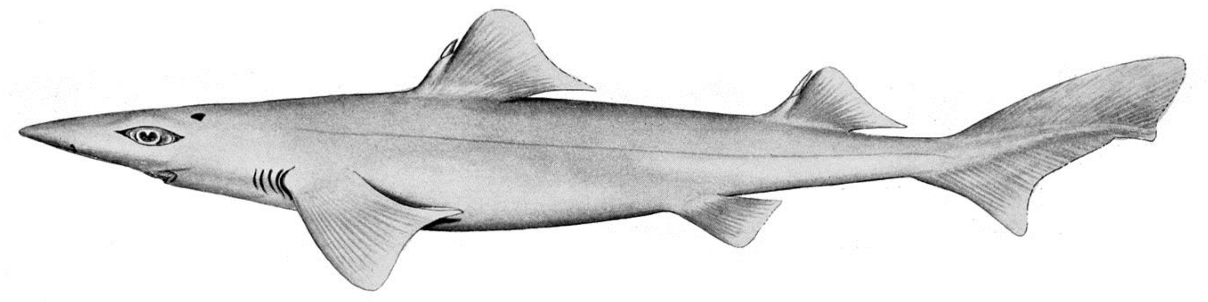
Status Review Report: Harrisson's Dogfish (*Centrophorus harrissoni*)



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EXECUTIVE SUMMARY

This report provides the best available information on the status of the gulper shark, Harrisson's dogfish (*Centrophorus harrissoni*).

Harrisson's dogfish is a species of shark that is endemic to subtropical and temperate waters off eastern Australia and neighboring seamounts. It is primarily a demersal species, found along the upper to mid-continental and insular slopes, in depths of 180 m to 1000 m (Last and Stevens 2009, Williams et al. 2013a). Female sharks are viviparous (i.e., give birth to live young) with a gestation period that is thought to last 2 to 3 years (Kyne and Simpfendorfer 2007; Graham and Daley 2011). Litter sizes are extremely small, with usually two pups per litter and sometimes only one. In addition, both female and males of the species mature late (23-36 years for females; 15-34 years for males) after reaching sizes of around 88% of their maximum size (Daley et al. 2002, Wilson et al. 2009, Last and Stevens 2009, Graham and Daley 2011). Due to these life history characteristics, Harrisson's dogfish is considered to be one of the most unproductive species of the chondrichthyan fishes (Kyne and Simpfendorfer 2007).

Historically, Harrisson's dogfish and other gulper sharks were taken in significant numbers by both Commonwealth (mainly the Australian Southern and Eastern Scalefish and Shark Fishery, (SESSF)) and state-managed commercial trawl and line fisheries operating on the upper slope off eastern Australia. These fisheries developed off New South Wales (NSW) in the 1970s and off Victoria and Tasmania in the 1980s. Unfortunately, species-specific catch data is unavailable for these deep-water sharks, primarily due to the historical lack of resolution of data reporting. In an effort to quantify the effect of historical overutilization on the abundance of gulper sharks, data from fishery-independent surveys conducted in the SESSF operational area before and after the expansion of the commercial trawl-fishery were compared. Results indicate severely depleted gulper shark populations on the upper-slope off NSW, with an over 99.7% decline in catch rates specifically of *C. harrissoni* after 20 years of trawling activity (Graham et al. 2001). Although Harrisson's dogfish is no longer targeted, and in fact its retention is now prohibited, it can still be incidentally caught in the Commonwealth Trawl Sector (CTS) and the auto-longline portion of the Gillnet, Hook, and Trap Sector (GHaT) of the SESSF, and by the NSW Ocean Trap and Line Fishery and Ocean Trawl Fishery. Given that sustainable harvest rates of gulper sharks are thought to be < 5%, even as low as 1%, this additional fisheries interaction poses a threat to the species (Forrest and Walters 2009; Daley et al. 2012).

In 2008, Harrisson's dogfish was nominated for listing as a threatened species under Australia's Environment Protection and Biodiversity Conservation (EPBC) Act 1999. In response to this nomination, as well as the findings from the Australian Fisheries Management Authority's (AFMA) Ecological Risk Assessment for the SESSF, a number of comprehensive management measures were implemented to protect Harrisson's dogfish. In Commonwealth waters, these management measures, as described in the Upper-Slope Dogfish Management Strategy 2012, include: 1) prohibiting commercial retention of gulper sharks, 2) creating, expanding, and revising a network of spatial/area closures that provide protection for the species from high-risk fishing methods over an estimated 29.5% of its core habitat in Australian waters; 3) 100% monitoring in closures that allow limited fishing methods; 4) move-on provisions in closures; 5) prohibiting gulper sharks from being taken through auto-longline de-hooking rollers or spiking with a gaff; and 6) gear restrictions in closures that allow power hand-line fishing. In NSW waters, landing of Harrisson's dogfish by commercial, recreational, and charter boat fishermen is prohibited. In addition, a number of restricted areas have been established with prohibitions against various fishing methods. These areas provide an additional 2.4% of habitat protection from trawling for Harrisson's dogfish. However, as many of these regulatory mechanisms have only recently been implemented (February 2013), it is unknown if these measures are currently adequate in addressing threats to the species and will remain so during the timeframe needed for recovery (which is likely to exceed 75 years (Irvine et al. 2012; SWG 2012)).

An evaluation of abundance trends, growth and productivity, spatial structure, and diversity factors, shows that the species faces current demographic risks that significantly increase its susceptibility to extinction. The species has suffered substantial declines as a result of historical overutilization and is estimated to be at approximately 21% of its total virgin population size. In areas where historical trawling effort on southeastern Australia's continental slope was highest and most extensive, depletion estimates are drastically low, ranging from only 5% to 10% (of virgin population size), with the current population likely fragmented throughout its range and potentially insufficient to support mate choice, fertilization, and recruitment success. Due to its already severely depleted status, the species' natural life history traits (low fecundity, slow growth rates, and late maturity) are inhibiting population recovery and placing the species' current and future viability into question.

Based on the best available data, there has been a substantial decline in the overall population of Harrisson's dogfish as a result of overutilization by commercial fisheries and further exacerbated by the species' natural biological vulnerability to overexploitation, inhibiting population recovery. As a result of this decline, the species faces current demographic risks, including low abundance, extremely low productivity, fragmented populations, and potential loss of diversity, that make it likely to be influenced by stochastic or depensatory processes. Additional mortality may further exacerbate its risk of extinction, and, as such, the potential for the species to be incidentally caught throughout its range is considered an ongoing threat of overutilization. An evaluation of the effectiveness of recently implemented management measures to adequately reduce this threat and protect Harrisson's dogfish from further decline was not part of this review.

Due to the aforementioned threats and demographic risks, I conclude that the Harrisson's dogfish is currently at a high risk of extinction throughout its range.

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INTRODUCTION

Scope and Intent of the Present Document

This document is the status review of the Australian gulper shark, Harrisson's dogfish (*Centrophorus harrissoni*); it has also been referred to historically as 'dumb shark'. This status review is in response to a petition[1] to list 81 species as threatened or endangered under the Endangered Species Act (ESA). Under the ESA, if a petition is found to present substantial scientific or commercial information that the petitioned action may be warranted, a status review shall be promptly commenced (16 U.S.C. 1533(b)(3)(A)). The National Marine Fisheries Service (NMFS) determined the petition had sufficient merit for consideration and that a status review was warranted for 27 of the 81 species (see http://www.nmfs.noaa.gov/pr/species/petition81.htm for the Federal Register notices), including Harrisson's dogfish. The ESA stipulates that listing determinations should be made on the basis of the best scientific and commercial information available. NMFS appointed a contractor (the current author) in the Office of Protected Resources Endangered Species Division to undertake a scientific review of the biology, population status and future outlook for Harrisson's dogfish.

This document reports the findings of the scientific review as well as analysis and conclusions regarding the biological status of the species as a potential candidate for listing under the ESA. These conclusions are subject to revision should important new information arise in the future. Where available, I provide literature citations to review articles that provide even more extensive citations for each topic. Data and information were reviewed through April 7, 2015.

LIFE HISTORY AND ECOLOGY

Taxonomy and Distinctive Characteristics

Centrophorus harrissoni is a shark belonging to the family Centrophoridae (Order Squaliformes). The Centrophoridae contain two genera: *Deania* (long-snouted or bird-beak dogfishes) and *Centrophorus*, usually referred to as gulper sharks; 'gulper shark' is also the common name for the largest species, *C. granulosus* (White et al. 2013). *Centrophorus* sharks are deep-water sharks, found worldwide in temperate and tropical oceans, usually along the upper continental and insular slopes in depths between 200 and 2400 m (Graham et al. 2001; Carpenter 2002; Duffy 2007; Last and Stevens 2009). Although taxonomic questions still remain regarding *Centrophorus* found in other parts of the world, the taxonomy of the

[1] (1) WildEarth Guardians submitted to U.S. Secretary of Commerce, Acting through the National Marine Fisheries Service, an Agency within the National Oceanic and Atmospheric Administration, July 15, 2013, "Petition to list eighty-one marine species under the Endangered Species Act."

Centrophorus species in Australia has been greatly improved due to advances in DNA analyses and an increased number of available specimens for study. Last and Stevens (2009) recognized seven species of *Centrophorus* from Australian waters: *C. harrissoni, C. moluccensis*, *C. zeehaani* (previously referred to as *C. uyato* Australian subpopulation; White et al. 2008), *C. niaukang, C. squamosus, C. westraliensis* (previously considered to be conspecific with *C. harrissoni*; White et al. 2008), and *C. granulosus*; with White et al. (2013) synonymizing *C. naiukang* with *C. granulosus*, this number has been reduced to six.

