1975; Mottet 1975; Cosgrove 1993). Both sexes undergo senescence and eventually die; males after mating and females during egg brooding or soon after hatching occurs (Cosgrove 1993; Anderson et al. 2002).

Hatchlings are approximately 3.5 mm and weigh approximately 0.02–0.03 g (Hartwick 1983; Cosgrove 1993). After hatching, paralarvae spend 2–3 months in the plankton and settle to epibenthic habitat at approximately 1 g (Rigby 2004). Mottet (1975) estimated survival to 6 mm at 4% while survival to 10 mm was estimated to be 1%; mortality at the 1 to 2 year stage is also estimated to be high (Hartwick 1983). Since the highest mortality occurs during these early stages, it is probable that ocean conditions have a strong impact on early survival and result in large interannual fluctuations in recruitment. Rigby (2004) estimated absolute growth rates of 0.82 to 0.95g/day, depending on water temperature, for *E. dofleini* of 2–4 kg. Brewer (2016) showed that specific growth rates of immature octopus decreased with increasing body size; growth of 10–15 kg *E. dofleini* tagged in the southeast Being Sea ranged from 0.2 to 1.3%/day. Hartwick et al. (1981) reported specific growth rates of 0.1–1.8%/day based on tag recoveries in Clayoquot Sound, British Columbia.

12.1.1. Stock identification

The stock structure and phylogenetic relationships of *E. dofleini* throughout its range have not been well studied. Three subspecies have been identified based on large geographic ranges and morphological characteristics including *Enteroctopus dofleini dofleini* (Wülker, 1910) (far western North Pacific), *Enteroctopus dofleini apollyon* (Berry, 1912) (waters near Japan, Bering Sea, Gulf of Alaska), and *Enteroctopus dofleini martini* (Pickford, 1964) (eastern part of their range) (Pickford 1964). Hochberg (1998) rejected subspecific designations and referred to *E. dofleini* as a species complex. Hochberg and Fields (1980) suggested that an undescribed subspecies was present off southern California. Recent genetic studies (Toussaint et al. 2012; Barry et al. 2013) suggested the presence of cryptic species of *E. dofleini* in Prince William Sound and possibly Stephens Pass, Alaska. Although sample sizes were small, Larson et al. (2015) found evidence of moderate genetic diversity and moderate population structure amongst sample groups from Oregon, coastal Washington, Puget Sound and British Columbia. Additional genetic and/or tagging studies are needed to clarify the stock structure of this species in the northeastern Pacific.

There is little information available about the migration and movements of this species in the Eastern Pacific. Kanamaru (1964) proposed that *E. dofleini* in waters off of the coast of Hokkaido, Japan move to deeper waters to mate during July through October and then move to shallower waters to spawn during October through January. Studies of movement in British Columbia (Hartwick et al. 1984) and south central Alaska (Scheel and Bisson 2012) found no evidence of a seasonal or directed migration for this species. Tagging studies in the southeast Bering Sea (Brewer 2016) saw limited movement of both small and large *E. dofleini*, with the highest movement rates in intermediate size ranges (15–18 Kg). Within-season movement vectors from this study were up to 4.6 km, and between-season movement between 0.95 and 11.5 km. Further studies are needed to document spatial distributions and seasonal movement patterns of *E. dofleini* in the eastern Pacific.

12.1.2. Catches/landings

There currently is no directed octopus fishery in coastal or offshore waters in the Northeast Pacific. There is, however, substantial incidental catch (bycatch) of octopus from groundfish fisheries in Alaska, and historic contributions from a directed dove fishery and bycatch in crustacean trap fisheries in British Columbia (Figure 82).

12.1.2.1. Alaska and U.S. Pacific Northwest. From 1992–2003 total incidental catch of octopus in Alaska was estimated from observed hauls (Gaichas 2004). Since 2004 the total octopus catch in federal waters (including discards) has been estimated using the National Marine Fisheries Service (NMFS) Alaska Regional Office catch accounting system. Bycatch of octopus (species not identified) is estimated between 200 and 500 mt/yr in the BSAI and between 300 and 800 mt/yr in the GOA. Both total catch and percentage retention have increased in recent years, especially

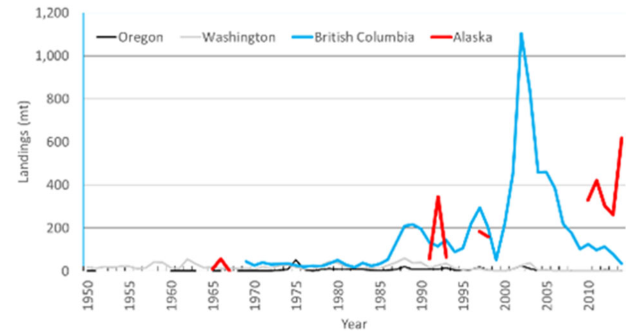

Figure 82. Catch of octopus (all species, mt) from fisheries in Northeast Pacific (FAO Statistical Area 67), 1950–2014.

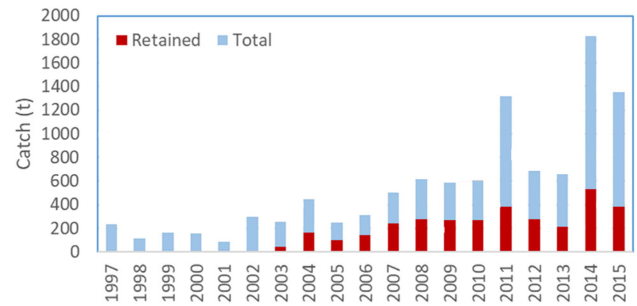

Figure 83. Retained and total catch of octopus (all species) from state and federal fisheries in the Gulf of Alaska (NMFS Region). Note that only total catch was estimated before 2003.

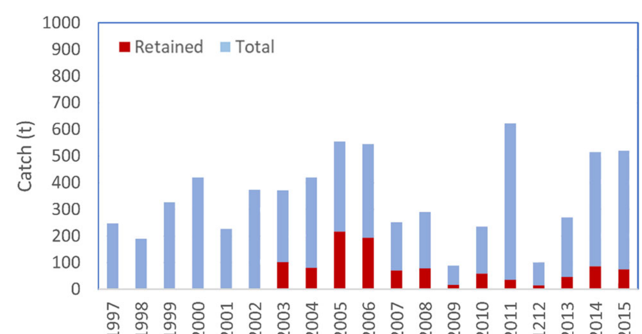

Figure 84. Retained and total catch of octopus (all species) from state and federal fisheries in the Bering Sea and Aleutian Islands (NMFS Region). Note that only total catch was estimated before 2003.

in the GOA (Figures 83 and 84). Some of this increase is probably due to improved catch reporting and catch accounting, but awareness of octopus and its potential commercial value has also increased. Landings of octopus in commercial fisheries off Oregon and Washington has ranged from 2.7 to 6.1 mt/yr, with particularly high catches in 2012 and 2015 (Pacific Fisheries Information Network [PACFIN] 2015). Ex-vessel prices for landed octopus are higher in Oregon and Washington than in Alaska, ranging from $0.62 to $1.17 per pound.

12.1.2.2. British Columbia. Historically, catches in BC were documented using fish slip data maintained by the Pacific Region Commercial Catch Statistics Unit; these data were summarized in annual reports between 1951 and 1995 (DFO 1951–1995). Octopus were not reported until 1969. Catches post-1995 are from Pacific Region Commercial Catch Statistics Unit databases until 1999; data from 2000 to present are a combination of logbooks and at-sea or dockside monitoring, depending on the programs in use for each fishery. There were considerable discrepancies between fish slip and other monitoring data, with fish slips reporting significantly more catch from 1980 to 1999 and other monitoring program reporting significantly more catch after 2000.

Catch of octopus was relatively low until the mid-1980s when increased demand for octopus bait supported further development of a directed dive fishery. Landings peaked briefly in 1988–1990 surpassing 200 mt and then declined (Figure 82). Landings again exceeded 200 mt in 1996–1998 with a peak of 294 mt in 1997. After a poor year in 1999 landings increased dramatically to a historic high of 1,103 mt in 2002. Participation and effort declined after 2002 and landings fell consistently thereafter.

All increases were driven primarily by increased landings in the dive fishery; incidental bycatch in the shrimp trap fishery became more important after 2008 and became the sole producer after closure of the dove fishery in 2013 (Figure 85).

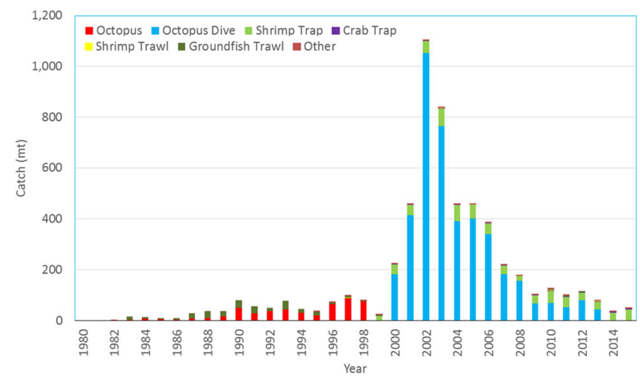

Figure 85. Landed catch (mt) of octopus from commercial fisheries in British Columbia, as reported in logbooks (1980–1999) or catch monitoring programs (2000–2015).

12.1.3. Fisheries/fishing methods/fleet

12.1.3.1. Inshore tribal and recreational fisheries. Octopus harvested by hand from intertidal areas have historically been part of the diet of many native tribes throughout the Pacific Northwest, Alaska, and the Aleutian Islands (Morris 1987; Lape and Kopperl 2013). First Nations in British Columbia traditionally harvested octopus for both food and bait (e.g., Ellis and Swan 1981). Fishers would search for octopus dens by wading or canoe in shallow water and octopus were driven from their den and dispatched using sharpened yew "octopus lances." Mantles, arms and suckers were occasionally eaten but most of the flesh was prepared for bait; some was dried and stored for later use. Octopus were also used to fashion dressings for burns. There are no reliable estimates of British Columbia recreational or First Nations' harvests but there are two permanent area closures in regulation specifically to ensure First Nations access for Food, Social and Ceremonial purposes.

Recreational octopus fishing is regulated by states in the western U.S. and the Federal government (DFO) in Canada. In the US, permitted recreational catch methods range from angling to scuba diving and traps; use of chemical toxins or irritants is prohibited. In Oregon and Washington, one octopus per day is the limit for recreational permits. The state of Alaska permits octopus to be harvested under recreational and "subsistence" licenses, with similar regulations. In Alaska, there is no bag limit, but the number of traps is limited to five per individual and ten per vessel. There are no seasonal restrictions in any of the state recreational fisheries. Canadian regulations allow recreational harvest of one octopus per day with a possession limit of two; use of sharp-pointed instruments, snares, hand pumps or chemical irritants is prohibited and a tidal waters personal fishing license is required (DFO 2016d).

12.1.3.2. State and provincial fisheries. Directed commercial fishing for octopus is allowed in Alaska state waters (within 3 mi of shore) only with a special "commissioner's permit" from the Alaska Department of Fish and Game. These permits are issued on a case-by-case basis and usually include either total effort or total catch restriction. This fishery has been limited to trap gear, using a variety of trap types and sizes from commercial crab and shrimp traps to experiments with small "habitat" traps selective for octopus (Sagalkin and Spalinger 2011; Conners et al. 2012). Efforts were made in the late 1980s to evaluate the potential for a state octopus fishery (Paust 1988, 1997); catches from 1988–1995 were reportedly less than 8 mt per year (Fritz 1997). In 2004–2016 commissioner's permits have occasionally been given for directed harvest on an experimental basis. An experimental fishery in the Bering Sea in 2004 had 13 participating vessels and landings of 4,977 octopus totaling 84.6 mt. The majority of this catch was from larger pot boats during the fall season cod fishery (September–November). From 2005 to 2014, few permits have been requested and all catch of octopus in state waters was incidental to other fisheries (Bowers et al. 2010; Sagalkin and Spalinger 2011).

In British Colombia, dive fishers would search for octopus dens, often using midden piles of discarded crustacean and bivalve shells as a cue (Wylie 2006; Cosgrove and McDaniel 2009). Octopus were flushed from their dens using an irritant; copper sulfate, ammonia or liquid bleach were used historically but these were banned and after 1999 divers primarily used dilute hydrogen peroxide. Octopus were placed in mesh bags and returned to the surface for processing. Divers would revisit known areas of high den concentrations and harvest new octopus that had inhabited dens after the previous occupants had been removed.

The dive fishery occurred primarily along the east coast of Vancouver Island from Port Hardy to Sooke, with some fishing occurring on the west coast of Vancouver Island in Barkley and Clayoquot Sounds. From 2000 until the fishery was discontinued in 2013 approximately 60% of the landings reported in logbooks originated from inside waters and 40% from the west coast of Vancouver Island.

Historically, very little trap effort was directed at octopus; most landings were of octopus caught incidentally in trap fisheries for crab and shrimp (Jamieson 1987; Gillespie et al. 1998). Crustacean trap fishers considered octopus a nuisance as they consume shrimp or crabs confined in traps; octopus move from trap to trap and several in sequence may be found with only carapaces and an octopus in the final trap. Brief attempts to establish directed octopus trap fisheries in British Columbia (e.g., Hartwick et al. 1978; Adkins et al. 1980; Hartwick and Barriga 1997) and Alaska (e.g., Paust 1988, 1997) were unsuccessful, but interest continues (Barry et al. 2010).

Octopus caught incidentally in shrimp trawl and groundfish fisheries may be retained; those taken in groundfish fisheries cannot be landed, only retained for use as bait (DFO 2016b, 2016c). Shrimp trawls (both otter and beam configurations) are fished on soft, level bottom. Groundfish trawls are larger and use heavy ground gear to fish grounds that have harder bottom but are still of relatively low relief. Unlike the dive fishery, which seeks out denning octopus, trawl fisheries likely encounter octopus that are foraging.

12.1.3.3. U.S. federal fisheries. Waters from 3 nm to 200 nm offshore the coast of the U.S. are regulated as federal fisheries through regional Fishery Management Councils (North Pacific Fishery Management Council [NPFMC] 2015a, 2015b). While octopus are regulated as shellfish by the states of Oregon and Alaska, in federal fisheries of the northeastern Pacific they are considered part of the groundfish fishery (NPFMC 2015a, 2015b). Groundfish fisheries are regulated by Fishery Management Plans for three regions: the U.S. West Coast, the Gulf of Alaska (GOA) region, and the Bering Sea and Aleutian Islands (BSAI) region (Figure 81). At present there is no directed fishing for octopus allowed in any of these three regions, but regional plans permit some retention of non-target species, including octopus. Retention of incidental catch in the BSAI and GOA regions is permitted up to a Maximum Retainable Allowance (MRA) which varies by fishery and species. In most groundfish fisheries, retention of octopus and other non-prohibited species is allowed up to a fixed percentage (usually 20%) of the retained catch of target species.