The Centrophoridae are deep-water sharks that mature at lengths of 0.9 m – 1.7 m. They have cylindrical body forms, with pre-oral snouts. They have two dorsal fins with spines and the first dorsal fin originates before the pelvic fin. They lack an anal fin. They have large green or yellowish eyes, blade-like teeth, and large spiracles (Last and Stevens 2009). *Centrophorus* species usually have a shorter to moderate-sized snout whereas the *Deania* species have flatter and longer snout (Duffy 2007). Harrisson's dogfish is distinguished from other *Centrophorus* species by its slightly longer and flatter snout, with the distance from its snout tip to the front corner of its eye much greater than the distance from the front corner of the eye to the spiracle (Duffy 2007). It has a light grey to brown upper body and pale ventral side and there is often a dark smudge found along the base of the dorsal fins. The front dorsal fins often have a noticeable dark patch that is less obvious in adults.

Range, Distribution, and Habitat Use

Harrisson's dogfish is endemic to subtropical and temperate waters off eastern Australia and neighboring seamounts (Figure 1). It can be found in waters from Mooloolaba (southern Queensland; ~26°40'S) south to South East Cape (Tasmania; 43°45'S) on seven of the eight Tasmantid Seamounts off eastern Australia, and in waters around Lord Howe Island (Graham and Daley 2011; Graham 2013; Williams et al. 2013b). Specimens identified as *C. harrissoni* have also been collected along the Three Kings, Kermadec, and Norfolk Ridges north of New Zealand, and possibly off New Caledonia; however, DNA samples are needed to verify that these specimens do not belong to a cryptic species (Duffy 2007).

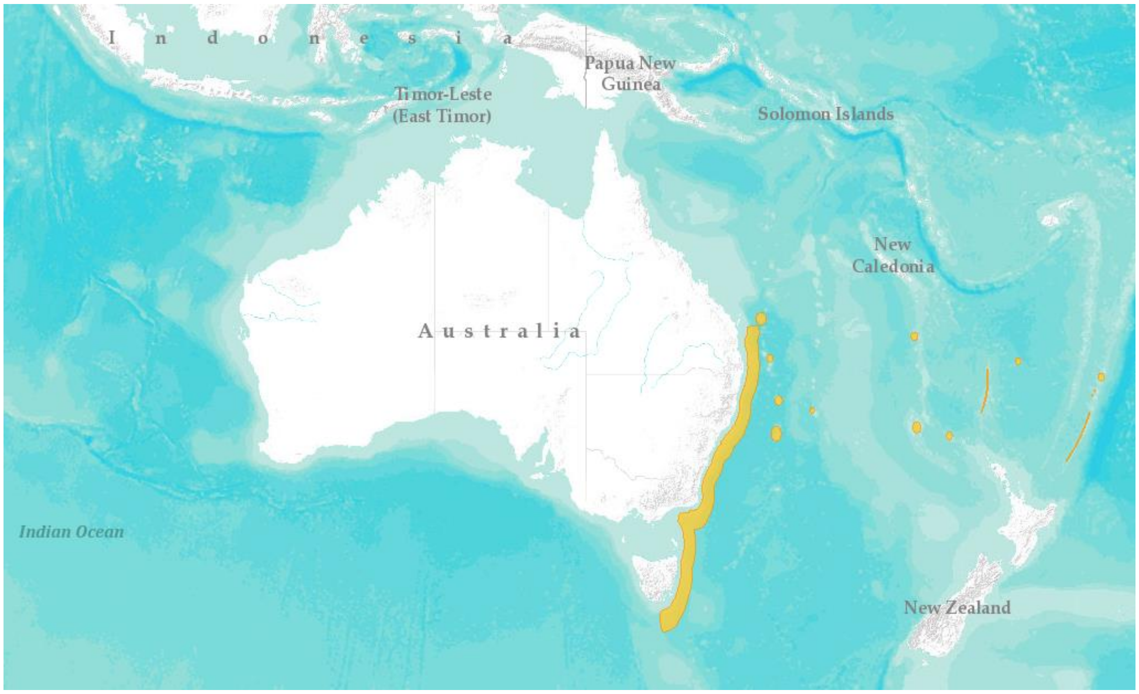

Figure 1. Range map of Harrisson's Dogfish (*Centrophorus harrissoni*) (with inclusion of unverified range off northern New Zealand) (source: IUCN 2014).

The Harrisson's dogfish is primarily a demersal species, found along the upper to mid-continental and insular slopes off eastern Australia, in depths of 180 m to 1000 m, with a core depth range of 200 m to 900 m (White et al. 2008; Last and Stevens 2009; Williams et al. 2013a). However, specimens have been collected in deeper waters from the seamounts and ridges north of New Zealand (450 m to 1048 m – Norfolk Ridge) and off southeastern Australia (900 m to 1050 m) (Daley et al. 2002; Graham and Daley 2011). Specimens have also been collected in shallower depths off eastern Bass Strait (recorded from a gillnet at 155 m to 180 m depth) (Williams et al. 2013a).

In 2009, Australia's Commonwealth Scientific and Industrial Research Organization (CSIRO) conducted an auto-longline (ALL) and drop line survey along eastern Australia to map the distribution of gulper sharks, including Harrisson's dogfish. Out of the 23 sampled sites (see Figure 2), Harrisson's dogfish were recorded at 19 of them. They were not caught from the Border Bank, Gipps Marine Protected Area (MPA), Seiners Canyon, and Freycinet MPA sites. Sites that recorded "high" abundance (where catch rates were above 1% - one shark/100 hooks) included waters off Port Stephens (with high numbers of juveniles < 80cm total length (TL) and neonates recorded) and North of Flinders (southeastern Australia). The other sites were recorded as having low abundance (Williams et al. 2012).

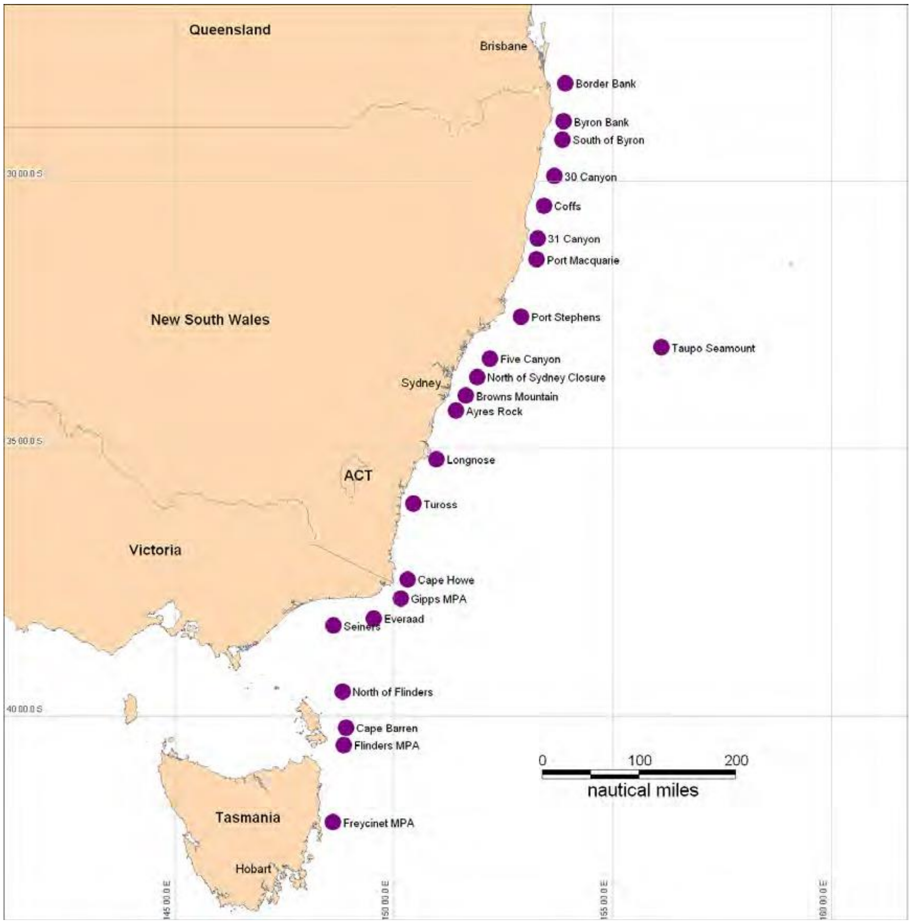

Figure 2. Map of the 23 sampling sites from the 2009 CSIRO auto-longline (ALL) and drop line surveys (source: Williams et al. 2012).

Data from research trawling and longline studies conducted between 1976 and 2009 indicate that *C. harrissoni* may exhibit spatial sexual segregation (Graham and Daley 2011). Males tended to dominate the sex ratios among survey grounds, where sex ratios varied from 1.5:1 to 4.9:1 along the east coast of Australia (Graham and Daley 2011). However, there were two notable sites that found higher ratios of females: 1) northern New South Wales (NSW), from Newcastle to Danger Point, where females were more abundant than males (at a ratio of 1:0.8, but the difference was not statistically significant), and 2) off Taupo Seamount, where a total of 12 *C. harrissoni* were taken, 11 of which were females (Graham and Daley 2011). There is no evidence of sexual segregation by depth, as data from pre-fishery trawl research studies (conducted from 1976-1977) showed a dominance of large, primarily adult males in all depth ranges off NSW, with a relatively small number of mature females, and few juveniles of either sex (Graham and Daley 2011). In addition, there is no evidence of seasonal migrations of males or females.

Feeding and Diet

There is little published data on the feeding behavior and diet of this species. Gulper sharks, including Harrisson's dogfish, are thought to conduct diel-vertical feeding migrations whereby the sharks ascend the continental slope around dusk to around 200 m depths to feed and then descend before dawn (Williams et al. 2013a). Electronic tracking of *Centrophorus zeehaani*, a closely related species, indicates these individuals move between the 300 and 600 m bathymetric contours near the seafloor on a diurnal basis (Daley et al. 2014).

Small bathypelagic bony fishes (particularly myctophids – lantern fishes), cephalopods, and crustaceans have been found in the stomachs of *C. harrissoni*; based on a sampling of 116 *C. harrissoni* stomachs, over 80% of those with food contained lantern fishes and 16% contained cephalopods (Daley et al. 2002).

Reproduction and Growth

The Harrisson's dogfish is viviparous (i.e., gives birth to live young) with a yolk-sac placenta. Females have litters of one or (more commonly) two pups, with size at birth around 35-40 cm (Graham and Daley 2011). Although the gestation period is unknown, a 2 to 3 year period has been estimated for other *Centrophorus* species, with continuous breeding from maturity to maximum age (Kyne and Simpfendorfer 2007; Graham and Daley 2011). Female *C. harrissoni* mature at sizes around 98 cm (L_{50} maturity = 99 cm) and reach maximum sizes of 112-114 cm while males mature around 75-85 cm (L_{50} maturity = 84 cm) and reach maximum sizes of 95-99 cm (Graham and Daley 2011). A preliminary ageing study of *C. harrissoni* by Whitely (2007) (thesis cited in TSSC 2013) found that females matured between 23 and 36 years of age, and males between 15 and 34 years. Current breeding sites for Harrisson's dogfish are thought to include waters off eastern Australia, from Port Stephens to 31 Canyon, areas off North Flinders and Cape Barren in southeastern Australia, and waters around Taupo Seamount (Williams et al. 2012). These are areas where mature males, mature females, and juveniles have been recorded and are thus likely to be areas that support viable populations where mating and pupping occur (Williams et al. 2012).

The longevity of the species is unknown but assumed to be high and similar to the closely related *C. zeehaani* (formerly referred to as *C. uyato*; White et al. 2008), which was estimated to exceed 46 years by Fenton (2001). However, the methods used in the Fenton (2001) study, specifically radiometric dating of vertebrae and otoliths using ^{210}Pb and ^{226}Ra, have been recently found inappropriate for ageing calcified structures for deepwater elasmobranch species (Cotton et al. 2013).

Generation time, which is defined as "the average age of a reproductively mature animal in an unexploited population," has been estimated at 28.5 years (using an age at maturity of 23 years for female sharks) (Independent Upper-Slope Dogfish Scientific Working Group (SWG) 2012).

Population Structure

Although genetic data are unavailable, two separate stocks of Harrisson's dogfish are thought to exist off the coast of Australia. One stock occurs continuously along the continental margin, down the east coast of Australia from north of Evans Head in northern NSW to Cape Hauy in Tasmania (referred to as the "continental slope stock"). The rare occurrences of individuals beyond this range (including in both the northerly and southerly directions) are considered to be cases of vagrancy and not part of the core range. The other stock occurs on the Tasmantid Seamount Chain off NSW and southern Queensland, including the Fraser, Recorder, Queensland, Britannia, Derwent Hunter, Barcoo and Taupo Seamounts (referred to as the "seamount stock") (see Figure 3).

Figure 3. Range of Harrisson's dogfish off Australia. The "core" range of the continental stock is identified in green and marked by a "1"; the core range of the seamount stock is identified in green and marked by a "2"; the extra-limital range of the continental stock (rare/vagrants) is identified in yellow and marked by a "3" and "4"; and the extra-limital range of the seamount stock is identified in green and "+" and marked by a "5" (source: Williams et al. 2013a).

According to the SWG (a technical, science-based group established to provide technical reviews and advice to inform the management of upper-slope dogfish in Australia), the deep water between the Australian eastern continental margin and the seamount chain likely works as a habitat barrier between these two stocks, separating the species into two possibly distinct populations (SWG 2012). In addition, the SWG identifies the populations found off the seamounts as a single stock rather than separate seamount stocks based on evidence of strong sex-biased distribution in dogfish that occurs at some of the offshore seamounts (for example, the Taupo, Recorder, and Britannia seamounts show a predominance of mature females; Williams et al. 2013b); hence, reproduction in this population may require movement between these seamounts (SWG 2012).

However, there are a number of uncertainties associated with the assumption of two separate Harrisson's dogfish stocks. For example, the seamount catch data from Williams et al. (2013b) were collected during a study to determine if Harrisson's dogfish can be avoided during normal commercial power handline fishing operations targeting blue-eye trevalla (*Hyperoglyphe antarctica*) on Taupo and Barcoo Seamounts. As such, it is unclear if the sex ratio bias was an artifact of the sampling design (i.e., females are more common in the commercially fished areas for blue-eye trevalla whereas males may be found elsewhere on the seamount) or accurately represented the sex composition of the Harrisson's dogfish seamount population. In addition to the sex ratios on the seamounts, the specific movement of Harrisson's dogfishes between seamounts is unknown. Although the SWG assumed that reproduction would require movement between the seamounts (based on the above sex-biased distribution), some of the distances between these seamounts are, in fact, greater than the distances from the seamounts to the continental slope and would also require travel over deep water. For example, the Queensland and Britannia Seamounts are less than 30 nautical miles apart from each other (Williams et al. 2013b); however, the distance to Derwent Hunter, the next seamount in the chain, is approximately 120 nautical miles and would require traversing deep water. The distance between these seamounts is greater than the distance from the Queensland and Britannia seamounts to the continental slope, which is less than 90 nautical miles (Williams et al. 2013b). Thus, there may be potential for mixing of the continental margin and some seamount populations, but without further information on the specific movement behavior of *C. harrissoni*, this cannot be verified. To date, no genetic studies have been conducted to confirm that these two populations are genetically distinct, and tagging studies are limited, with insufficient recapture rates to make any determination regarding the connectivity of the populations. Due to these uncertainties, the evidence of separate stocks of Harrisson's dogfish is inconclusive.

Additionally, Duffy (2007) provisionally identified three specimens of *C. harrissoni* off New Zealand (using morphometric measurements) and suggested that they may be distinct from those sharks found in Australian waters. Specifically, Duffy (2007) points to apparent regional differences in depth preferences between these two populations. Collection depths of nominal *C. harrissoni* from Norfolk Ridge (33°07'S, 166°52'E), Three Kings Ridge (31°15'S, 172°56'E), and Kermadec Ridge (31°45'S, 178°52'E) around northern New Zealand show a preferred depth range of ~ 600 to 800 m. This is in contrast to the population found in Australian waters which appear to prefer shallower depths of 220 – 680 m (Last and Stevens 2009). Given the evidence of a substantial eastward range extension of *C. harrissoni* (based on the Kermadec Ridge specimens), and the differences in depth preferences between these specimens and those from Australian waters, Duffy (2007) suggests that the *C. harrissoni* population off northern New Zealand likely is distributed continuously along Norfolk Ridge from 17°30'S to at least 33°S, and is distinct from the population found in Australian waters. However, further research, including the collection of more specimens (to verify that these are not simply vagrants) and genetic analyses (to gather molecular evidence of population structure), is needed to support this theory. For the purposes of this status review, I consider these three specimens off New Zealand as *C. harrissoni* individuals.

ANALYSIS OF THE ESA SECTION 4(A)(1) FACTORS

The ESA requires NMFS to determine whether a species is endangered or threatened because of any of the factors specified in section 4(a)(1) of the ESA. The following provides information and analysis on each of these five factors as they relate to the current status of Harrisson's dogfish.

Present or Threatened Destruction, Modification, or Curtailment of Habitat or Range

The ESA requires an evaluation of any present or threatened destruction, modification, or curtailment of habitat or range. Currently, *C. harrissoni* are found along the upper to mid-continental and insular slopes and seamounts off eastern Australia, with no evidence of a curtailment from its historical habitat or range. The species is considered to be at 99% of its historical distributional range on Australia's continental margin and 100% of its historical range on the seamounts (Williams et al. 2012; Williams et al. 2013a).

Provisionally identified specimens of *C. harrissoni* off Three Kings Ridge, Norfolk Ridge, and Kermadec Ridge in New Zealand indicate a much larger range of the species than previously assumed (Duffy 2007). In 1956, Three Kings Island was declared a Nature Reserve for the preservation of flora and fauna, and is now managed by the New Zealand Department of Conservation. In addition, both the Kermadec Ridge and the neighboring Colville Ridge are contained within established benthic protection areas, which restrict the use of dredges and trawling activities (New Zealand Regulation SR 2007/308).

Preferred habitat and bottom type is currently unknown for Harrisson's dogfish, but it is assumed that the species uses a variety of habitat types for different purposes (Williams et al. 2012a). Although it is likely that the intensive trawling within the range of Harrisson's dogfish (Williams et al. 2013a; see below section for more details) has altered the seafloor over the years, there is no information that shows this habitat modification has affected the shark's abundance.

Overutilization for Commercial, Recreational, Scientific, or Educational Purposes

For the purposes of this status review, evidence of overutilization as a threat to the species was analyzed using available abundance data, trends, historical, and current fishing effort information.