Octopus are not included in the Fishery Management Plan for the U.S. West Coast and are infrequently encountered in West Coast commercial fisheries. Most octopus taken by offshore fisheries are discarded at sea. Total annual landings of octopus (both federal and state fisheries) in the West Coast region from 2010 to 2015 ranged from 2.7 to 6.1 mt, with an average of 4.1 mt.

The most substantial catch of octopus occurs in the federal groundfish fisheries in the two regions off Alaska, which are among the largest and most economically important in the U.S. Total Alaskan commercial fish harvest in 2014 exceeded 1.2 million mt and was valued at $4.3 billion dollars (Alaska Fisheries Science Center [AFSC] 2016). Commercial groundfish fleets in Alaska include catcher vessels, which deliver to shoreside processors or motherships, catcher-processors, which process and freeze catch in onboard factories, and floating processors known as motherships, which buy and process catch from smaller vessels. Because of the extreme weather conditions in Alaska, these fleets are generally made up of larger vessels; catcher-processors in the BSAI range from 80 to 160 ft, and motherships exceed 200 ft (NMFS 2016). Gear used includes mid-water and bottom trawl nets, longline (hook-and-line) gear, jigging, and traps or pots. The "pots" used in Alaska commercial fisheries are large steel frames (usually 7 ft by 7ft by 3 ft) covered in 4" mesh, with two or three entrance tunnels. While these pots are primarily used by crab fisheries, they are also used in groundfish fisheries targeting Sablefish (*Anoplopoma fimbria*) and Pacific cod (*Gadus macrocephalus*). The majority of the incidental catch of octopus in federal groundfish fisheries is taken in this pot gear. While octopus are undoubtedly attracted to these pots by the bait used, fishermen have also reported frequently finding octopus in unbaited traps, presumably using them as temporary habitat or shelter. Some incidental catch of octopus also occurs from prawn and shrimp fisheries using smaller trap gear.

The highest octopus catch rates are from Pacific cod pot fisheries in the western GOA and in the southeast Bering Sea near the tip of the Alaska Peninsula. While some octopus are taken in trawl and longline fisheries, the overwhelming majority of the catch in both regions is taken with pot gear fished for Pacific cod. Crab and sablefish are generally fished at greater depths, but cod pots are fished at 50–200 m, and octopus are taken throughout this depth range. Cod pot gear is selective for larger individuals; this catch is almost completely composed of octopus >5kg. While most octopus bycatch was discarded in past years, in recent years both the total catch and the percentage retained has been increasing, particularly in the western GOA (Figure 83). Retained octopus is generally either kept by the vessel or sold to a processor for use as bait, but there is a small market for octopus prepared for human consumption. This market has the potential to substantially increase, based on the worldwide demand for octopus.

12.1.4. Fishery management and stock assessment

12.1.4.1. Alaska. The only explicit management for octopus in the U.S. portions of the northeast Pacific occurs in the two management regions off Alaska. An octopus assemblage, including all species of octopus, is included in the Fishery Management Plans for the BSAI and GOA regions. Octopus in observer and catch data are not identified to species; for management purposes all octopus species are grouped into a single assemblage. The species composition of the octopus community is not well documented, but data indicate that the giant Pacific octopus *E. dofleini* is most abundant in shelf waters and predominates in commercial catch (Conners et al. 2016).

Prior to 2011, octopuses were managed as part of an "other species" complex in both the BSAI and GOA regions. Until 2003, catch of other species (squid, octopus, sharks, skates, and sculpins) was reported only in the aggregate, and annual catch limits were set for the entire category. Separate catch reporting for different components of the other species complex was initiated in 2003, but octopus are still reported as an aggregate catch for all species. Catch of other species from 2005–2009 was limited by a TAC set at ≤5% of the combined target species TAC. In October 2009, the NPFMC voted unanimously to amend both the BSAI and GOA Fishery Management Plans to eliminate the "other species" category. New regulations to set separate annual catch limits for species assemblages from this group were implemented in January 2011 for the BSAI and January 2012 for the GOA. The National Marine Fisheries Service (NMFS) Alaska Fisheries Science Center (AFSC) prepared preliminary stock assessments for each species assemblage from 2006 through 2010 and annual assessment of each assemblage, with recommended overfishing levels and allowable catch limits, since 2011.

Assessments of the octopus assemblage in the BSAI and GOA management regions are extremely data-limited (Conners et al. 2016). There are several problems trying to apply the standard methods for groundfish stock assessment in these regions to octopus. There is as yet no established aging technique for *E. dofleini*. Statoliths of this species are too soft and chalky to age (Robinson and Hartwick 1986). While banding structure has been observed in the stylets and beaks, a linking of these bands to specific time intervals has not been established. Since octopus bodies are pliable and growth is highly plastic, there is no equivalent to a fixed length measure or length/age relationship. Size frequency of octopus caught is highly gear-dependent, with trawl nets catching primarily small (<1 kg) octopus and pot gear catching only large (>5kg) animals. Because of this size selectivity, no effective methodology exists for determining the size or age structure of the population.

The biggest problem is estimating the standing biomass of octopus populations in the BSAI and GOA. The AFSC conducts annual (BSAI) and biennial

(GOA) bottom trawl surveys as the basis for estimating groundfish biomass. These surveys are not, however, an effective sampling tool for octopus; octopus are present in only 4–12% of survey tows and variance of extrapolated catch per area is very high. The research bottom trawl net captures primarily small octopus, with the occasional individual over 20 kg, which results in high variance of estimates. The survey does not cover shallow inshore areas and extremely rocky or high relief areas, both of which are known octopus habitat. As a result, there are survey estimates of overall biomass for each region, but they are not considered accurate and are probably far less than the true biomass.

A variety of methods for setting annual catch limits have been attempted for the octopus assemblages in the BSAI and GOA. With other groundfish species, when no reliable biomass estimates are available an average of historical catch rates is recommended. Since the only historical catch data for octopus is incidental catch, however, this average catch rate is very low. Historical rates of incidental catch of octopus have been estimated for 1997–2003, but these catches do not represent any directed effort and are unlikely to have caused any measurable depletion of the stock. Catch limits for octopus in the BSAI for 2011 were set using the maximum historical incidental catch rate of 428 mt. The BSAI catch in 2011 was the highest yet observed, reaching the overfishing level by mid-October. On 21 October 2011 the NMFS regional office closed directed fishing for Pacific cod with pot gear, resulting in substantial economic loss.

In 2012, a new methodology was introduced based on an estimated natural mortality of octopus due to predation by Pacific cod (Conners et al. 2016). Food habits data collected by the AFSC indicates that Pacific cod is the major predator of octopus in the Bering Sea, and data from large numbers of stomach samples of Pacific cod are available. Estimates of numbers of Pacific cod by year, spatial stratum, and one cm length bins were obtained from the bottom trawl survey. Cod ration, in mt prey/cod/year was estimated from allometric growth relationships (Essington et al. 2001) and cod weight-at-age data, and the proportion by weight of octopus in the diet of cod for each year, stratum, and cod size class was estimated from stomach samples. The total consumption of octopus (t/year) was calculated, and is used as a conservative approximation of natural mortality for octopus. Estimates of annual predation mortality by Bering Sea cod on octopus ranged from <200 to over 20,000 mt; the majority of the annual estimates prior

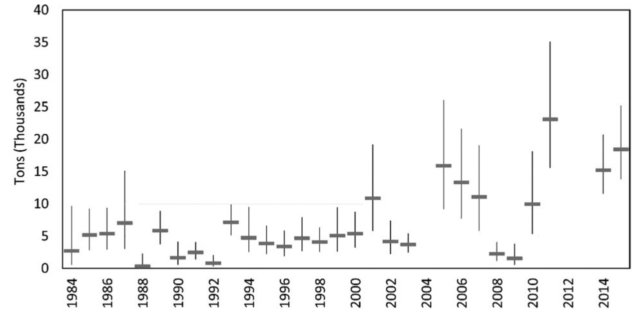

Figure 86. Estimated consumption of octopus by Bering Sea Pacific cod, 1984–2015. Error bars show 95% confidence intervals of posterior distribution; solid bars are annual hyperbolic means.

to 2004 were in the range of 3,000 to 6,000 t (Figure 86). Annual predation rates increased in 2010–2015, due to both an increase in the abundance of Pacific cod and increased presence of octopus in the diet. The geometric mean of the posterior distribution for all annual predation estimates yielded a conservative long-term average predation rate of 4,770 mt, which is a full order of magnitude higher than the estimated rate of incidental catch in current fisheries. This calculation was presented in the 2011 BSAI octopus stock assessment, and has been selected as the best available procedure to set BSAI catch limits from 2012 through 2017.

Catch limits for octopus in the GOA have been based on different procedures. The bottom trawl survey of the GOA uses trawl nets more suitable for rocky habitat and catches a wider range of octopus sizes, so the bottom trawl survey biomass estimate is considered more representative of octopus populations. The consumption-based estimator was considered but rejected in this region for two reasons. Food-web analysis for the GOA indicates that there are several important predators for octopus, and estimating overall consumption for multiple predators would be complex. Secondly, stomach sampling in the GOA is less extensive that in the BSAI, and greater uncertainty is associated with consumption estimates for the GOA. As the best choice among poor alternatives, the GOA currently uses the standard surplus production model where the overfishing fishing mortality rate (F) is set by the calculation $F = M$ (Alverson and Pereyra 1969; Francis 1974), where M is an estimated rate of natural mortality. The overfishing fishing mortality rate is applied to estimated biomass to determine overfishing levels. The natural mortality rate currently used is 0.57, based on the Rikhter and Efanov (1976) equation and a presumed average age at maturity of 3 years. For future assessments,

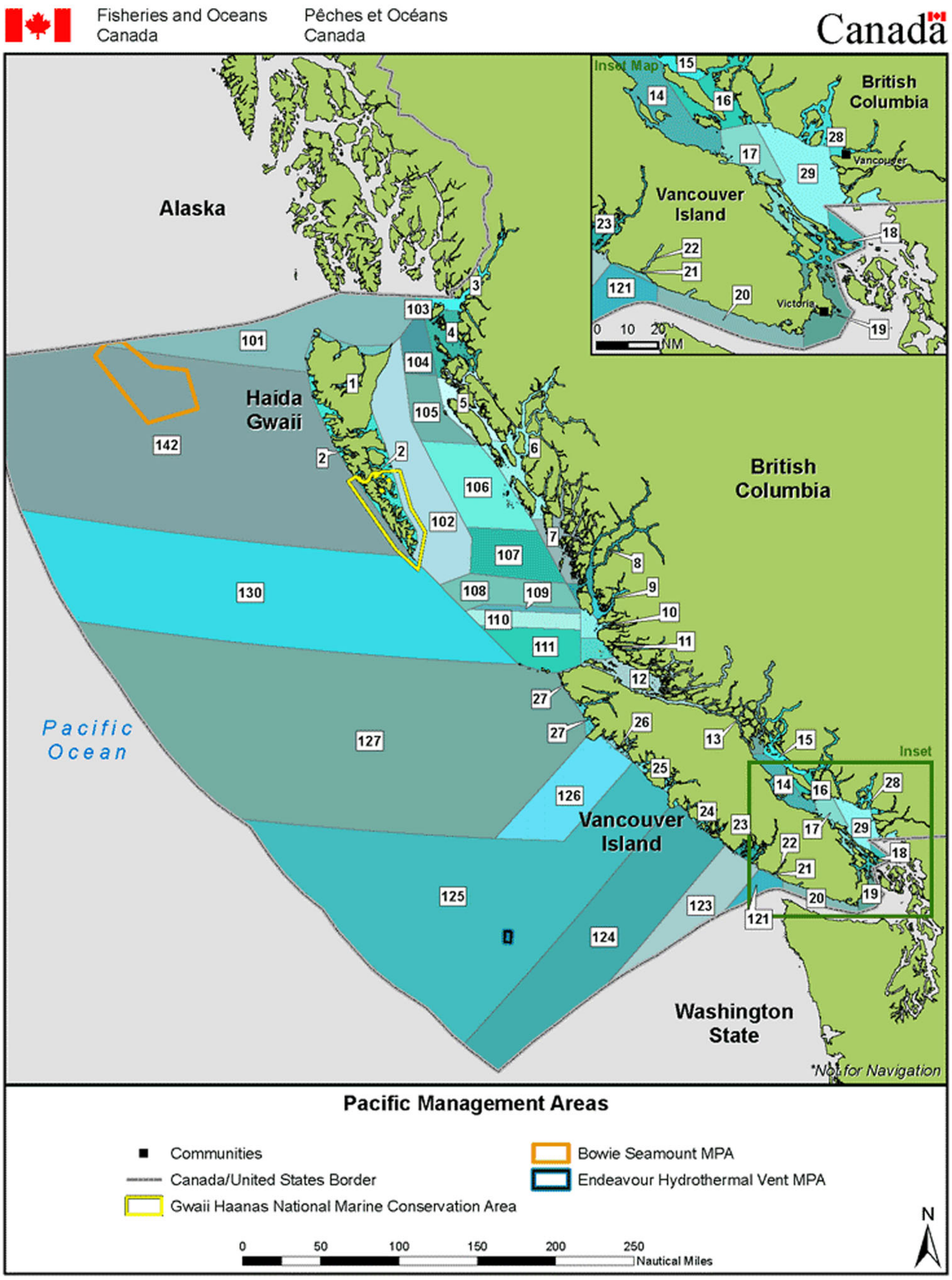

Figure 87. Pacific Fishery Management Areas for the North and South Coast of British Columbia.

an exploratory size-based population model is being developed. Estimation of model-based population parameters would, however, require both a dedicated octopus survey (time series of biomass) and some estimation of size frequency in octopus catch (catch at stage).

12.1.4.2. British Columbia. All directed commercial fisheries for octopus in BC were managed under a single license until 1992 when dive and trap fisheries were shifted to separate licenses. By regulation, North Pacific giant octopus (*E. dofleini*) is the only species that can be commercially harvested.