Description of Fisheries

In Australia, there are both Commonwealth-managed fisheries (those that are managed by the Australian Federal Government in coordination with Australian State fisheries agencies through the Australian Fisheries Management Authority (AFMA) (Kyne and Simpfendorfer 2007)) and State-managed fisheries. In terms of Commonwealth-managed fisheries, Harrisson's dogfish are primarily caught as bycatch by the Australian Southern and Eastern Scalefish and Shark Fishery (SESSF), which operates over an extensive area of the Australian Fishing Zone (AFZ) around eastern, southern, and southwestern Australia (Figure 4). It is a multi-species, multi-gear fishery that comprises the following sectors: Commonwealth Trawl Sector (CTS; comprising the South East Trawl Fishery and the Commonwealth Victorian Inshore Trawl Fishery), the Great Australian Bight Trawl Sector (GABT), the East Coast Deepwater Trawl Sector, and the Gillnet, Hook and Trap Sectors (GHaT). The CTS has been responsible for the majority of the deepwater shark bycatch throughout the years (1970s – present). This sector primarily utilizes two methods: otter trawling and Danish seining (a boat sets long wire warps and a net around fish and the action of the warps herd fish towards the central net as it is hauled), The main area of operation of this fishery (Figure 4) overlaps with the core range of Harrisson's dogfish (Figure 3). The GHaT operates east of a line about 80 nautical miles from the coastline between Fraser Island, Queensland and the NSW-Victoria border; it then operates in all waters south of the NSW border, around Tasmania to South Australia and including Bass Strait (Figure 4). Auto-longliners in this sector operate on the upper-slope off eastern Bass Strait and eastern Tasmania (part of the core range of Harrisson's dogfish – see Figure 3).

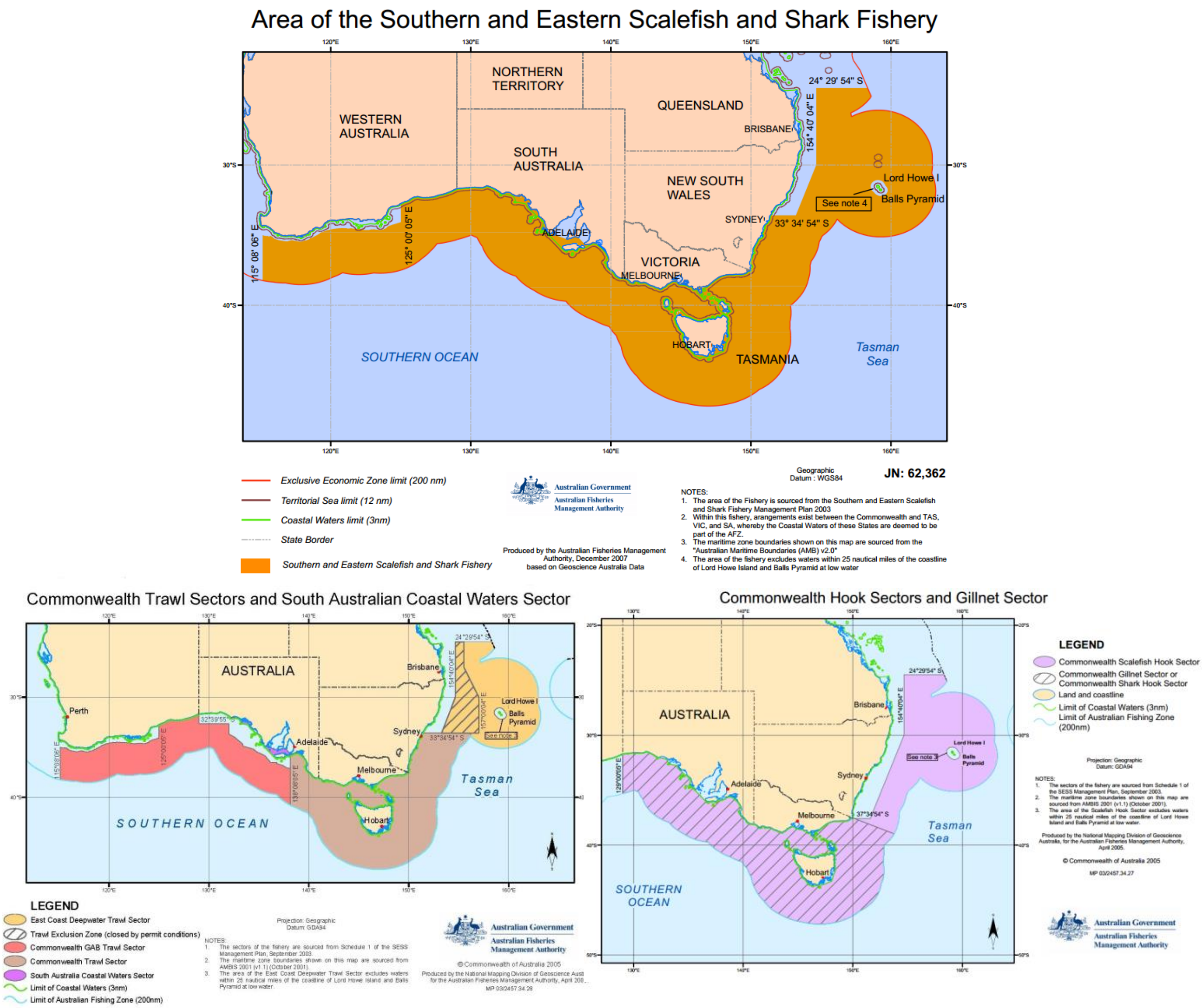

Figure 4. SESSF area of operation and further identified by sectors that interact with Harrisson's

dogfish (source: AFMA 2014).

In terms of state-managed fisheries, the range of Harrisson's dogfish extends within NSW, Victoria, and Tasmania jurisdictions but is primarily caught in the NSW fisheries. In fact, around 27% of Harrisson's dogfish core habitat range is found in NSW state-managed waters (AFMA 2012a). NSW has jurisdiction over waters north of Barrenjoey Head (near Sydney) out to 80 nautical miles offshore, and out to 3 nautical miles south of Barrenjoey Head. In NSW commercial fisheries, Harrisson's dogfish may be caught by the Ocean Trap and Line Fishery and the Ocean Trawl Fishery.

Historical Fishing Pressure

Historically, Harrisson's dogfish and other gulper sharks were taken in both Commonwealth and State-managed commercial trawl fisheries operating on the upper slope off eastern Australia. Unfortunately, little information is available on the specific catch of these deep-water sharks, primarily due to the historical inaccuracy of data reporting. In the Commonwealth and NSW commercial fishery logbooks (which were introduced in the 1990s), many of the gulper species were lumped into a single genus or family category instead of by species. Discards were not recorded until late in 2002. In scientific observer data, similar confusion in the identification of gulper sharks and tendency to use generic *Centrophorus* codes in the records prior to 2002 also rendered this dataset not useful for identifying species-specific interactions for gulper sharks. Since 2002, improvements have been made but not yet to the point where these datasets can be confidently used to provide accurate fishery catch records for specific gulper species (Wilson et al. 2009).

These Commonwealth and State-managed commercial trawl fisheries developed off NSW in the 1970s and off Victoria and Tasmania in the 1980s. By the early 1980s, more than 100 trawlers were operating off NSW, with around 60% regularly fishing on the upper slope. In fact, between 1977 and 1988, catches from these upper-slope trawl operations comprised more than half of the total trawl landings in NSW (Graham et al. 2001). Large numbers of *C. harrissoni*, *C. moluccensis* and *C. zeehaani* were likely caught and discarded off NSW during this time due to the absence of a market for deepwater shark carcasses (a result of mercury content regulations and preference for more marketable teleosts) (Daley et al. 2002; Graham and Daley 2011). Similarly, trawlers operating on the upper-slope off eastern Victoria reported minimal catches of *Centrophorus* dogfishes, but also likely discarded substantial numbers due to Victorian State restrictions on mercury content in shark flesh (Daley et al. 2002). Graham and Daley (2011) estimate that landings of *Centorphorus* spp. were around several hundred tonnes per year during the 1980s and early 1990s.

In the early 1990s, Daley et al. (2002) notes that significant quantities of *Centrophorus* spp. were caught off eastern Victoria by fishermen using droplines targeting blue-eye trevalla (*Centrolophus antarctica*) and ling (*Genypterus blacodes*). In addition, some SESSF operators off Victoria used deep-set gillnets to target *Centrophorus* species for their livers in the 1990s (Daley et al. 2002). Squalene oil, which is extracted from the liver of deep-sea sharks, is used in a number of cosmetics and health products, and the livers of *Centrophorus* species have the highest squalene oil content (67-89%) of any deep-sea shark. These fishermen would keep the livers of the *Centrophorus* spp. and discard the carcasses due to their mercury content. However, by the time the mercury restrictions were eased in 1995 (allowing for carcasses to also be sold), very few *Centrophorus* species were being caught off eastern Victoria, with targeting of these sharks essentially ceased (Daley et al. 2002). Since 2002, total catch of gulper sharks by Commonwealth licensed vessels has been less than 15 t per year (Woodhams et al. 2013).

Market data also reflect this decline in *Centrophorus* spp. catch. From 1992 to 1999, monthly sales and volume of *Centrophorus* spp. in the Sydney Fish Market significantly decreased. Although the decline in sales and volume of *Centrophorus* spp. could be indicative of a decrease in demand rather than availability, Daley et al. (2002) showed that the average monthly price for *Centrophorus* spp. carcasses in the Sydney Fish Market remained relatively high ($3.33/kg) and stable from 1992-1999. Thus, because the price remained stable over the years, indicating that the demand for the product was still present, the decrease in volume is likely an indication of a decline in abundance of the *Centrophorus* spp.

In 2001, Graham et al. (2001) quantified the effects of this historical trawling on the abundance of gulper sharks off NSW. They examined data from fishery-independent surveys conducted along the NSW upper slope before and after the expansion of the commercial trawl-fishery. The initial stratified trawl-survey was carried out during 1976 and 1977 on the upper-slope habitat (200–650 m depth) off NSW using the fisheries research vessel *Kapala*. This trawling was conducted during the early years of commercial exploitation of the NSW upper slope, prior to the main development of this fishery in the late 1970s, early 1980s. There were three trawling survey grounds: 1) Sydney – Newcastle, 2) Ulladulla – Batemans Bay, and 3) Eden – Gabo Island (see Figure 5). The total area of the three grounds was ~440 square nautical miles. During each survey on each ground, usually three tows were conducted along each of eight isobaths i.e 24 tows per survey. The two northern grounds were surveyed twice in 1976 and twice in1977; the southern (Eden-Gabo Island) ground was surveyed three times in 1977. Data from the tows were compiled into four depth zones: 220-275 m; 330-385 m; 440-495 m; and 550-605 m. These stratified surveys were repeated in 1996-1997, using the same vessel (*Kapala*), trawl gear and similar sampling protocols, to examine the changes in relative abundances of the main species (number and kg per trawling hour) after 20 years of trawling on previously unexploited stocks (Andrew et al. 1997; Graham et al. 2001).

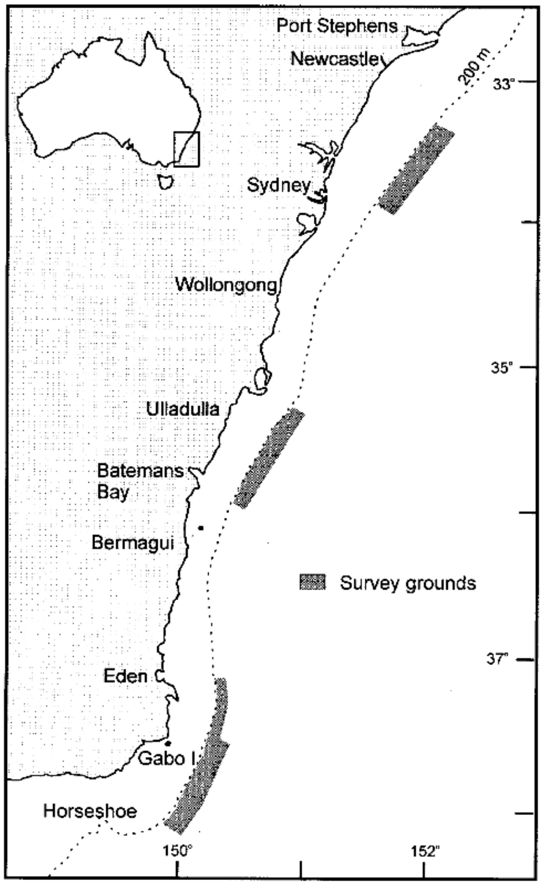

Figure 5. Map showing the location of survey grounds off the NSW coast (source: Graham et al. 2001).

Results from these surveys show that Harrisson's dogfish were present and, at one time, were caught across all of the survey grounds and depth zones. In 1976, catches of Harrisson's dogfish were combined with southern dogfish (*C. zeehaani*) in the initial two surveys off Sydney and one off Ulladulla. When these species were separated in the later 1976 surveys, and in 1977, southern dogfish comprised around 75% and Harrisson's 25% of the combined catch. In 1976-77, Harrisson's and southern dogfishes represented around 9%, 18%, and 32% of the total fish catches off Sydney, Ulladulla, and Eden, respectively. Catches of these sharks were greatest in depths of 440 – 605 m off Ulladulla and Eden (Figure 6). The overall mean catch rate (for all grounds and depths) was 126 kg/hour. This is in stark contrast to the 0.4 kg/h catch rate in 1996-1997, when only 14 southern and 8 Harrisson's dogfishes were caught, comprising 0.18% of the total fish catch weight (Graham et al. 2001). For the 1976-77 tows where the two species were separated, the mean catch rate of Harrisson's dogfish was 28.8 kg/hr, with over 5,000 kg of *C. harrissoni*, or ~1,100 sharks, caught over the course of 173 tows. In 1996-97, only 15 kg, or 8 Harrisson's dogfish, were caught over the course of 165 tows, with a mean catch rate of 0.1 kg/hr (Graham et al. 1997, 2001). These decreases in survey catch rates provide compelling evidence of declines of over 99.7% in relative abundance of *C. harrissoni* on the upper-slope of NSW, a core part of their range, after 20 years of trawling activity (Graham et al. 2001).

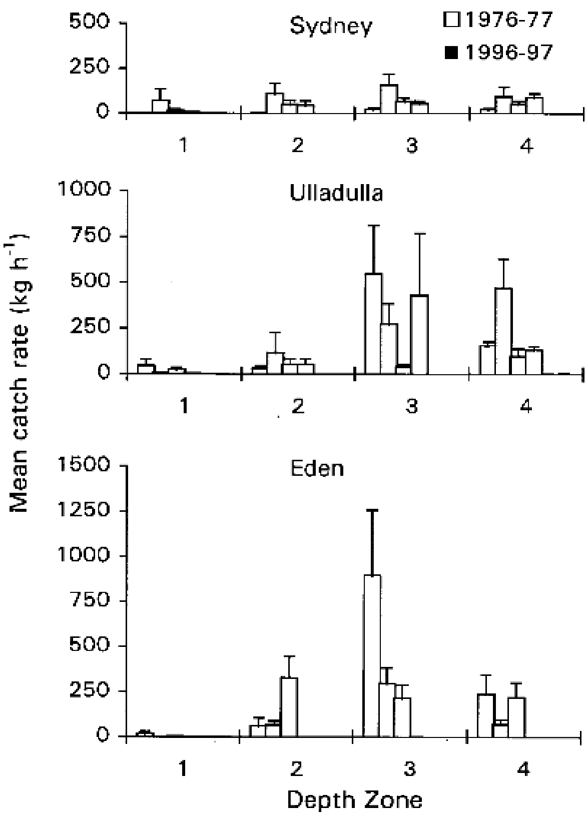

Figure 6. Mean catch rate kg/hour for Harrisson's and southern dogfishes (combined) at each survey location by year. Depth zones are numbered: 1= 200-275m; 2= 330-385 m; 3= 440-495 m; 4= 550-605m. In 1976-1977, 4 surveys were conducted off Sydney and Ulladulla, and 3 off Eden. In 1996-1997, 2 surveys were conducted off Sydney and Ulladulla, and 3 off Eden (source: Graham et al. 2001).

Current Fishing Pressure

The distribution of recent (2006-2010) commercial fishing effort in the SESSF (Figure 7) shows that there is still substantial fishing effort on Commonwealth upper-slope grounds from demersal gears, specifically trawl and auto-longline operations. Around 30 trawlers and 2 auto-longliners in the SESSF still operate along the upper-slopes (Graham 2013; Australian Government, personal communication 2015). Since auto-longline vessels, which deploy up to 15,000 hooks per vessel per day, can operate on the steep and rough ground that would potentially be a refuge for *C. harrissoni* from trawling (R. Daley, personal communication), the combined operation of both the trawl and auto-longline fisheries within the range of Harrisson's dogfish significantly increases the likelihood of incidental catch of the species. Although catch rates of Harrisson's dogfish in the SESSF have been minimal in recent years, likely due to their low abundance on the continental margin, the combined operation of these demersal gears on the upper-slope grounds may further decrease abundance of the remaining population.


(a) Auto-longline
(b) Trawl
(c) Other demersal gears
(bottom line, drop line, trottline, handline & gillnet)
SESSF - Auto-longline
no. operations
9.4 to 87.2
4 to 9.4
0 to 4
SESSF - Trawl
no. operations
246 to 777
88 to 246
2 to 88
SESSF - other gears
no. operations
3.5 to 33.2
1.3 to 3.5
0 to 1.3
30 n.m.
Endeavour Dogfish Closure
South of Endeavour Clos
Wollongong
Kiama
Shoalhaven
Jervis Bay Canyons
Ulladulla
Tuross Canyon area
Tathra
Eden
Green Cape
Cape Howe
Gabo Canyo
Big Horseshoe Canyon
Little Horseshoe
Seiners Horseshoe
Second Howe Ground
Middle Bight
No. 1 Ground
Rigs Area
Smithy's Corner
Fingers area
Hole Shot Canyon
Hole Shot
Babel Area
Babel Horseshoe
Flinders Area
Cape Barren Area
Banks Strait Gullies