Commercial octopus dive licenses were no longer issued in 2000. Some harvest continued under experimental guidelines and scientific licenses with the intention of testing environmentally acceptable and efficient irritants and collecting more detailed biological information to support stock assessment (DFO 2006). Experimental guidelines required fishers to select one of three fishing areas: North Coast (Pacific Fishery Management Areas (PFMA) 1–10) (Figure 87), East Coast Vancouver Island (PFMA 11–19, 28 and 29) or West Coast Vancouver Island (PFMA 20–27) (Figure 87) (DFO 2006; Wylie 2006). Experimental guidelines were discontinued after 2007 and harvests continued under exploratory fishing guidelines and permits (DFO 2011). After significant declines in effort and landings, the commercial dive fishery for octopus was discontinued 31 July 2013.

Historically, harvest opportunities for octopus by trap were limited to periods of time when shrimp trap fisheries were open; typically April to August. This was to eliminate bycatch of shrimp during periods in which the shrimp trap fishery was closed for conservation reasons (DFO 1998). Currently, octopus retention is allowed in periods and areas that each trap fishery is open; now typically April through July for shrimp trap and year-round for crab trap fisheries except management areas with seasonal softshell closures (DFO 2015, 2016a). The shrimp trap and crab trap management plans include numerous octopus closure areas (where any octopus encountered are required to be released unharmed) for provincial and national parks, marine and ecological reserves, First Nations Food, Social and Ceremonial concerns, research and study areas and navigational issues. New logbooks requiring octopus catch information were introduced to shrimp and crab trap fisheries; the logbook for crab requires total number and weight of both retained and released octopus (DFO 2015). Octopus stocks are not assessed in BC beyond catch reporting requirements.

12.1.5. Economic importance

Octopus caught in U.S. groundfish fisheries are often discarded at sea, but may be retained in small quantities (up to the Maximum Retainable Allowance) for sale as either seafood product or bait. In 2004–2007 a commercial market for human consumption of octopus developed in Dutch Harbor, Alaska, with ex-vessel prices running as high as $U.S. 0.90/lb. The main processor marketing this food-grade octopus went out of business in 2009, decreasing demand. Other processors in both the GOA and BSAI continue to buy octopus for bait at ex-vessel prices in the $U.S. 0.40–0.60/lb range. Octopus is a desirable bait both for longline and pot fishing; some vessels retain their octopus catch for their own later use as bait. At present, octopus products contribute only a small amount to the total value of fishery products in Alaska (AFSC 2016). Total wholesale value of octopus from Alaskan fisheries in 2010–2015 averaged $U.S. 412,000 per year out of total returns over 4 billion per year. Due to the worldwide demand for food-grade octopus, however, the possibility of increased future marketing effort for octopus products exists.

12.1.5.1. British Columbia. Most octopus landed in BC are utilized as bait in longline fisheries for Pacific halibut (*Hippoglossus stenolepis*), sablefish and other groundfish (Adkins et al. 1980; Parker 2002; Wylie 2006). Introduction of Individual Vessel Quotas in the halibut fishery in 1991 greatly reduced demand for octopus bait, as fishers were able to utilize bycatch such as pink salmon (*Oncorhynchus gorbuscha*) or other less expensive alternative baits (Parker 2002; Wylie 2006).

Reported total value of octopus fisheries in British Columbia ranged from 1.1 million $Cdn in 1997 to 14,000 $Cdn in 2014 and 2015 (DFO Pacific Region Commercial Catch Statistics Unit, Vancouver). These likely underestimate true value as fish slips account for only a portion of total landings after 1999 when other catch monitoring methods (logbooks, dockside and at-sea monitors) were implemented. Values declined steadily except for a brief recovery in 2002 through 2004. Declines post-2004 were apparent in the shrimp trap fishery but driven primarily by the decline of the dive fishery. Since licenses were separated in 2000, the dive fishery represented 40% of the landed value, shrimp trap accounted for 58% and there were minor contributions from shrimp trawl and crab trap fisheries.

Average annual price over all gear types between 1982 and 2015 ranged between $Cdn 2.25–4.25/kg ($Cdn 1.02–1.93/lb). Average annual price was highest in the dive fishery (1982–2013) ranging between $Cdn 2.67–7.73/kg ($Cdn 1.19–3.50/lb) with the peak in 2010.

13. Central-Eastern Pacific

The Central-eastern Pacific encompasses a variety of regions where several octopus species co-exist and octopus fisheries of different levels of development are carried out. The coastline of the FAO Major Fishing Area 77 extends from Cape Mendocino in northern California to Panama, and westward to 175°00′W, covering all of western Polynesia. During the first half of the past century, a targeted octopus fishery operated in California. In contrast, octopus catches off the Mexican Pacific only increased significantly during the 1980s with landings over 1,000 t year^{-1}. In Polynesia, octopus fishing is a significant age-old practice linked to myths.

The area reports mean octopus landings of 1,384 t year^{-1} during this century (FAO 2016), of which 95% of the landings are from western Mexico. There is little biological and fisheries information available from some regions within the fishing area; moreover, most octopus catches are not reported at the species level. As a result, there is a significant lack of information on the life history, stock identification, recruitment, catches, size of the fleet and people employed, among others, which limits the capacity to develop robust management measures.

13.1. California and Mexican Pacific

13.1.1. *Enteroctopus dofleini*

Although *E. dofleini* occurs in the North Pacific from California to southern Japan, no studies on this octopus have been conducted in Californian waters, although it has been well studied in the areas of the North Pacific where fisheries targeting this species occur (see sections 11 and 12).

13.1.2. *Octopus hubbsorum*

This species, commonly known as the Hubb's octopus, was originally described for the Gulf of California in 1953. It was not until 1995, however, identified as the main component of the octopus fishery along western Mexico. This species is known as "pulpo verde" in Mexico and is reported from Magdalena Bay off southwestern Baja California, into the Gulf of California and south to Oaxaca, as well as around the Revillagigedo Islands. It is found from the intertidal to shallow subtidal zones (0–30 m), in rocky areas in holes, crevices or under boulders (Aguilar and Godínez-Domínguez 1997; López-Uriarte et al. 2005; Domínguez-Contreras et al. 2013).

All of the information available of *O. hubbsorum* is from studies conducted in western Mexico. This octopus grows to a maximum of 220 mm ML and 3,700 g BW at Magdalena Bay, Baja California Sur and off Oaxaca (Alejo-Plata et al. 2009; Domínguez-Contreras et al. 2013; Alejo-Plata and Gómez-Márquez 2015). Modal size analysis estimated ML growth rates of 0.40–0.76 mm day^{-1}, and a post-settlement life span of 9 months for females and 7 months for males, with an estimated maximum life span of 15 months (López-Uriarte 2006).

Size at maturity varies depending on the location. At Oaxaca, females mature ($ML_{50\%}$) at 160 mm ML and males at 140 mm ML (Alejo-Plata et al. 2009), although another study estimated the $ML_{50\%}$ at 90 mm ML for females and 74 mm ML for males (Alejo-Plata and Gómez-Márquez 2015), and BWs of 1,195 g for females and 527 g for males (García-Guadarrama 2013). At Jalisco females mature at 115 mm ML and 758 g BW while males mature at 70 mm ML and 320 g BW (López-Uriarte and Ríos-Jara 2009). In the Gulf of California females mature at 615–680 g BW and males at 405–445 g BW (Bravo-Olivas 2008; Pliego-Cárdenas et al. 2011), similar to females from Bahía Magdalena (628 g BW; 120 mm ML; Domínguez-Contreras et al. 2018).

Mean potential fecundity ranges from 107,103 to 240,050 oocytes female^{-1}, with a minimum value of 22,447 oocytes and maximum of 545,444. Mean relative fecundity is 32–471 oocytes g^{-1} of female BW (López-Uriarte and Ríos-Jara 2009; Pliego-Cárdenas et al. 2011; García-Guadarrama 2013; Alejo-Plata and Gómez-Márquez 2015). The average size of the eggs is 1.6–2.1 mm length and embryonic development lasts from 20 to 30 days at 28–30 °C. Hatchlings are planktonic and measure 1.2 mm ML (Monsalvo-Spencer et al. 2013; Alejo-Plata and Herrera-Alejo 2014).

Reproduction extends throughout the year with spawning peaks defined in most studies. In some cases, however, small sample sizes analyzed resulted in discordant spawning peaks. Off Oaxaca spawning peaks were observed in May–June and October–November (Alejo-Plata et al. 2009; Alejo-Plata and Gómez-Márquez 2015), whereas at Jalisco they occur in June and September (Aguilar-Chávez 1995; López-Uriarte and Ríos-Jara 2009). In the Gulf of California different reproductive peaks have been reported. At Loreto one spawning peak was identified in June, and a weaker second peak was detected in February (Bravo-Olivas 2008). Spawning peaks occurred from September to December, and during March off Espiritu Santo Island (Pliego-Cárdenas et al. 2011). Off the west coast of the Baja California peninsula, reproduction takes place from May to October (Ibarra-García 2012; Domínguez-Contreras et al. 2018).

Octopus hubbsorum is an opportunistic predator that feeds on crustaceans (e.g., brachyuran crabs), mollusks (including octopuses) and small fishes (López-Uriarte and Ríos-Jara 2010; Alejo-Plata et al. 2018).

13.1.2.1. *Stock identification.* Recently it has been suggested that *O. hubbsorum* and *O. mimus* from Peru and northern Chile are the same taxon (Pliego-Cárdenas et al. 2014); in which case the species would occur from Baja California to northern Chile. Specimens from western Mexico, Costa Rica and Ecuador form a distinct subgroup from those from the Peruvian province (Pliego-Cárdenas et al. 2016).

13.1.3. *Octopus bimaculatus*

The geographic range of *O. bimaculatus*, the Two-spotted octopus, extends from Point Conception, California to Baja California and the Gulf of

California (Norman et al. 2014). Recent studies suggest that its distribution extends further to the Gulf of Tehuantepec and may be as far south as Central America (Alejo-Plata et al. 2012); although the taxonomic status of ocellate octopus in the region has not been resolved yet (Norman et al. 2014). This species occupies depths from 0 to 50 m depths in intertidal and subtidal kelp forests, rocky substrates, and reefs, where they use rock crevices, sand, and rubble as shelter (Ambrose 1982; Norman et al. 2014).

Maximum recorded size of *O. bimaculatus* has been recorded at 260 mm ML and 3,400 g BW (Castellanos-Martínez 2008; Rodríguez-García 2010; López-Rocha et al. 2012). The growth parameter K has been estimated at 1.2–1.61 y^{-1} (López-Rocha et al. 2012). Maturity is reached at a broad range of sizes; with female $ML_{50\%}$ maturity occuring at 143 mm ML and 1,029 g BW, and males reaching maturity at 124 mm ML and 757 g BW at Bahía Los Angeles (Castellanos-Martínez 2008). At Bahía Sebastián Vizcaíno, females reach maturity at a smaller size of 112 mm ML (Rodríguez-García 2010).

Mature individuals are found throughout the year, with females spawning mostly from April through to July off southern California (Ambrose 1988). At Bahía Los Ángeles spawning occurs in June and September (Castellanos-Martínez et al. 2007; Castellanos-Martínez 2008), whereas the reproductive season at Bahía Sebastián Vizcaíno extends from January through June (Rodríguez-García 2010).

The egg clutch contains an average of 20,000 eggs, with eggs being 3.8 mm long. Embryo development takes 1–2 months at 16–20 °C. Paralarvae, hatching at ~2.6 mm ML, spend one to several months in the plankton before settlement (Ambrose 1981, 1988; Alejo-Plata et al. 2012). The settlement to adult phase takes approximately 8–10 months, with the adult phase lasting 11–12 months. The overall lifespan of *O. bimaculatus* is thus estimated at 19–22 months, plus several months in the plankton (Ambrose 1988). Two life cycle models have been proposed for *O. bimaculatus* in Catalina Island, California. The "alternating generation" model suggests that octopus that hatch in June will spawn the next year, while those that hatch late in September will spawn until the following second year. The "alternating years" model states that all octopus take 2 years to spawn (Ambrose 1988).

Octopus bimaculatus is active all day long with activity peaks at dusk and dawn. The preferred prey are crabs, although bivalves, chitons, limpets and snails are also preyed upon (Ambrose 1984; Armendáriz-Villegas et al. 2014).

13.1.4. *Octopus bimaculoides*

The species *Octopus bimaculoides* (Pickford and McConnaughey 1949) (or the lesser two spotted octopus), is reported as occupying the inter- and sub-tidal zone from San Simeon and the California Channel Islands, to at least Magdalena Bay at western Baja California peninsula (Lang 1997; Monsalvo-Spencer et al. 2013; Sánchez-García 2013; Norman et al. 2014). In the Baja California peninsula it is referred to as "pulpo manchado."

This species grows to 130 mm ML and to BW ranging from 800 g to over 1,000 g (Forsythe and Hanlon 1988b; Ibarra-García 2012). Life span has been recorded as 15–17 months in captivity at 18 °C, or 12–14 months at 23 °C (Forsythe and Hanlon 1988b). Females mature at a mean weight of about 500 g and a size of 110 mm ML. The spawning season is wide-ranging and variable; for example at Santa Barbara *O. bimaculoides* spawn from December through May, with hatchlings occurring from May through September. At San Quintin (western Baja California peninsula), spawning occurs from October through January, with hatchings occurring from January through May. Approximately 137–774 large eggs of 8–18 mm in length are laid. Embryonic development lasts from 82 days at 17.8 °C to 46–51 days at 23.4–22.5 °C, respectively. Hatchlings are benthic and weigh 0.07 g (Forsythe and Hanlon 1988a, 1988b; Lang 1997; Ibarra-García 2012; Monsalvo-Spencer et al. 2013).

13.1.5. *Octopus rubescens*

The Red octopus *O. rubescens* is distributed from the Gulf of Alaska to western Baja California peninsula, and in the Gulf of California, Mexico at depths of 0 to 300 m. It is probably the most common shallow-water species of octopus in the North-eastern Pacific (Hochberg 1997; Norman et al. 2014). It inhabits rocky areas or can be found occupying the large shells of dead gastropods or barnacles, empty bottles, and cans on soft bottoms.

Spawning peaks occur in shallow waters during April–May and July–August in California. It spawns 20,000–50,000 small eggs, each with a length of 3–4 mm ML, that hatch in 40–90 days. Hatchlings measure 2.5–2.8 mm and are planktonic for 1–2 months. This is a migratory species that moves offshore during winter. It grows up to 400 g during a life span of 12–18 months. Individuals are most active at night and feed mainly on crustaceans, mollusks, and occasionally on fishes (Hochberg 1997).

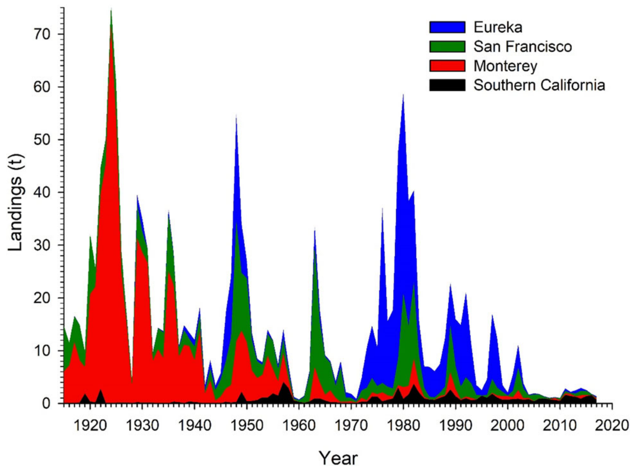

Figure 88. Cumulative octopus annual landings in California by area. Data from Duffy (1997), Leos (2014), selected Calif. Dep. Fish Game, Fish Bull. and CDFW (2018).

Other octopus species such as *"Octopus" alecto* and *Paroctopus digueti* occurring in the Eastern Tropical Pacific are occasionally taken in minor quantities in the intertidal and upper subtidal (Norman et al. 2014).

13.1.6. Fisheries

The Monterey Bay area led octopus catches in California over two decades (1920 to 1944), due to an established trap fishery targeting *E. dofleini*. Octopus traps were cone-shaped wicker baskets made from rattan with a funnel shaped mouth (see illustrations in Bonnot 1932; Phillips 1933). Octopus used to be caught by approximately 30 fishers at rocky areas in 35–55 m of water using jig boats, and landed at Monterey and Santa Cruz. Octopus weighed 10–15 kg, which supplied the low local demand. This has been the only directed octopus fishery in California (Phillips 1933; Duffy 1997; Figure 88).

San Francisco was an important port for octopus landings in the 1940s and 1950s. Since 1972, most octopus were landed in the Eureka area as bycatch in net trawlers for rockfish and flatfish (Cox 1949). Landings again decreased during the mid 1980s and have averaged only 4 t year^{-1} since 2003. Today, most catches (bycatch) occur in Southern California (Cox 1949) (Figure 88). Currently there is no directed octopus fishery in California. Although there have been attempts to assess the fisheries potential of several species using PVC pipes, clay pots and box traps (Engle 1997; Hochberg 1997; Rasmussen 1997), the only large species occurring in this region, *E. dofleini*, is not abundant in California, with the more abundant species being of a much smaller size (Rasmussen 1997).

Prior to the 1980s, octopus caught in the Mexican Pacific were considered bycatch and returned to the ocean, or used as bait for fin fisheries (López-Uriarte et al. 2005). Octopus have, however, been targeted by artisanal fishers since the 1980s. Most are caught by hooka or snorkel during low tide, using 60–80 cm long hooks to catch the octopus (DOF 2018). In the most productive fisheries, however, fishermen use "pangas," 7 m long open boats with outboard engine. In Jalisco the fishery is carried out with one diver per panga using hooka at 5–30 m depths (Aguilar-Chávez 1995), whereas in Oaxaca four to eight free divers per panga catch the octopus at 3–15 m depth (Alejo-Plata et al. 2009). While diving for octopus, fishers usually also spear for finfish and lobsters or collect gastropod or bivalve mollusks (Alejo-Plata et al. 2009); this practice is widespread in Latin America. Diving is also common inside the Gulf of California (Bravo-Olivas 2008; Pliego-Cárdenas et al. 2011; Armendáriz-Villegas et al. 2014) and in some parts of western Baja California peninsula such as Magdalena Bay (Ibarra-García 2012; Sánchez-García 2013) and Guerrero Negro (González-Meléndez 2012).

In western Baja California most fishing is done using baited traps. Pangas can carry up to 50 traps made with wire. They are baited and set along rocky areas at 2–50 m depth during fishing trips that last 8 hours (Rodríguez-García 2010; DOF 2012b; Figure 89). These traps seem to have evolved from lobster traps commonly used in the area. Alternatively, unbaited PVC shelter tubes of 8 cm diameter and 30 cm long are set in shallow waters (González-Meléndez 2012). Chlorine sprayed in octopus shelters at low tide or diving are also methods commonly used in some localities of western Baja California peninsula such as Guerrero Negro lagoon. Although the use of chlorine represents a hazard to the octopus, the consumer, and the environment, fishers still use it due to its low cost and the limited surveillance by authorities (González-Meléndez 2012).

13.1.7. Catches

Although octopus landings are not recorded at the species level in western Mexico, *O. hubbsorum* makes up the majority of the octopus catch at most localities in the tropical Mexican Pacific including the central and southern Gulf of California (López-Uriarte et al. 2005; Markaida and Gilly 2016). Octopus fishing in this region is performed throughout the year although landings peak during summer (CONAPESCA 2016). At Magdalena Bay, *O. hubbsorum* is generally caught in October–November and accounts for up to 80–98%

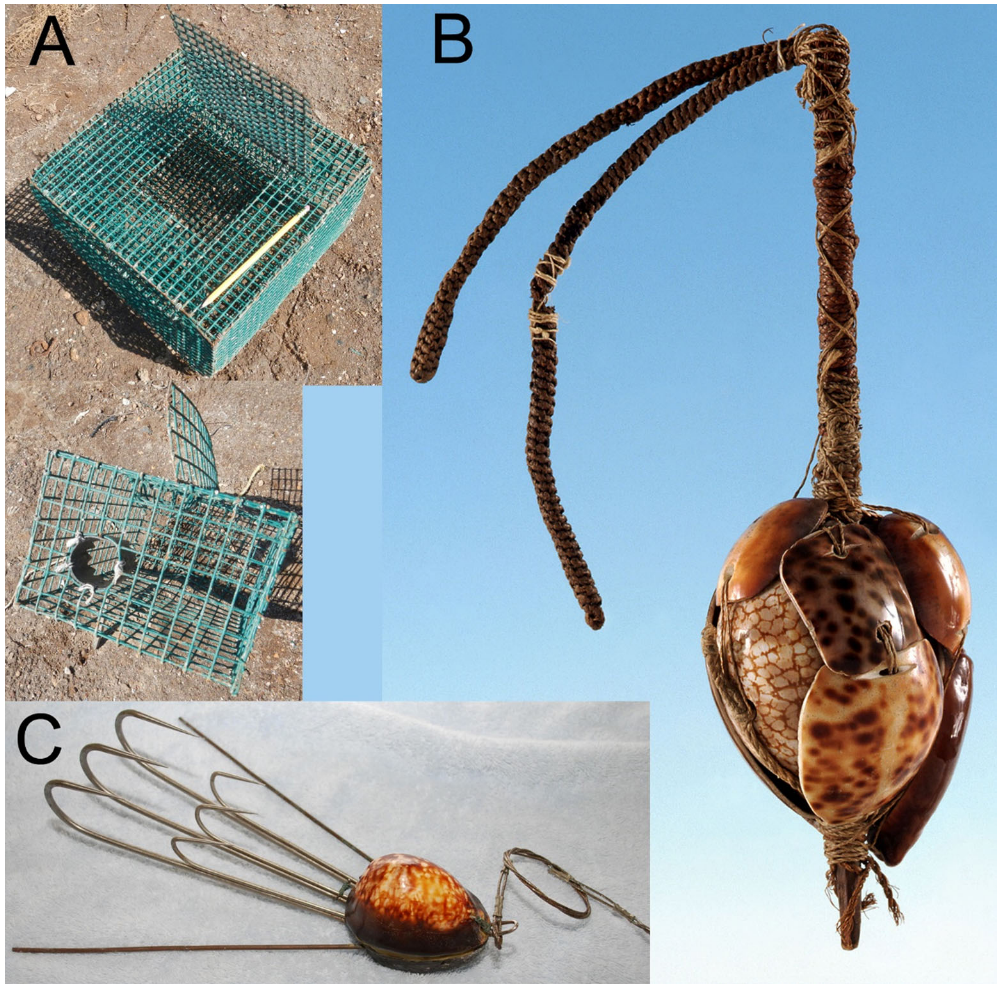

Figure 89. Octopus fishing methods used in the Central-eastern Pacific. (A) Octopus trap from Baja California Sur (Mexico); (B) Traditional octopus lure from Tahiti and the Society Islands (Cook-Forster Collection, Univ. Göttingen); (C) Modern octopus lure with metal hooks from Hawaii (http://www.bdoutdoors.com).

of the average catch of 95 t year^{-1} taken by ~218 small boats (Domínguez-Contreras et al. 2013; Sánchez-García 2013; CONAPESCA 2018). The CPUE for *O. hubbsorum* in Oaxaca was found to average 13 kg day^{-1} (Alejo-Plata et al. 2009), whereas in Jalisco it is approximately 26 kg per fishing trip (López-Uriarte 2006; Espino-Barr et al. 2007).

The species *O. bimaculatus* is caught mostly during March and April off western Baja California peninsula, mainly using traps. Octopus are of great concern to local fishermen as it preys on valuable resources such as lobster and abalone (Rodríguez-García 2010). In the temperate northern Gulf of California, at Bahía Los Angeles, octopus are taken from January to August via scuba diving (Castellanos-Martínez 2008; CONAPESCA 2018). Octopus landed in those regions account for a quarter of all the Mexican Pacific production, ranging 235–404 t year^{-1}. Some *O. bimaculoides* are also taken in coastal lagoons of western Baja California peninsula and represent a minor contribution to catches in Magdalena Bay (Ibarra-García 2012; Monsalvo-Spencer et al. 2013; Sánchez-García 2013; DOF 2018). Some confusion may arise when identifying both species, *O. bimaculatus* and *O. bimaculoides*, in catches from western Baja California peninsula (González-Meléndez 2012).

As landings are not reported at the species level (Domínguez-Contreras et al. 2018), cumulative octopus landings are discussed in this review. Octopus landings remained low in the 1970s; increasing steeply during the second half of the 1980s, from 283 t in 1985 to 1,569 in 1991. Between 1992 and 2017, annual landings fluctuated around 900 t. Landings peaked at over 2,000 t in 2017 and 2018 (Figure 90, CONAPESCA 2018). Mean monthly landings ranged from 145 to 247 t with a peak in summer, from May through July. Jalisco reported most octopus landings during 1980–2007 (204 t year^{-1} corresponding to 30% of the total landed). Since 2008, however, Baja California Sur led catches accounting for 40% of

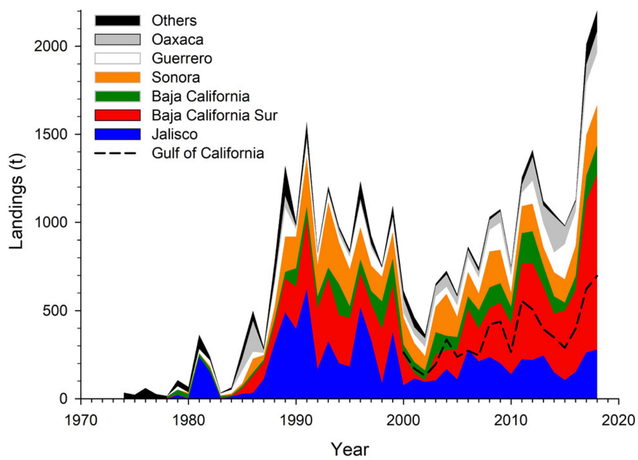

Figure 90. Cumulative octopus annual landings along the Mexican Pacific by state (CONAPESCA 2018).

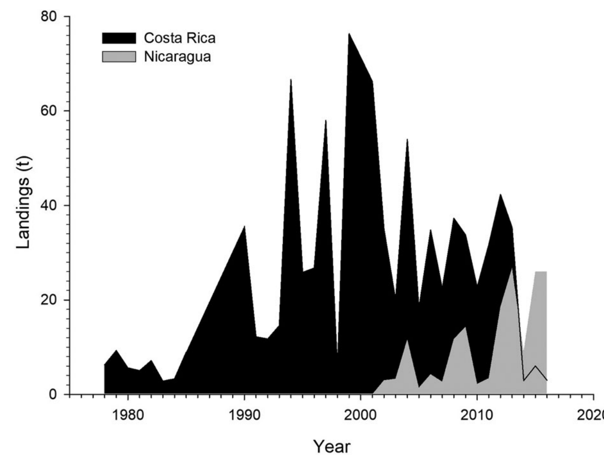

Figure 91. Commercial annual landings for octopus in Costa Rica and Nicaragua. Data from INCOPESCA (2014) and INPESCA (2017).

Mexican Pacific landings. About 30–44% of the western Mexico annual catches occur inside the Gulf of California.

13.1.8. Fisheries management and stock assessment

In Mexico, octopus fisheries management is mainly focused on the octopus fishery from the Yucatan peninsula, with little or no attention to other regions. The only management measure for octopus in the Mexican Pacific concerns the effort through commercial fishing permits. In Baja California Sur there are 103 permits covering 370 fishing boats with 10,300 traps. Guerrero and Oaxaca hold 17 to 19 permits for around 100 boats and 450 fishermen each. Jalisco has 24 permits. Other states account for 15 permits for over 100 boats (DOF 2018).

The need for a normative and a management plan for octopus in the Mexican Pacific is acknowledged by the Carta Nacional Pesquera (DOF 2018). This document assumes that octopus are fished at the MSY in some places but have fishery potential in others. Recommendations have been made to not increase fishing effort, and to avoid the use of chlorine or other chemicals, which are major threats in western Baja California peninsula. Efforts by the Mexican government and NGOs are currently being made to stop the use of chlorine. The use of non-hazardous and selective fishing techniques is being encouraged instead (González-Meléndez 2012).

A recent agreement regulates the octopus fishery in Bahia Los Angeles in the Gulf of California (DOF 2016b), where an annual closure is established from August to November. In addition, MLS of 1,029 g BW for females and 757 g BW for males are established. Capture of spawning females is forbidden.

13.1.9. Economic importance

The value of octopus annual landings from 2014 to 2017 in the Mexican Pacific ranged from US$3.8 to 9.7 million. Baja California Sur landings contributed to 35% of that value followed by Jalisco (19%) and Guerrero (16%) (CONAPESCA 2018).

13.2. Central America

13.2.1. Catches

In Costa Rica octopus are caught almost entirely in the northern province of Guanacaste, where they are taken by free and hooka diving. Catches averaged 33 t year^{-1} since 2000 and most are done from April to August (INCOPESCA 2014). Octopus represent the most important catch by weight in diving landings and are the second most important catch by value after lobster (Naranjo-Madrigal and Salas-Márquez 2014; Figure 91). Most of the catch is consumed locally for subsistence or sold to local restaurants, and is therefore not officially reported (Naranjo-Madrigal, pers. comm., 28 October 2016).