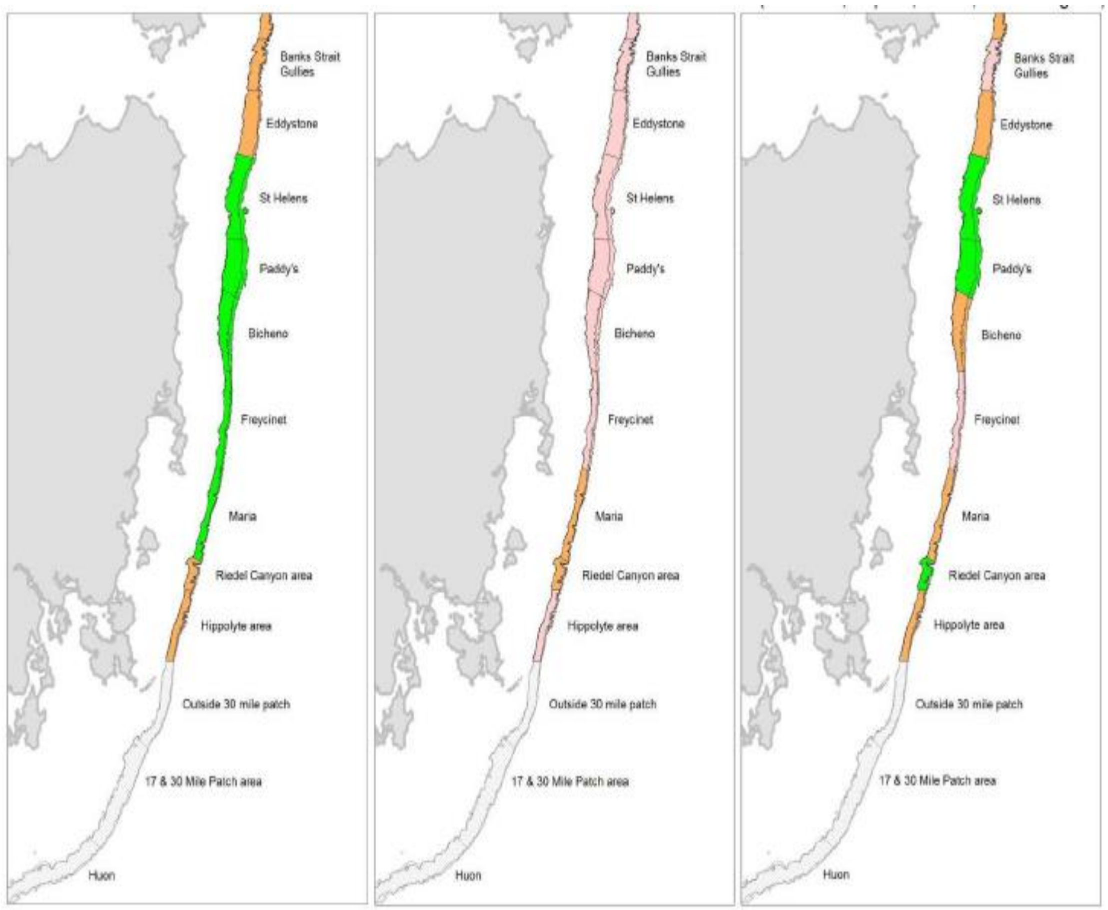

Figure 7. Distribution of commercial fishing effort in the SESSF (2006-2010) depicting average number of (a) auto-longline operations, (b) trawl operations, and (c) other demersal gear operations per year in three areas off southeast Australia (from just north of Sydney to the southern extent of the core range of Harrisson's dogfish off Tasmania) (Source: Williams et al. 2013a).

In 2007, Zhou et al. (2007) conducted a "rapid quantitative assessment" of five sub-fisheries of the SESSF as part of AFMA's Ecological Risk Assessment process (risk assessments are used to prioritize and identify key ecological areas in a fishery that require management attention). Based on fishing mortality rates and life history parameters, Zhou et al. (2007) determined that Harrisson's dogfish is at a "precautionary extremely high risk" of overfishing in the auto-longline sector of the GHaT and is at a "precautionary high risk" of overfishing in the South East Trawl Fishery component of the CTS. Below are the definitions of the categories:

Precautionary extreme high risk = $E[u] \geq \min[ucrash]$ or $E[u] + 90\%\ CI \geq E[ucrash]$.
Precautionary high risk = $E[u] \geq \min[ulim]$ or $E[u] + 90\%\ CI \geq E[ulim]$

u = mean fishing mortality
ulim = fishing mortality rate corresponding to limit biomass *Blim*, where *Blim* is defined as half of the biomass that supports a maximum sustainable fishing mortality (0.5*Bmsm*)
ucrash = minimum unsustainable fishing mortality rate that, in theory, will lead to population

Extinction in the longer term
CI = confidence interval

In terms of the corresponding ecological consequence, an ecological risk assessment of a "high risk" in the fishery was noted as fishing mortality rates that could potentially drive a population to very low levels over the longer term, and an "extreme high risk" was noted as fishing mortality rates indicative of an unsustainable population over the longer term, with a possibility of extinction (Zhou et al. 2007).

For the 2012-2013 season, reported gulper shark (*C. harrissoni*, *C. moluccensis*, *C. zeehaani*) landings (in trunk weight) for the CTS and GHaT sectors (combined) was 0.9 t with discards of 1.2 t (Woodhams et al. 2013). This is a decrease from the previous year, which reported landings of 3.8 t. (Figure 8).

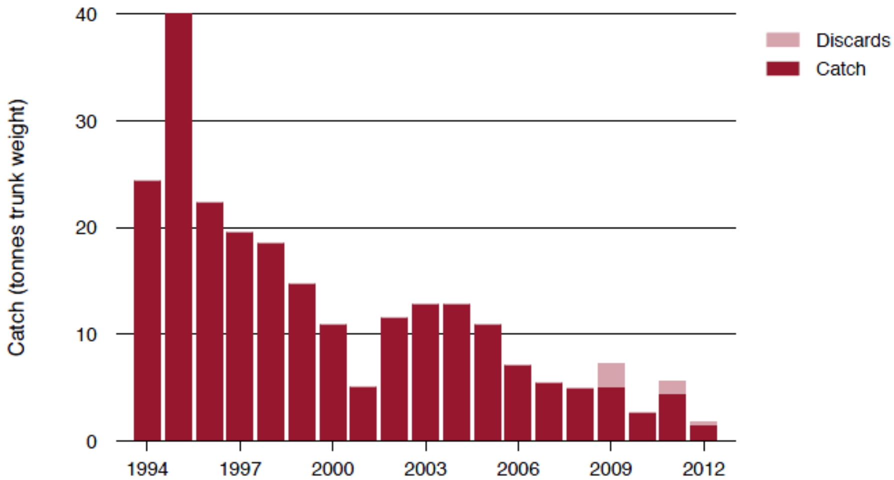

Figure 8. Annual catch and discards of gulper sharks for the SESSF from 1994 to 2012 (source: Woodhams et al. 2013).

Relative fishing intensity for the 2012-2013 season in the CTS and GHaT sector (specifically the Scalefish Hook Sector of the GHaT) are shown in Figures 9 and 10, respectively. In February 2013, a zero retention limit was implemented for Harrisson's dogfish (Woodhams et al. 2013) along with other management measures detailed in AFMA's Upper-Slope Dogfish Management Strategy (AFMA 2012b; see **Adequacy of Existing Regulatory Mechanisms** below).

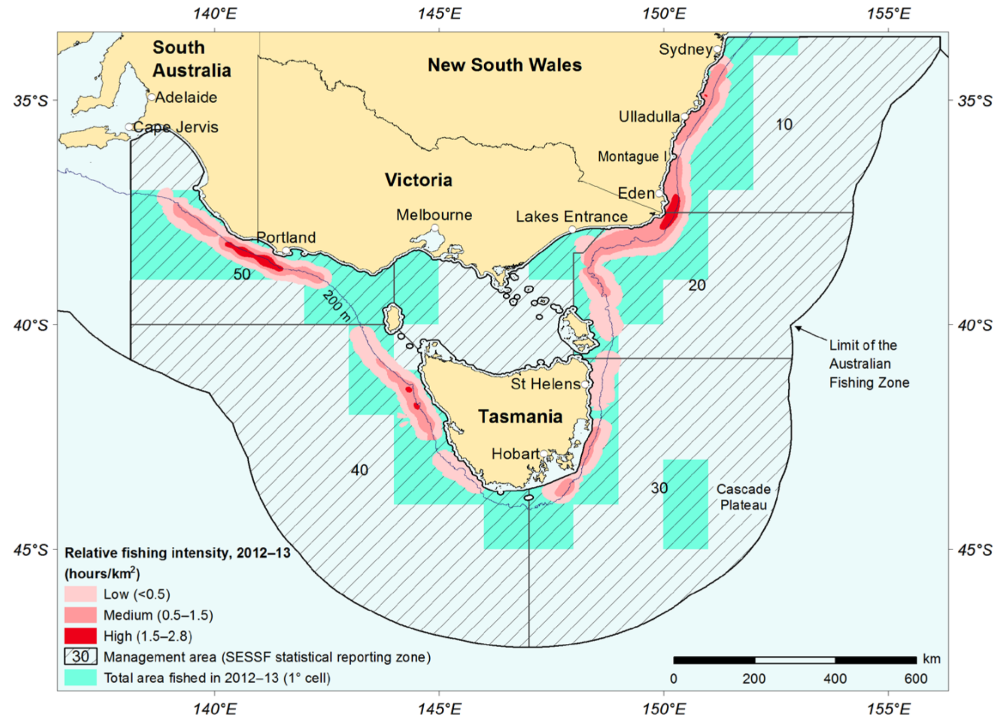

Figure 9. Relative fishing intensity (hours/km^2) for the 2012-2013 fishing season in the Commonwealth Trawl Sector (Source: Woodhams et al. 2013).