In Nicaragua, octopus landings averaged yearly almost 10 t from 2002 to 2015, with increasing catches since 2012. A third of the catches are done during July and August (INPESCA 2017; Figure 91).

13.3. Polynesia (including Hawaii)

13.3.1. *Octopus cyanea*

This species is commonly known in Hawaii as "He'e mauli" or "day tako" (Young and Harman 1997; Norman et al. 2014). It shows stronger affinities with the genus *Abdopus* and its generic placement remains unresolved (Norman et al. 2014). Most information about the biology of *O. cyanea* is from laboratory studies. It is one of the largest octopods with a maximum BW of 5,000–6,000 g. Growth rates vary, decreasing during its lifetime from 5.8 to 1.3% of BW day^{-1}. The lifespan is 12–15 months from settlement (Van Heukelem 1983b; Kramer 1986; Young and Harman 1997). Males mature at 7–9 months and females mature at 10–11 months at a wide range of BW, i.e., 600–5,000 g. The presence of paralarvae and juveniles in Hawaiian waters throughout the year suggests an extended reproductive season (Van Heukelem 1983b; Young and Harman 1997).

13.3.2. *Callistoctopus ornatus*

The species *Callistoctopus ornatus* (Gould 1852) (previously *O. ornatus*), commonly known as the "white-striped octopus," "night octopus" or "he'e pūloa" (Young and Harman 1997; Norman et al. 2014), is widely distributed in shallow waters (0–10 m) of the Indo Pacific. This species grows up to 500–1,000 g. The small egg size suggests that hatchlings are planktonic. It is a nocturnal species (Houck 1982; Norman et al. 2014). It is harvested on a small scale throughout its range, primarily in local subsistence fisheries. It is sold in fish markets in the central and southern tropical Pacific, but less frequently than *O. cyanea*. It has been historically harvested at night using torches and spears in Hawaii (Young and Harman 1997).

13.3.3. Fisheries

Fisheries in this region are largely based on the day octopus, "he'e mauli" or "day tako" (*O. cyanea*), while small amounts of the "night octopus" or "he'e pūloa" (*C. ornatus*) are also caught (Titcomb 1978; Kramer 1986; Young and Harman 1997). Given the large diversity in this area, other octopus species might be occasionally taken as well (Norman et al. 2014).

The octopus lure is a specialized and complex tool used to catch octopus with handlines in the Pacific. The most extended type is a mere lure colloquially known as the "imitation rat" (Figure 79B). It is barbless and bears several cowrie shell plates tied over a conical stone sinker. A coconut tree root, or other slender stick, is tied to this component. This lure is widely distributed across the Pacific, being found in both Polynesia and Micronesia, where a tale tells about the octopus longstanding hatred of the rat (Beasley 1921; Pfeffer 1995).

Another type of lure includes a hooking device and often a distinctive coffee-bean-shaped sinker. It is known from the Marquesas and mostly from Hawaiian Islands, where it reached the most complex and varied form (Pfeffer 1995). In Hawaii the "kilo" (watching) method targets octopus looking into clear waters from a canoe at shallow bottoms ∼11–18 m depth. Visibility was enhanced by spitting some chewed candlenut (*Aleurites moluccanus*) on the sea surface. The kilo or stone lure, "okilo he'e," was made with a stick and a hook, a sinker stone and a tuft of ti (*Cordyline fruticose*) leaves. Once an octopus burrow was spotted, the lure was lowered with a line to the burrows inhabited by octopus, which would grab the lure. By jerking the line, fisherman could impale the octopus on the hook (Young and Harman 1997; Pfeffer 1995).

A second handline method traditionally used was the "lu he'e". The lure was made with the same materials used above, but with the addition of one or two cowrie shells (*Cypraea* spp.) on the side opposite to the stone sinker. It is used only in exceptionally deep waters of 80-fathom depth. The cowries and stone sinkers were carefully chosen and different cowries were used depending on the time of day. The cowrie (wife) and the sinker (husband) represented a dancing ritual to which the octopus were attracted when the fisherman jerked the line up and down. These fishing methods have changed little in modern times, although diving masks have replaced candlenut chewing; gas or electric lamps have replaced torches, and metal has replaced the hardwood for spears and bones for hooks (Young and Harman 1997; Pfeffer 1995; Figure 79C).

Diving for octopus is widespread in the Polynesia. Fuka (1979, quoted in Bell et al. 1994) noted that due to the time and effort needed to prepare the traditional lure "makafeke," fishermen from Tonga have abandoned this technique and are turning to spear guns and free diving equipment as the more popular method for octopus fishing.

A clear gender division occurs in the artisanal and subsistence fisheries of Oceania (Chapman 1987). Octopus are also traditionally speared by women in shallow waters in Hawaii, and torches used at night to catch *C. ornatus* (Kramer 1986; Young and Harman 1997). Women from American Samoa gathering shellfish, octopus, seaweed, and small fish on the reef, while men fish by snorkeling, diving with a spear or angling with a rod (Armstrong et al. 2011). Women in Tonga and Tokelau use metal rods to glean for octopus at low tide in the reef, while the men use

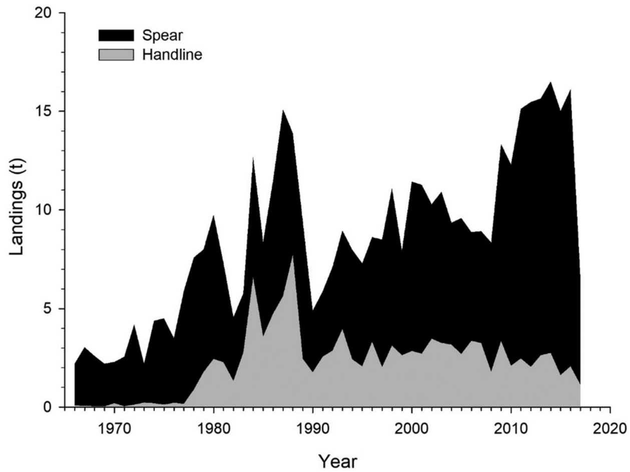

Figure 92. Cumulative commercial annual landings for octopus in Hawaii by fishing gear. Data from WPRFMC (2017).

lures inside the lagoon (Bataille-Benguigui 1988; Tiraa-Passfield 1999). In Fiji, women use cowrie lures to catch octopus in shallow waters (Wright 1994). Some octopus are also taken as bycatch in lobster traps (Kramer 1986; Young and Harman 1997).

13.3.4. Catches

Only three political entities from western Polynesia (Hawaii, American Samoa and Cook Islands) report octopus catches to the FAO (2016). In Hawaii 24 t were landed in the year 1900, half by spears, a quarter collected by hand and another quarter using lines (lures). Half of the catches were made in Oahu (Cobb 1902). In 1903, approximately 44 t were reported with the same pattern of distribution (Cobb 1905). Although catches reported since 1966 did not exceed 16 t year^{-1} (Figure 92), there is no requirement to report subsistence and recreational catches, which are carried out mostly with spears and which are thought to vastly exceed commercial catches. Commercial catches used to be equally divided between octopus caught by lures and by spears. Although the catch with handlines has remained stable, spear-fishing landings have increased in recent years probably due to the introduction of scuba diving (WPRFMC 2018). Largest catches occur during fall (Kramer 1986; Young and Harman 1997). Official landing records do not distinguish between octopus species until the year 2004, when *O. cyanea* was recorded, which accounts for virtually all of the catches.

The Cook Islands reported annual catches in the 30–80 t range since 1970, while American Samoa reported 4 t in the entire series (FAO 2016).

Reconstructed estimations are available for a few entities of Polynesia: Samoa, American Samoa, Kiribati and Niue (New Zealand). Estimated octopus landings from Samoa are particularly large, averaging 1,458 t year^{-1} this century. This figure is comparable to annual landings in western Mexico, the current leader in the whole Eastern Central Pacific. The subsistence fishery (Lingard et al. 2012; Figure 93A) accounts for 93% of the total catch.

Anecdotal landing records have been found in some regional reports. The species *O. cyanea* accounts for 2.2 t annually in the subsistence fisheries of American Samoa, where it represents 5% of all the catches. This species is caught with spears or by hand (Craig et al. 1993, 2008). This figure almost doubles reported octopus annual landings (FAO 2016) for this territory. The reconstruction of unreported catches is still, however, much larger (Pauly and Zeller 2015). A sharp decrease of subsistence harvest occurred from over 100 t year^{-1} in the 1950s to barely three t year^{-1}. Recreational catches ranged from 20 to 13 t/year^{-1} and currently they constitute most of the share (Figure 93B). Reconstructed catches from Kiribati, mainly subsistence, shows a sharp decrease in octopus landings from 77 t year^{-1} in the 90s to 3.6 t year^{-1} during this century (Pauly and Zeller 2015; Figure 83C). Reconstructed unreported subsistence catches from Niue have steadily fallen since the 50s from 1.4 to 0.4 t year^{-1}. Three surveys in the early 1990s estimated landings of 3.7–24.1 t year^{-1} at two landing sites at Nukualofa, Tonga, with a worth of T$12,500–30,000 (Bell et al. 1994; Vaikona et al. 1997).

13.3.5. Fisheries management and stock assessment

During much of the early 20th Century, customary practices in Hawaii controlled many aspects of fishing activity. A closed season was established in octopus habitats, beginning in January or February and lasting four to six months. During this closed season, women were forbidden to go to the beach or to fish with nets; and after the season spear fishing was again allowed (Buck 1964). According to Kamakau (1961, quoted in Maly and Maly 2003), it was taboo to fish in the month of "Kaelo" [May–June], and in other places in "Kaulua" [June–July]; with the taboo lasting four, five, or even six months in some places. Octopus could only be speared when the rainy, winter months "ho'oilo" began, while "Welo," the sixth month, was the time to catch octopus with lures.

Currently in Hawaii there is a minimum size of one pound for both commercial and recreational take

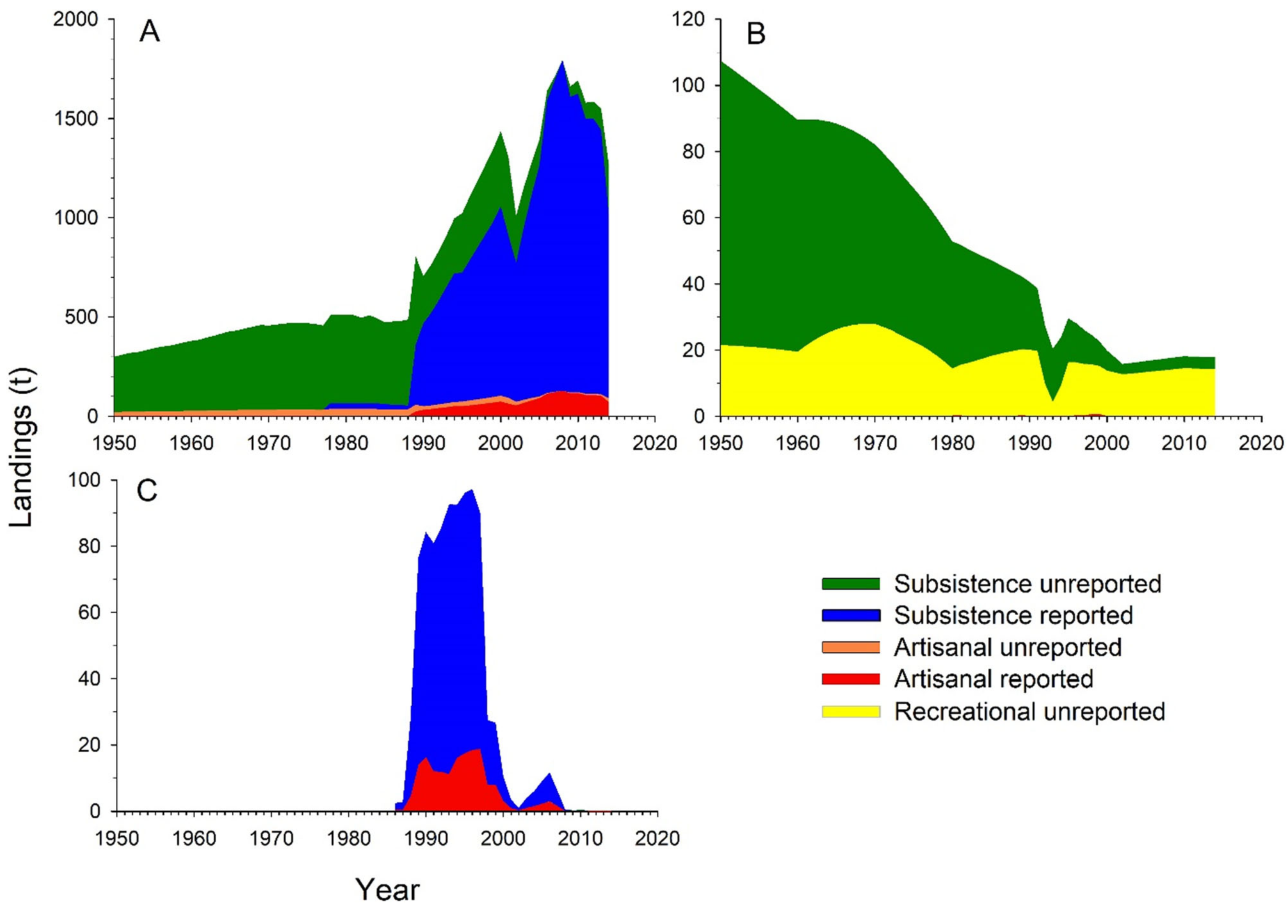

Figure 93. Cumulative reconstructed annual landings for octopus by fishing sector and reported status for (A) Samoa, (B) American Samoa and (C) Kiribati. Data from Pauly and Zeller (2015). Note that vertical scales vary between graphs.

of octopus; however, there is no closed season nor bag limits (Young and Harman 1997). Permits for spear fishing average 66 while those for handline are 23 for the last ten years (WPRFMC 2018). In the rest of Polynesia there is no MLS (Bell et al. 1994).

Management plans for octopus in Tonga include banning of scuba and hookah to capture octopus, limiting "domestic" consumption exports, legislation to protect octopus burrows, initiation of studies on taxonomy and life history, encouraging a commercial, and undertaking public awareness activities (Anonymous 1995).