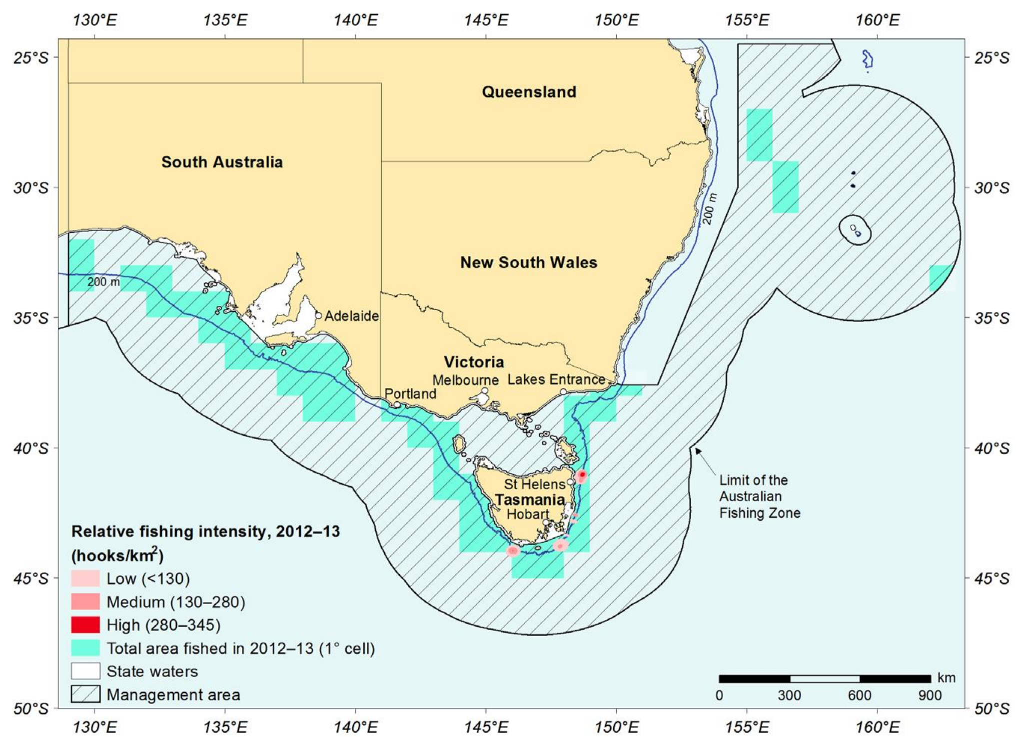

Figure 10. Relative fishing intensity (hours/km^2) for the 2012-2013 fishing season in the Scalefish Hook Sector of the GHaT (Source: Woodhams et al. 2013).

Given the evidence of substantial depletion of both Harrisson's and southern dogfish in Australian waters over the years, high risk to overfishing in the SESSF, with no current indication of recovery (based on 2012-2013 season data), the Australian Government Department of Agriculture classified gulper sharks as "overfished" in 2012, with the current level of fishing mortality noted as "uncertain" (Woodhams et al. 2013). In fact, upper slope gulper sharks have been classified as overfished since they were first included in Australia's Fishery Status Reports in 2005 (Woodhams et al. 2011).

In NSW-managed waters, problems with species identification in logbook data have prevented species-specific assessments for the NSW commercial fisheries (Rowling et al. 2010). Landings of all dogfish by NSW commercial fisheries from 1997-2009 are presented in Figure 11. Recreational harvest of dogfish in NSW waters is thought to be less than 10 t (Rowling et al. 2010). According to Graham (2013), there are up to 5 trawlers in the NSW Offshore Trawl fishery who fish seasonally between Newcastle and Sydney and may incidentally catch Harrisson's dogfish, and only minimal line fishing effort on the upper-slope (K. Graham, personal communication). In 2013, a zero retention limit was implemented for Harrisson's dogfish (unless for scientific purposes as agreed by Fisheries NSW) (NSW DPI 2013).

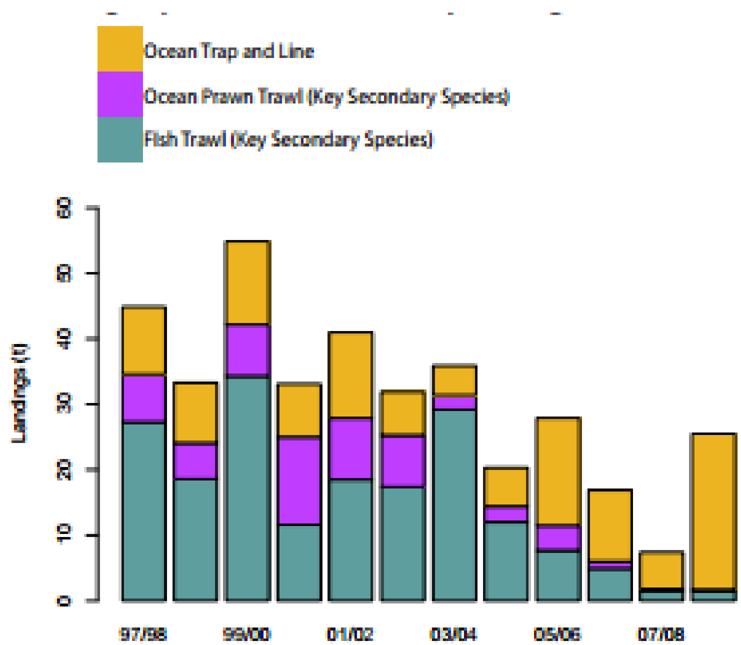

Figure 11. Reported NSW commercial fishery landings of dogfish from 1997-2009. Those fisheries that contributed < 2.5% of landings were excluded from this graph (source: Rowling et al. 2010).

Fisheries NSW (the part of NSW DPI that manages NSW fisheries) also conducted a risk assessment to evaluate the impacts of both commercial and recreational ocean-based fishing methods on a number of deepwater sharks, including Harrisson's dogfish (NSW DPI 2012). Results showed that Harrisson's dogfish was at high risk from dropline and bottom setline/trotline fishing, medium risk from handline and royal red prawn trawl fishing, and at low or no risk from all other methods (NSW DPI 2012). These results were taken into consideration as Fisheries NSW developed a management strategy to complement the Commonwealth's Upper-Slope Dogfish Management Strategy, and provide protection to Harrisson's dogfish in NSW waters and waters where both jurisdictions overlap (NSW DPI 2012; see **Adequacy of Existing Regulatory Mechanisms** below).

Although Harrisson's dogfish is no longer targeted by the Commonwealth and NSW fisheries, it can still be incidentally caught in the trawl and line fisheries, which can lead to additional fishery-related mortality. Understanding the survival rate of the species on different types of demersal gear, such as trawls, longlines, droplines, and deep-set gillnets, is an important consideration when examining the species' mortality in fisheries. In terms of trawl gear, Harrisson's dogfish sharks are not expected to survive after capture (Rowling et al. 2010); however, very little is known about their at-vessel fishing mortality on other types of fishing gear. In a study that evaluated survival on auto-longline fishing gear, Williams et al. (2013a) examined observer data from two fishing trips on auto-longline fishing vessels near the Flinders Research Zone in 2012. During the two trips, a total of 105 Harrisson's dogfish were observed caught on the auto-longline gear. Of this number, 4 were dead when released from the gear, placing at-vessel mortality at approximately 4%. If sharks that did not swim away (indicating duress and potential shock) but were not dead were counted as also suffering from at-vessel fishing morality, then mortality increases to 29%. If sharks that swam away slowly (indicating some stress from capture) are included in the estimate, the mortality rate increases dramatically to 73% (Williams et al. 2013a). Overall, these data indicate post capture mortality of Harrisson's dogfish on this type of fishing gear is highly uncertain and likely to vary with soak time, in particular. Hence, results should be interpreted with caution.

Given the high risk of Harrisson's dogfish to overfishing by Commonwealth and NSW fisheries, with sustainable harvest rates of gulper sharks thought to be < 5%, even as low as 1% (reflecting the proportion of total population that can be caught and still maintain sustainability of the population; Forrest and Walters, 2009), and the evidence of high at-vessel mortality in trawl gear and potentially high mortality in auto-longline gear, the continued fishing effort on the upper-slope and potential for incidental capture of Harrisson's dogfish in the trawl and line fisheries described above is considered a threat contributing to the overutilization of the species and its risk of extinction.

In the areas off New Zealand where *C. harrissoni* have been observed (Three Kings Ridge, Norfolk Ridge, and Kermadec Ridge), there is limited commercial fishing effort (Graham 2013). The fishing activities include trawling on the West Norfolk Ridge, drop-lining for large teleosts on the Three Kings Rise, West Norfolk Ridge, and Wanganella Bank, and minimal longlining and close to no trawling on the Kermadec Ridge. No bycatch of gulper sharks have been reported from these fishing activities (based on a personal communication from C. Duffy in Graham (2013)). Given the uncertainty surrounding the *C. harrissoni* abundance in this area, it is currently unknown if these fishing activities are impacting Harrisson's dogfish populations or significantly contributing to its extinction risk (Graham 2013).

Disease or Predation

No information has been found to indicate that disease is a factor in Harrisson's dogfish abundance or status. In addition, no information is available to indicate that predation (other than by humans) is a threat to the species.

Adequacy of Existing Regulatory Mechanisms

The ESA requires an evaluation of existing regulatory mechanisms to determine whether they adequately address threats to the Harrisson's dogfish population. Existing regulatory mechanisms may include Federal, state, local, and international regulations. Below is a description and evaluation of current management measures that affect Harrisson's dogfish.

Australia's Environment Protection and Biodiversity Conservation (EPBC) Act 1999 provides a legal framework to protect and manage Australia's nationally and internationally important flora, fauna, ecological communities and heritage places that are of national environmental significance. The EPBC Act applies to any group or individual whose actions may have a significant impact on a matter of national environmental significance. The action must then be assessed under the under the Act to determine its environmental impact.