13.3.6. Economic importance

Octopus fisheries in Polynesia are characterized for being more important as subsistence and recreational fisheries than commercial, and catch values are seldom considered. Octopus fishing in Hawaii is an old tradition that involved ceremonial associations, careful confection of gears and ritual regulation rules (Maly and Maly 2003), similar to other Polynesian islands. For example, in the Cook Islands a mother breastfeeding a child was not allowed to eat octopus (Mokoroa 1981). The remains of octopus lures (dated as at least 2,500 years old) have been found at Tonga (Connaughton 2007) and octopus lure sinkers are the most abundant relics of the Old Stone Age (Brigham 1902). These stone sinkers have proved to have archeological value for studying Polynesian culture, as their different forms and distribution allow tracing the migrations of these people through the Pacific (Lavondes 1971). In addition to being a significant age-old practice, women play a main role in these subsistence fisheries for octopus (Voss 1973; Kronen and Malimali 2009; Gillett 2011; Norman et al. 2014). Octopus are also commonly used as bait in other fisheries (Bell et al. 1994).

14. South-Eastern Pacific

Octopus fisheries in the Southeast Pacific Ocean (or FAO major fishing area 87) probably started in pre-Hispanic times (Guerra et al. 1999; Markaida and Gilly 2016). During the late 80s and early 90s octopus' exploitation began in northern Chile and Peru, being operated and marketed as the European species *O. vulgaris*, without studies on the identity of the species being exploited (Ibáñez et al. 2010). The study of

Guerra et al. (1999) determined that this species from northern Chile and Peru was instead the "Changos' octopus" *O. mimus*, with further molecular studies confirming the identity of the species (Söller et al. 2000; Warnke et al. 2000, 2004).

In Latin America, octopus fisheries are less developed than squid fisheries, representing only about 8% of world catches (Markaida and Gilly 2016). Octopus catches in the Southeast Pacific are concentrated in Chile and Peru. In Ecuador, Peru and Chile, the only commercially exploited species is *O. mimus* (Pliego-Cárdenas et al. 2016; Markaida et al. 2018), whilst in southern Chile and the Argentinean Patagonia, *E. megalocyathus* is the only species commercially exploited. Both are caught by small-scale operators, and sold in local markets, although most of the catch is exported to Asia and Europe. Other benthic octopus such as *Muusoctopus eicomar* (Vega, 2009), *Muusoctopus longibrachus* (Ibáñez, Sepúlveda, and Chong, 2006) and *Graneledone boreopacifica* (Nesis, 1982) are common as bycatch in the crustacean fisheries in Chile (Ibáñez et al. 2006, 2011, 2012, 2016). Artisanal fishers occasionally catch the small-sized octopus *R. fontaniana*, but despite the species does not represent a commercial resource (Osorio et al. 1979, Ibáñez et al. 2008), it constitutes an important aquaculture candidate in Chile as its small size ("baby octopus") is very attractive for Asian and European markets (Uriarte et al. 2011).

14.1. *Octopus mimus*

This species is distributed along the east coast of South America from northern Peru to Caldera, Chile (4°S–25°S) (Ibáñez et al. 2009). This species inhabits rocky substrata and is common from intertidal reefs to at least 30 m depth, where it seeks cover in crevices and under boulders (Guerra et al. 1999). Genetic studies confirmed the presence of this species in Ecuador (Pliego-Cárdenas et al. 2016).

The evaluation of *O. mimus* diet in Peruvian waters showed 18 prey items, predominately crustaceans over other taxonomic groups such as mollusks and echinoderms (Cardoso et al. 2004). Recently, Cisneros (2016), based on analysis of 741 stomachs of *O. mimus* captured in Callao between 2013 and 2014, found a higher number of items (>30) in the diet, which consisted mostly on Porcellanidae and Xanthidae crabs. Furthermore, the diet was similar between sexes, with some important prey species being highlighted, including *Petrolisthes desmarestii* in summer–autumn and *Allopetrolisthes angullosus* in winter–spring. In Chile *O. mimus* feeds mostly on grapsid crabs and bivalve mollusks, although up to 25 prey items have been identified (Cortéz et al. 1995a). The drilling ability of this species on bivalve shells has also being documented (Cortéz et al. 1998).

Reproduction takes place all year round with a peak during austral spring–summer (October–February) (Cortéz et al. 1995b, Nacarino 1997; Cardoso et al. 2004). The oocyte development comprises eight stages during oogenesis (Ishiyama et al. 1999). Gonadal maturation and size at maturity is achieved at smaller sizes in males than females (Zúñiga et al. 1995; Nacarino 1997; Ishiyama et al. 1999; Villegas and Tafur 2000). In northern Chile males reach their sexual maturity at 200 g and females at 1,200 g of BW (Olivares et al. 1996). Females mature at a 1,000–1,200 g BW, whereas males mature at 500–800 g BW (Markaida et al. 2018). The egg sizes range between 1.8 and 2.2 mm in females from Peru (Baltazar et al. 2000) and between 2.3 and 3.2 mm in females from Chile (Guerra et al. 1999). Fecundity can reach from 200,000 to 400,000 eggs in Chile (Guerra et al. 1999). The embryonic development is inversely related to water temperature, ranging from 37 to 66 days at 19.7 °C and 17 °C, respectively (Warnke 1999, Baltazar et al. 2000). Paralarvae swim actively after hatching, with TL ranging from 0.9 to 2 mm (Baltazar et al. 2000).

14.1.1. Stock identification

Genetic analyses using microsatellites and mitochondrial markers have been independently carried out in specimens from Chile and Peru, with no genetic structure being found (Galleguillos et al. 2010, Pardo-Gandarillas et al. 2018).

14.1.2. Catches

The *O. mimus* catches in Peru and Chile show similar trends (Figure 94). In the Peruvian coast catches are common from 3°S to 18°S. Octopuses are landed all year round, although with a high spatial and temporal variation. Specifically, during 2013–2015, the highest monthly landings (>80 t) were recorded in Ancash (9° S) and the lowest in La Libertad (8° S), Tacna (18° S) and Tumbes (3° S). Landings of *O. mimus* in Chile (first recorded in 1978 under the name *O. vulgaris*) (Rocha and Vega 2003), increased over 1,000 t since 1983 and reached 4,877 t in 1998 (Figure 94). This fishery is concentrated in Regions XV, I, II, III (18°S–27°S), being the most important ports Iquique, Tocopilla and Antofagasta (Rocha and Vega 2003). Annual landings during 1993–2014 varied between

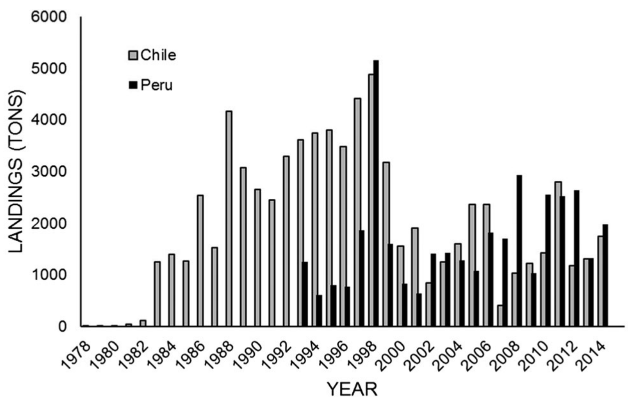

Figure 94. Landings (t) of *Octopus mimus* in Peru and Chile during 1978–2014.

602 and 5,153 t, and had a mean value of 1,686 t. The largest landings were recorded in 1998, coinciding with the El Niño 1997–98 event (Castilla and Camus 1992; Defeo and Castilla 1998) (Figure 94). In addition to continental landings from northern Chile, *O. mimus* and *O. vulgaris* have also been genetically identified in oceanic islands at the Juan Fernández Archipelago (33°S, 78°W; ~600 km from continental Chile; see Amor et al. 2017; Cifuentes-Bustamante 2018), where octopus small-scale fishery has been developed from around the year 2000. Up-to-date records at the main island, Robinson Crusoe, suggest annual landings that range from 1 to 3 t in the last three years (SERNAPESCA 2015, 2016, 2017); however, these values may possibly correspond to a combined catch of the two species sharing shallow water environments around the island, *O. mimus* and *O. vulgaris* (S.A. Carrasco; unpublished data). Information on proportions of both species in artisanal landings is not yet available, but ongoing studies are unveiling important life-history traits of both species, including reproductive periods, spawning habitats, egg and hatching traits, among others (S.A. Carrasco; unpublished data).

14.1.3. Fisheries/fishing methods/fleet

In Peru, there is no fleet dedicated exclusively to *O. mimus*, with the artisanal fishery consisting of multispecies boats (<15 m). Fishing for this resource is mainly carried out by scuba divers. In Chile, the fishery occurs mostly intertidally, with octopus being caught with gaffs (by fishers known as "pulperos"), and subtidal collection occurring in the surf zone by snorkel divers and in deeper waters by hookah divers (Defeo and Castilla 1998). In the 90s, the octopus fishery of northern Chile was composed by over 2,000 small-scale fishermen, working in boats of less than 15 m length (Rocha and Vega 2003). In Robinson Crusoe Island, octopuses are caught by no more than 10 snorkel divers at depths ranging from 1 to 15 m. As in northern Chile, boats do not exceed the 10 m length. In Ecuador octopus is taken by free diving or hookah (Markaida et al. 2018), while some intertidal collection exists.

14.1.4. Fishery management and stock assessment

In Chile, the minimum catch size is 1 kg (Exempt Decree No. 137 of 1985) (Subpesca 2011). The Chilean government (Exempt Decree No. 254 of 2000) established two reproductive biological closed seasons for the octopus resource (Family Octopodidae) in northern Chile (i.e., Regions I to IV) from 1 June to 31 July each year, and between 1 November to 28 February of the following year, both dates inclusive (Subpesca 2011).

Population assessment for *O. mimus* in the Peruvian coast has not been carried out; however, there is a constant monitoring of landings, effort, size structure and biological aspects of the species along the Peruvian coast. There is also a minimum catching size of 1 kg, but no catch quotas or biological reference points.

In Ecuador the octopus fishery has no official status as there are no catch records or management measures (Markaida et al. 2018).

14.1.5. Economic importance

In northern Chile, octopuses are one of the most important resources after the Chilean abalone (*Concholepas concholepas*), and prices between 2005 and 2010 fluctuated from 1.2 to 2.4 USD by kilogram of octopus (Subpesca 2011). During 2008–2012, *O. mimus* caught in Peru was exported for a value of 31 million dollars to 29 countries, 6 of which accounted for 90% of exports. It is also marketed and consumed internally in both countries Peru and Chile.

14.2. *Enteroctopus megalocyathus*

As previously mentioned, *E. megalocyathus* is distributed throughout the southern coast of South America, from Chiloe Island (~42°S) in the southeast Pacific Ocean (Rocha 1997; Ibáñez et al. 2009) to San Matías Gulf (42°S) in the southwest Atlantic Ocean (Ré 1998a). It is a sub-Antarctic species, inhabiting rocky reefs from lower intertidal zone to 170 m depth in Argentina (Ortiz 2009) and up to 220 m in Chile (Osorio et al. 2006).

It is considered an important subtidal predator in southern Chilean waters (Ibáñez and Chong 2008), feeding primarily on brachyuran and anomuran crustaceans, fish and conspecifics (Ibáñez and Chong 2008). Whilst dietary composition depends on octopus size and fishing area, it does not depend on octopus sex (Ibáñez and Chong 2008). Cannibalistic behavior is common (Ibáñez and Chong 2008), especially on conspecific eggs, which may play an important role when food is scarce (Ibáñez and Chong 2008; Ibáñez and Keyl 2010). In addition, *E. megalocyathus* predators include marine mammals such as sea lions (*Otaria flavescens*, Alonso et al., 2000) and dolphins (*Lagenorhynchus australis*, Schiavini et al., 1996), penguins (Schiavini and Rey 2004; Schiavini et al. 2005), elasmobranches (Laptikhovsky et al. 2001; Alonso et al. 2002) and teleost fishes (*Salilota australis*, Arkhipkin et al. 2001).

This species has a large size, reaching approximately 1 m TL and 4–5 kg BW (Ré 1998a; Chong et al. 2001), although individuals with maximum weights of 8 kg have been reported (Olguin et al. 2014). It reaches maturity at 149 mm of ML in both sexes in Chile (Chong et al. 2001), although differences among sexes were found along the Argentinean coast (male, 158.8 mm; female, 135.3 mm; Ortiz et al. 2011). The sex ratio on fishing grounds was 0.87:1 with a higher proportion of females (Ortiz et al. 2011). In Argentina, sexual maturity has a strong seasonal component, with maximum reproductive peaks from middle spring to late summer, although with few reproductive individuals in winter (Ortiz 2009). Mating can depend on octopus' size as reported under laboratory conditions (Gutiérrez et al. 2012). In addition, mating may occur mainly in deeper waters of fishing grounds given the more stable environmental conditions (e.g., bottom sea temperature) (Ortiz et al. 2011). The breeding season can extend from summer to late winter on the Atlantic coast (Ortiz et al. 2006; Ortiz et al. 2011), and between December to February in Chile (Chong et al. 2011).

Potential fecundity is highly variable (Chong et al. 2011), ranging from 1,429 to 6,427 oocytes (Ortiz et al. 2011). Likewise, absolute fecundity can range from 1,469 to 5,000 eggs in the wild (Ortiz et al. 2006) and under captivity (Uriarte and Farías 2014) conditions, respectively. Feeding is absent during maternal egg care as demonstrated in controlled conditions (Farías et al. 2011). Eggs (10.7 mm TL) and paralarvae (7–12.8 mm ML) are large (Ortiz et al. 2006; Pardo-Gandarillas et al. 2016), with a free-swimming planktonic stage after hatching (merobenthic species, Villanueva and Norman 2008). A suprabenthic mode of life was suggested, however, as both planktonic (e.g., swimming) and benthic (e.g., crawling) behaviors were observed in newly hatched individuals (Ortiz et al. 2006). Embryonic development takes around 150–180 days at 12 °C under controlled conditions (Uriarte and Farías 2014). Additionally, natural mortality was reported between 1.9 and 2.1 year^{-1} (Chong et al. 2001).

14.2.1. Stock identification

No stock identification has been undertaken, although recent studies have suggested two populations for both Pacific and Atlantic coasts (Pardo-Gandarillas 2012).

14.2.2. Catches

The first official octopus landing in Southern Chile occurred in 1984 (1 t, Olguín et al. 2014), although these were identified as *O. vulgaris* (Rocha and Vega 2003). The *E. megalocyathus* fishery landings were continuously reported from 1991 onwards (Rocha and Vega 2003; Olguin et al. 2014), being identified in fishery statistics as "Southern octopus" in Chile from 2007. In addition, the fishery mainly occurs in X region (~40°S–42°S) in Chile (99% total catches), although it is also existent in southern regions (XI and XII regions, ~42°S–54°S). Major landings in X region come from Quellón, Dalcahue, Ancud, San Rafael and Queilen (Olguín et al. 2014) (Figure 95). A total of 10,282 t were landed between 1998 and 2014 in Chile, representing around 25% of the total octopus Chilean landings. Inter-annual variability in octopus catches is evident (Figure 95), with maximum peaks in years 2003 (768 t; 38% total octopus Chilean landing), 2008 (1,738 t; 62%) and 2012 (976 t; 44%). Additionally, octopus CPUE in X region in Chile is highly variable, ranging from 5 to 24.5 kg h^{-1} between 1995 and 2012 (Olguín et al. 2014).

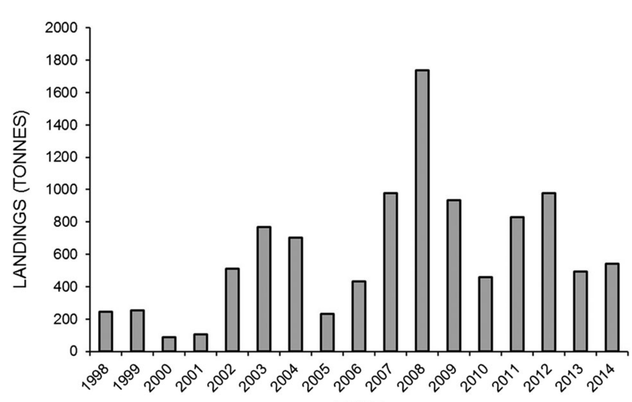

Figure 95. Landings (t) of *Enteroctopus megalocyathus* in Chile during 1998–2014.

14.2.3. Fisheries/fishing methods/fleet

This species supports small-scale fisheries in Chile (Rocha and Vega 2003; Olguín et al. 2014) and Argentina (Ré 1998a; Ortiz et al. 2006). In both countries, the red Patagonian octopus is harvested by free diving or by hookah using gaffs to extract octopuses from crevices and holes located in isolated rocky outcrops or in submerged limestone platforms (Ré 1998a; Ortiz et al. 2006). Although smaller, an intertidal rocky fishery exists along the Patagonian Atlantic coast (Ortiz et al. 2011). Previous attempts to fish by using octopus traps were not successful in Chile. For the 1995–2012 period, a total of 1,578 divers and 1,151 boats extracted this resource in Chile (Olguín et al. 2014).

14.2.4. Fishery management and stock assessment

Fishing closure extends from November 15 to March 15 in Chile (D.S N° 137/85), with a minimum catch size of 1 kg (D.S N° 137/85) ibeing implemented. The Chilean Fishery Institute (IFOP) has identified this resource as highly exploited (Olguín et al. 2014), although no fishery management has yet been developed in this country.

14.2.5. Economic importance

Historically, the *E. megalocyathus* fishery has not been identified as a key benthic resource in Southern Chile, although in recent years it has increased its participation in benthic landings around the X Region (Olguín et al. 2014). Regarding the commercialization, octopus price varies across years, with prices ranging from 2.55 to 1.13 USD between 2002 and 2012 in the X Region.

14.3. *Robsonella fontaniana*

This small-sized octopus, also known as "pulpito," is an endemic benthic species distributed along the entire coastal tip of South America, from Peru (6°S) to Cabo de Hornos in Chile (55 °C) in the Pacific Ocean, and from Puerto Madryn (41°S) to the south in Argentina in the Atlantic Ocean (see Ré 1998a; Ibáñez et al. 2008; Uriarte and Farías 2014). This species commonly inhabits rocky reefs, over hard substrata, crevices or underneath boulders; although some records also suggest the use of sandy habitats to a lesser degree. The bathymetric distribution extends from the intertidal to the subtidal zone, up to 225 m deep (reviewed by Ré 1998a; Ibáñez et al. 2008; Ortíz and Ré 2011). In central Chile (∼32°S), this species inhabits shallow subtidal kelp forests of *Lessonia trabeculata* and *Macrocystis pyrifera*, where it can be usually found beneath boulders or perfectly camouflaged with red-Colored crustose algae. Specimens inhabiting sandy substrata have also been recorded at these latitudes, although usually in association with anthropogenic structures such as wharfs, concrete moorings and benthonic fishing gear (e.g., crab traps) (S.A. Carrasco; unpublished data).

It is an important intertidal and subtidal predator consuming several species of crustaceans, fish and polychaetes. Nonetheless, observations suggest that this species possesses a selective hunting behavior and a specialized diet, with decapod crustaceans being their preferred prey item in the field (e.g., *Cancer setosus*, *Caridea* megalopa, Alpheidae) and in the laboratory (e.g., *Emerita analoga*, *Cyclograpsus cinereus*, and small-to-medium sizes *Rhynchocinetes typus*, *Homalaspis plana*, *Taliepus* spp., *Petrolisthes* spp.) (Ibáñez et al. 2009; S.A. Carrasco; unpublished data). Similar to previous observations for the northern Chilean octopus *O. mimus* (Cortéz et al. 1998), *R. fontaniana* is also able to drill bivalve preys when the preferred food items are not available. Feeding experiments in the laboratory have shown that the mussel *Perumytilus purpuratus* can be perforated and consumed, suggesting that other small bivalves present in the field (e.g., *Semimytilys algosus*, *Brachidontes granulata*) could also be incorporated as a food items (S.A. Carrasco; unpublished data).

Although benthic octopuses constitute an important prey for several species of mammals, birds and fish, their overall role in the marine environment as well as their significance as food resource for higher trophic levels is only recently being understood (reviewed by Piatkowsky et al. 2001). This is not the exception for *R. fontaniana*, as to date, there are only a few observations regarding the presence of this species in the stomach contents of mammals (i.e., the dolphin *Cephalorhynchus commersoni*) (Ré 1998a), teleost fishes (i.e., the conger eel *Genypterus chilensis*) and elasmobranches (i.e., the cat shark *Schroedericthys chilensis*) (C.M. Ibáñez; pers. obs.).

This is a small-sized octopus, with 273 and 209 mm TL for males and females, respectively. Arms correspond to 70% of the TL. DML can reach up to 69 mm in females and 68 mm in males (Ré 1998a; Ibáñez et al. 2008). Individuals do not exceed 200 g (Uriarte et al. 2010). No maturity stages have yet been assigned to particular size/weight classes, and additional information regarding field reproduction patterns (e.g., maturity, seasonality, reproductive peaks) is still lacking.

Although knowledge of the reproductive biology of *R. fontaniana* is limited, laboratory observations on mating behavior suggest that females do not copulate at small sizes, accepting males reproductive interactions only at ~43 mm ML and ~39 g in weight (S.A. Carrasco; unpublished data). Mating behavior can extend around 120 min under laboratory conditions, occurring mostly by mounting (Briceño 2004). Females may spawn from 4 to 8 weeks after mating (S.A. Carrasco; unpublished data) usually at sizes ranging from 59–145 g (Briceño 2004; González et al. 2008). Fecundity can reach up to 2,500 eggs per female, with egg sizes around 4.5 mm length and 3.0 mm width (see González et al. 2008; Ortíz and Ré 2011). The embryonic development varies from 83 to 103 days (González et al. 2008; Uriarte et al. 2009), but is highly dependent on thermal conditions (i.e., 74 days at 12 °C; 39 days at 14 °C; 91 days at 8 °C; reviewed by Uriarte and Farías 2014). After hatching, paralarvae (~3–4 mm ML) become competent predators, reaching the juvenile stage in 70 days when fed with appropriate food in controlled laboratory conditions (for details see González et al. 2008; Ortíz and Ré 2011; Uriarte et al. 2010). Despite the wide distribution range of the species, few studies have provided information on field-collected early life-history stages (Carrasco et al. 2012; Pardo-Gandarillas et al. 2016), highlighting the necessity to improve our understanding on the ecological role and potential economic importance of *R. fontaniana* in coastal areas along the Pacific and Atlantic coasts.

14.3.1. Stock identification

Genetic studies carried out in paralarvae *R. fontaniana* from southern Chile evidenced that these specimens shared the same haplotype with adult individuals collected from northern, central and southern Chile, suggesting that this species has a high dispersal potential and no genetic structure along the Pacific coast (see Pardo-Gandarillas et al. 2016).

14.3.2. Catches

There are no official records of landings for *R. fontaniana*. Field observations in shallow subtidal kelp-forests habitats in central Chile suggest that the CPUE by SCUBA diving is approximately 4–6 ind. h^{-1} per diver, although the proportion of sizes and sexes might vary (S.A. Carrasco; unpublished data).

14.3.3. Fisheries/fishing methods/fleet

This pigmy species does not support commercial fisheries through the distributional range. On the northern and central Patagonia, Atlantic coast, this species may be occasionally caught intertidally (i.e., hand-collected) and misidentified by fishermen as *O. tehuelchus* or as juvenile *E. megalocyathus*, both species of economic importance (Ré 1998a; Ortiz and Ré 2010). Additional records in southern Chile also suggest that adult specimens can be caught using cylindrical polyethylene traps of 5–7 cm diameter and 25 cm length (González et al. 2008). None of those collections, however, have been reported for commercial purposes.

14.3.4. Fishery management and stock assessment

No management or stock assessment has been undertaken for this species.

14.3.5. Economic importance

The commercial value for this species as "baby octopus" is recently being explored in Chile, and several studies have evaluated the feasibility of aquaculture in controlled conditions (see González et al. 2008; Uriarte et al. 2010; Uriarte et al. 2011). The growing interests of global markets for obtaining healthy and safe food may position baby octopuses such as *R. fontaniana* as important coastal resources, suggesting intensification of catches and increased interest for aquaculture production. Understanding the ecological role of *R. fontaniana* and its trophic or non-trophic interactions is therefore crucial before the development of a well established fishery, facilitating decisions on fishing methods, minimum fishing sizes, reproductive closures, among others.

15. Interactions between octopus fisheries and ecosystems

In a review of the squid fisheries of the world, Arkhipkin et al. (2015) listed two types of interactions affecting squid fisheries. These were ecosystem dynamics affecting fisheries, and fisheries (if conducted on a large scale) affecting and changing, sometimes irreversibly, existing ecosystems. Similar types affect the octopus fisheries around the world, and the reader is referred to Arkhipkin et al. (2015) for full details of these interactions. Here we discuss one way in which to address these interactions, which is the Ecosystem Approach to Fisheries (EAF), which has gained recognition in recent years (Cochrane et al. 2004). It is especially relevant to octopus fisheries due to the extensive use of bottom trawls in targeting this group of cephalopods (and resultant damage to the substrate), and the substantial problem of unreported catches. As previously discussed, non-reporting of catches is especially rife in FAO Area 34 where >30% of the global octopus catch is caught, and with the *O. vulgaris* fishery here being one of the worlds' most important octopus bottom trawl fisheries (Balguerías et al. 2000).

A study conducted on the impacts of hake directed trawling on the benthic environment in South African waters suggested that intense trawling is at least partly responsible for the significant differences observed in benthic infauna and epifauna occurring in heavily and lightly trawled areas (Sink et al. 2012). It was found that the abundance, biomass, diversity and community composition differed significantly at heavily versus lightly trawled sites, with epifauna (particularly larger, slower growing epifauna) showing a stronger response than infauna (Sink et al. 2012, Figure 96). This reduced epifaunal species diversity, abundance and biomass was considered likely to impact on ecosystem functioning, specifically in terms of bioturbation and its associated functional role in such habitat types (Sink et al. 2012).

Figure 97 is a good illustration of changes to the sea bottom appearance after repeated trawling using bottom trawls.

15.1. Ecological analysis of the ecosystem change as a tool for EAF

There are many excellent ecological studies on octopus, covering a wide range of topics, including influence of various environmental parameters (also climate change) on the life cycle of octopods (e.g., Faure et al. 2000; Caveriviere and Demarcq 2001; Otero et al. 2008; Caballero-Alfonso et al. 2010; Andre et al. 2009, 2010; Vargas-Yanez et al. 2009; Garofalo et al. 2010). There is an even larger number of population dynamics and stock assessment studies (e. g. Arreguín-Sánchez et al. 2000; Katsanevakis and Verriopulos et al. 2009; Leporati et al. 2009; Herwig et al. 2012). In many cases, however, data of these studies and their conclusions are not integrated into EAF, and into fisheries management in general. In reality EAF is not an easy approach, but there are current efforts to include octopus fisheries, for example *O. cyanea* in Tanzanian waters (Guard 2009), and a general octopus fisheries project in the western Indian Ocean (Rocliffe and Harris, 2015). As both of these projects are aimed towards Marine Stewardship Council certification in the longer term, such a holistic approach is mandatory. A large regional case study, conducted in Europe (Paijmans et al. 2013) provide a further example of an EAF-related initiative driven by "the Marine Strategy Framework Directive (MSFD)," which is a thematic strategy for the protection and conservation of the marine environment with the overall aim of promoting sustainable use of the seas and conserving marine ecosystems.

16. General discussion

The current review highlights the large number of countries targeting Octopus worldwide (some 90 countries according to FAO catch statistics for the current century), supporting innumerable coastal communities. Indeed we are harvesting more octopus than ever before supporting both our growing population and growing appetite for seafood (FAO 2018). Octopus fisheries are likely to continue to grow in importance and magnitude as many finfish stocks are either fully or over-exploited. Despite this increasing reliance on octopus as a source of food, we still know relatively little about the octopus species we harvest; in fact, some harvested species have even yet to be described (Norman and Finn 2014).

Given the critical role octopus play in marine ecosystems and their importance in supporting coastal livelihoods, there is a growing need to understand more about these complex animals. We do know that some octopus populations are increasing in abundance (Doubleday et al. 2016), despite exploitation and environmental change. This is not too surprising, given octopus and other cephalopods are highly adaptable and responsive to change (Rodhouse et al. 2014). In fact, octopus may become important sources of food in the future as longer-lived, less adaptable species struggle to compete in a rapidly changing environment (Doubleday and Connell, in press), and/or struggle to withstand continuous pressure from fisheries (Pauly et al. 1998). Species like octopus, however, are not immune to overexploitation and need to be managed sustainably like any other natural resource. Indeed, this review highlights several examples of overexploited populations, such as *O. vulgaris* in the Mediterranean (Quetglas et al. 2015) and *O. cyanea* in Rodrigues (Sauer et al. 2011).

16.1. Management of octopus fisheries

More than twenty described octopus species are harvested worldwide, mostly from shallow water coastal environments. These species represent a diverse range of biological characteristics, from small species (<1 kg) with benthic young to large species (>10 kg)

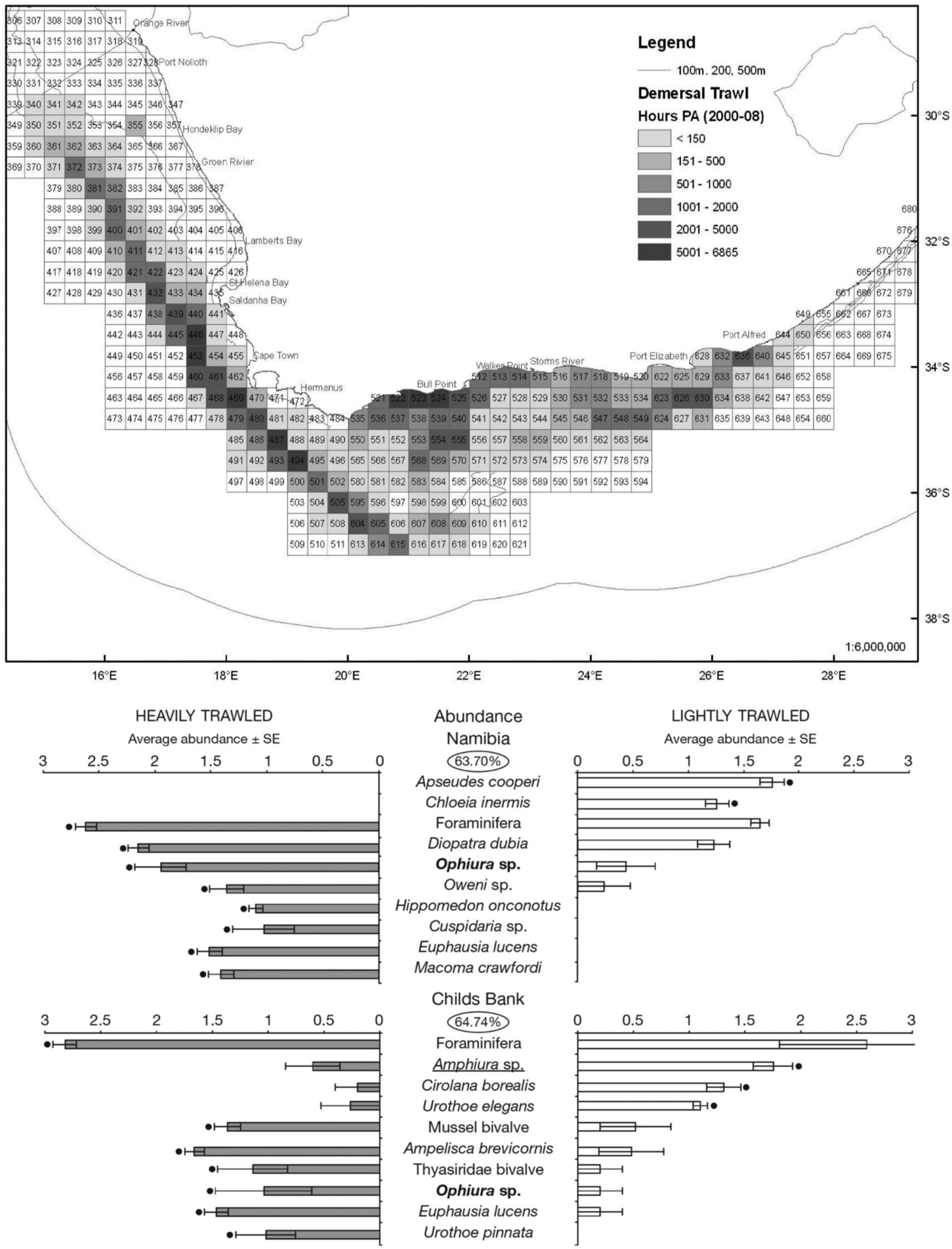

Figure 96. Top: The distribution of trawling effort as determined by hours trawled in the commercial grid blocks for the period 2000–2008. Data taken from commercial logbook records. From Sink et al. (2012). Bottom: Analysis of categorized abundance data (top 10 species contributing to differences) between lightly and heavily trawled areas in selected sites along the west coast of South Africa. Species in bold show consistent trends between sites. Species underlined show opposite trends between sites. Percentage dissimilarity between treatments at each site is indicated in ellipse. A black circle indicates the area of greater abundance per species. From Atkinson et al. (2011).

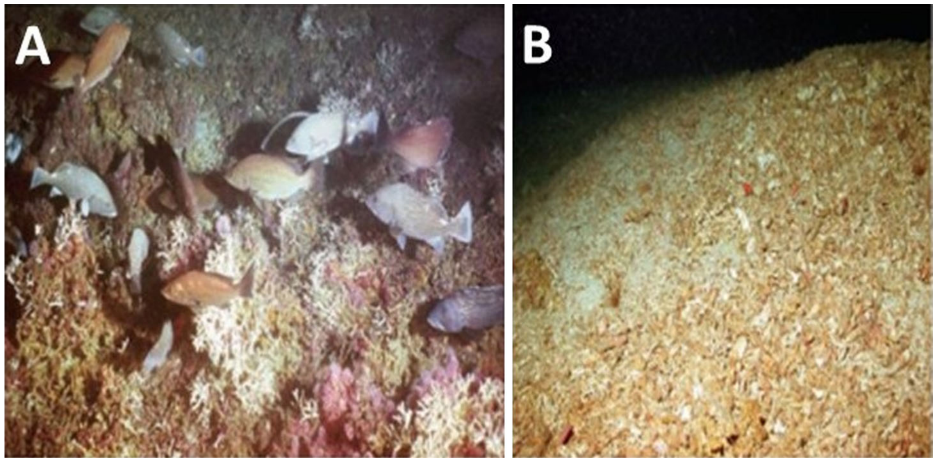

Figure 97. (A) An un-trawled coral reef area in the Oculina Banks off the coast of Florida, and (B) a trawled area. Photo Credits: NOAA/R. G. Gilmore and NOAA/University of North Carolina at Wilmington, Undersea Vehicles Program.

with planktonic paralarvae. Biological data for most species are still very limited and the management of stocks is inconsistent and diverse, and range from complex spatial management (for example the Australian *O.* aff. *tetricus* and Tasmanian *O. pallidus* fisheries) to no management or assessment at all. Indeed, only seven commercial octopus species have been aged, with only three aged using a validated method (Arkhipkin et al. 2018). As such, there needs to be a concentrated research focus on understanding octopus age and other fundamentals such as fecundity, brooding patterns, survival, and recruitment.

This general lack of information on octopus and octopus fisheries (Boyle 1990; Pierce and Guerra 1994; Lipiński et al. 1998) make the management of these fisheries particularly challenging. Many of the octopus fisheries discussed in this review are unassessed and unregulated; and so their productivity and status is unknown (i.e., under- vs. over-exploited). This reflects a broader problem for many marine invertebrate species, which are harvested without stock assessments and little knowledge of their basic biology (Anderson et al. 2011, Gibbons et al. 2016). In terms of stock assessment and management a key concern for short-lived, terminal breeders like cephalopods is that there is no overlap of generations, and therefore, little buffer against recruitment failure (Rodhouse et al. 2014). Current methods to estimate stocks are therefore limited, with depletion models (e.g., Young et al. 2004, Robert et al 2010) remaining one of the most widespread, despite limitations, such as the requirement for accurate catch and effort data. This data challenge extends across the globe, including in the official FAO records, making estimations of catch trends difficult and challenging. As an example, the recent increase in catches from China are likely to reflect better catch reporting as opposed to an increase in targeting. The "Seas around Us" project found major gaps in the reporting of artisanal catches, with octopus comprising a significant component for some countries (http://www.seaaroundus.org/). An analysis of catch in FAO Area 34 by Belhabib et al. (2012) has revealed the scale of underreporting that can occur, as much as a fourfold difference in that reported. It is indeed surprising that there are still octopods surviving in this area, where the bottom is continuously trawled by hundreds of ships, for over sixty years. Such high levels of illegal, unreported and unregulated fishing also makes trade in octopus products difficult to track.

16.2. Concluding remarks

This review highlights the breadth and diversity of octopus fisheries worldwide, from the largest fisheries in north-west Africa harvesting more than 100,000 t annually, to the smallest subsistence fisheries supporting villages in Madagascar and Polynesia. But this review also highlights a global industry that is under-resourced and, in many circumstances "running blind" as octopus are harvested without knowledge of their productivity. A sustainable aquaculture could relieve fishing pressure on octopus stocks and provide a mechanism to understand more about octopus life cycles and basic biology. Octopus are prime candidates for aquaculture because of their high rates of growth and food conversion (Vidal et al. 2014). Although commercialization is still constrained due to the major knowledge gaps associated with raising and sourcing juveniles, advances in octopus aquaculture have been made recently (Dan et al. 2018); and the next decade is likely to see commercial production underway. Octopuses are voracious carnivorous with a vigorous protein metabolism. The challenge for a future octopus aquaculture will be to obtain a sustainable artificial feed independent from fisheries products and formulated probably from vegetarian sources.

There is no doubt that, as our environment undergoes rapid change, octopus could be a key part of our future seafood supply, but to ensure this we need to invest in a pragmatic and holistic management of octopus fisheries (using an Ecosystem Approach–EAF) and provide the necessary incentives to assess both the resource and their roles in the ecosystem, as well as tracking and understanding local and global trade.

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Appendix A. Sources of octopus catch and import data for Japan

Data were obtained from the following sources:

1. *Statistics of Japan* (the Japanese governmental eStats web site portal for all statistics concerned with Japan; available in Japanese only). This enabled access to a useful data time series, though only for a single category of total octopus caught per year. Data on landings by prefecture from 1956 to 2015 were also available on this portal, in one row of values (in metric tonnes) headed "octopus species" within a spreadsheet of catch data covering all categories of sealife: one spreadsheet per prefecture (one each for Okinawa and Hokkaido, four for Shikoku, seven for Kyushu and 25 for the coastal prefectures of Honshu). These were each downloaded after scrolling down the following web page to section 5, which lists each prefecture in Japanese (last accessed in January 2018): https://www.e-stat.go.jp/stat-search/files?page=1&layout=datalist&toukei=00500216&tstat=000001015174&cycle=0&tclass1=000001034726
2. Japan Customs web site (providing catch and import values for octopus, broken down country-by-country, provided by the Japanese Foreign Ministry Trade Statistics portal). This requires selection of various categories at the following URL: http://www.customs.go.jp/toukei/srch/index.htm?M=01&P=0,1,,4,1,2017,0,0,0,2,030751,,,1,,,,,,200 (last accessed in January 2018)
3. More detailed catch data are available at certain Prefectural Fisheries Research Institutes. Some data were downloaded directly from a web site (e.g., from the Toyama Prefectural Fisheries Research Institute: data for both Toyama and Ishikawa, including some species-specific data). Other more detailed data were obtained through the co-operation of individuals. For the latter, IGG thanks, in particular, the staff of the Chiba Prefectural Office, who very kindly talked him through some of the non-intuitive steps required to reach pages of data on the eStats web site.
4. The *Japan Fisheries Information Service Center* (JAFIC). The JAFIC web site provides catch and price data for the previous 6 y, which have to be called up specifically (by pressing a "processing" button) after first selecting the port, species group and species of interest. Included are data for *E. dofleini*, *O. sinensis* and *A. fangsiao* but this is limited to a selection of ports around Japan (e.g., including ports contributing about 10% of catch data for *E. dofleini*). The category "All Japan" refers to inclusion of all the selected ports from which JAFIC has collected data (and does NOT mean the grand total for individual species landed at all the ports in Japan). Therefore, at present this source is not reliable for attempting to ascertain catch totals for Japan.

Appendix B. Estimated approximate percentage of each octopus species landed from local coastal waters at selected ports

Prefecture	Port	Species	Percent
Okinawa	Tomari	*Octopus cyanea*	98.6
		"Octopus" ornatus	1.2
		"Octopus" luteus	0.2
Fukuoka	Kitakyushu, Sone	*Octopus sinensis*	80
		Amphioctopus fangsiao	20
Shimane	Ohda	*Muusoctopus longispadiceus*	90
		Octopus sinensis	10
Kyoto	Maizuru	*Enteroctopus dofleini*	50
		Octopus sinensis	50
Tottori	Tottori	*Muusoctopus longispadiceus*	80
		Enteroctopus dofleini	20
	Sakai	*Enteroctopus dofleini*	80
		Octopus sinensis	10
		Amphioctopus fangsiao	10
Fukui	Mikuni	*Muusoctopus longispadiceus*	70
		Enteroctopus dofleini	30
Ishikawa	Kanazawa	*Muusoctopus longispadiceus*	80
		Enteroctopus dofleini	20
Toyama	Uozu	*Muusoctopus longispadiceus*	50
		Enteroctopus dofleini	50
Niigata	Nou	*Muusoctopus longispadiceus*	80
		Enteroctopus dofleini	20
Ehime	Uwajima	*Octopus sinensis*	90
		Amphioctopus kagoshimensis	5
		"Octopus" sasakii	5
Kochi	Irino	*Amphioctopus* sp. (ocellate)	33
		Amphioctopus kagoshimensis	33
		"Octopus" sasakii	33
	Susaki	*Octopus sinensis*	100
Hyogo	Hamasaka	*Muusoctopus longispadiceus*	70
		Enteroctopus dofleini	20
		Octopus sinensis	10
Osaka	Osaka Bay Market	*Octopus sinensis*	80
		Amphioctopus fangsiao	12
		Amphioctopus sp. (ocellate)	2
		Amphioctopus kagoshimensis	2
		"Octopus" minor	2
		"Octopus" sasakii	2
	Izumisano	*Octopus sinensis*	70
		Amphioctopus fangsiao	20
		"Octopus" minor	10
Wakayama	Saigasaki	*Octopus sinensis*	80
		Amphioctopus fangsiao	5
		Amphioctopus kagoshimensis	5
		"Octopus" minor	5
		"Octopus" sasakii	5
Mie	Owase	*Octopus sinensis*	50
		"Octopus" tenuicirrus	50
Shizuoka	Heta	*"Octopus" hongkongensis*	100

Percentages for Okinawa *fide* Ohta & Uehara (2015). Remainder are personal observations by H. Furuya over several years of specimen collection. Prefectures not listed have not been observed for catch proportions.