Under the EPBC Act, any person is allowed to nominate a native species, ecological community or threatening process for listing as a matter of national environmental significance, and in 2009, Harrisson's dogfish was nominated for listing as a threatened species under the Act. Its status was reviewed by the Threatened Species Scientific Committee (TSSC), a committee established under the EPBC Act 1999 to advise the Minister for the Environment on the amendment and updating of lists of threatened species, threatened ecological communities, and key threatening processes, and with the making or adoption of recovery plans and threat abatement plans. The TSSC was tasked with determining *C. harrissoni*'s eligibility for listing as a vulnerable, endangered, critically endangered, or conservation dependent species. Under the EPBC Act, a species may be eligible for listing as critically endangered, endangered, or vulnerable if it meets any of the following criteria:

Part A – Criteria for listing species under the *Environment Protection and Biodiversity Conservation Act 1999* and *Environment Protection and Biodiversity Conservation Regulations 2000*

For section 179 of the EPBC Act (which provides general eligibility for inclusion in a category of the list of threatened species), a native species is in the critically endangered, endangered or vulnerable category if it meets any of the criteria for the category mentioned in the following table:

	Criterion	Category Critically Endangered	Endangered	Vulnerable
1	It has undergone, is suspected to have undergone or is likely to undergo in the immediate future:	a very severe reduction in numbers	a severe reduction in numbers	a substantial reduction in numbers
2	Its geographic distribution is precarious for the survival of the species and is:	very restricted	restricted	limited
3	The estimated total number of mature individuals is: and either of (a) or (b) is true: (a) evidence suggests that the number will continue to decline at: or (b) the number is likely to continue to decline and its geographic distribution is:	very low a very high rate precarious for its survival	low a high rate precarious for its survival	limited a substantial rate precarious for its survival
4	The estimated total number of mature individuals is:	extremely low	very low	low
5	The probability of its extinction in the wild is at least:	50% in the immediate future	20% in the near future	10% in the medium-term future

After a comprehensive review of the available information (see TSSC 2013), the TSSC concluded that the species was eligible for listing as endangered under the EPBC because it met Criterion 1 – it has undergone a severe reduction in numbers. The TSSC also determined that not enough information was available to indicate the species met any of the other criteria under the EPBC Act.

To be eligible for listing as a "conservation dependent" species under the EPBC Act, the species must either be: 1) the focus of a specific conservation program the cessation of which would result in the species becoming vulnerable, endangered or critically endangered, or 2) is a fish and is the focus of a plan of management that provides for managed actions necessary to stop the decline of, and support the recovery of, the species so that its chances of long term survival in nature are maximized. Based on the recently developed plan of management for Harrisson's dogfish (including the "Upper-Slope Dogfish Management Strategy" for the Commonwealth jurisdiction (AFMA 2012b), and the "NSW Strategy to assist with the rebuilding of Harrisson's and southern dogfish populations" for the NSW jurisdiction (NSW DPI 2012)), the TSSC determined that the species met the latter requirements of the conservation dependent eligibility, and recommended the Minister to list the species in the conservation dependent category. In May 2013, the Minister officially listed Harrisson's dogfish as a conservation dependent species.

Below is a summary of some of the current regulatory measures (with some prior background information) from these two management plans that are applicable to Harrisson's dogfish and were deemed adequate by TSSC to stop the decline and promote recovery of the species:

Upper-Slope Dogfish Management Strategy (SESSF) - Commonwealth Jurisdiction (AFMA 2012b)

- <u>Commercial retention of dogfish is currently prohibited</u>: Previously, commercial fishermen were allowed a combined trip limit of 150 kg for Harrisson's, Southern, and Endeavour Dogfish (as a group). However, in 2010, AFMA decreased the daily catch limit to 15 kg (retained and discarded) in an effort to reduce targeted fishing of these gulper sharks (for any trip over 6 days in length, the trip limit was 90 kg) (Woodhams et al. 2011). An annual trigger limit of 4.5 t for the Harrisson's, Southern, and Endeavour Dogfish was also established in the SESSF. Based on the 2012-2013 season data, Woodhams et al. (2013) noted that there is no current indication of recovery to above the limit reference level, and the Australian Government Department of Agriculture classified gulper sharks as "overfished" in 2012 with the level of fishing mortality noted as "uncertain" (Woodhams et al. 2013). Based on this information, a complete prohibition on the commercial retention of dogfish was established and implemented in February 2013 as part of the Upper-Slope Dogfish Management Strategy.

- <u>New network of spatial/area closures</u>: There have been a number of spatial/area closures, fleet adjustments, and gear restrictions implemented since 2002 and detailed in Wilson et al. (2009). In 2007, upper-slope gulper shark closures were implemented and shark gillnets within the GHaT sector were prohibited in waters deeper than 183 m. In 2010, additional gulper shark closures were implemented, bringing the network closure coverage up to18.4% of the Harrisson's continental slope stock core habitat, and 25.7% of the seamount stock core habitat. However, these closures were deemed to be inadequate to prevent further declines or recover the species (Musick 2011; Woodhams et al. 2011). Therefore, as part of the strategy, AFMA implemented three new closures, extended four existing closures, and revised three existing closures (by amending management measures within the closures) based on the results from candidate area analyses (AFMA 2012b). These current closures now provide protection for the species from high-risk fishing methods over an estimated 29.5% of its core habitat (19.8% of core continental margin habitat and 98.2% of core seamount habitat). In addition, the following regulations also apply in these closures:

- 100% monitoring in closures that allow limited fishing methods: All line boats require either electronic monitoring or an observer on board while line fishing in closures.

- Move-on provision in closures: There is a vessel interaction limit of 3 gulper sharks in the closure area. If this limit is reached, the closure area will be closed to the vessel for 12 months.

- Gear handling: Gulper sharks are prohibited from being taken through auto-longline de-hooking rollers or spiking with a gaff.

- Gear restrictions: In closures that allow power hand-line fishing, there is a maximum soak time of 90 minutes and an allowance of no more than 25 hooks per individual line.

NSW Strategy – NSW Jurisdiction (NSW DPI 2012)

- Landing of Harrisson's dogfish by commercial, recreational, and charter boat fishermen is currently prohibited: In 2010, NSW had implemented a combined trip limit of 65 kg for upper-slope dogfish, including Harrisson's dogfish. However, based on the species' significant depletion and nomination for listing as a threatened species, NSW has since revised this to a zero retention limit.

- Restricted Areas in NSW waters: After conducting a risk assessment of all ocean-based fishing methods (both commercial and recreational), results showed that Harrisson's dogfish was at high risk from dropline and bottom setline/trotline fishing, medium risk from handline and royal red prawn trawl fishing, and low or no risk from all other methods (NSW DPI 2012). In order to minimize mortality and interactions with fishing operations, especially with regard to high-risk methods, a number of restricted areas were established with prohibitions against various fishing methods, including commercial line fishing (bottom setlining/trotlining and droplining) and trawl fishing. The TSSC estimated that the closures to trawl fishing, except at the shallowest depths, provided the whole species with an additional 2.4% protection in habitat area, and the continental margin stock an additional 3% protection (TSSC 2013).

- Gear restrictions: Only circle hooks may be used on setline fishing (because circle hooks are known to increase post-release survival for sharks).

As many of these regulatory mechanisms have only recently been implemented (February 2013), their likelihood of effectiveness at reducing the extinction risk of the species has not yet been demonstrated. As such, the adequacy of these regulatory mechanisms in decreasing threats to the species and potentially improving its status will be evaluated by NMFS before it makes its listing decision.

As mentioned previously, in the areas north of New Zealand where Harrisson's Dogfish has been recorded, there are some protections from fishing for the species. Both the Kermadec and Colville Ridges are covered by benthic protection areas which prohibit dredging and trawling. The sea around the Kermadec Islands (which extends 12 nautical miles around the islands and covers a portion of the Kermadec ridge) has been a no-take marine reserve since 1990. In 1956, Three Kings Island (found on Three Kings Ridge) was declared a Nature Reserve for the preservation of flora and fauna. However, the adequacy of these management measures in controlling threats to the species cannot be determined as the abundance and effect of fishing on the population of Harrisson's dogfish in this area is unknown.

Other Natural or Manmade Factors Affecting the Continued Existence of Harrisson's Dogfish

Many sharks are thought to be biologically vulnerable to overexploitation based on their life history parameters. Species with slow population growth rates, late age at maturity, long gestation times, low fecundity, and higher longevity are especially sensitive to elevated fishing mortality (Musick 1999; García et al. 2008; Hutchings et al. 2012). These life history traits increase the species' susceptibility to depletion by decreasing the species' ability to rapidly recover from exploitation. Harrisson's dogfish exhibits these same life history traits, with female age at maturity estimated between 23 and 36 years of age (Daley et al. 2002; Wilson et al. 2009; Last and Stevens 2009; Graham and Daley 2011), gestation times of 2-3 years (Kyne and Simpfendorfer 2007; Graham and Daley 2011), litter sizes of only one to two pups, and longevity assumed to be over 46 years of age (Wilson et al. 2009). Based on data from two closely related species with similar life history parameters (*Deania calcea* and *D. quadrispinosa*), in the case of depletion, recovery time is likely to exceed 75 years (Irvine et al. 2012). Thus, because the species has been faced with other threats, such as significant historical overutilization, these life history traits increase the species' risk of extinction by preventing the species from recovering quickly from depletion (as evidenced by the results from research surveys discussed above – Graham et al. 2001) and increasing its susceptibility to demographic risks (discussed later in this document under the **Extinction Risk Analysis** section).

ASSESSMENT OF EXTINCTION RISK

According to section 4 of the ESA, the Secretary (of Commerce or the Interior) determines whether a species is threatened or endangered as a result of any (or a combination) of the following factors: (A) destruction or modification of habitat, (B) overutilization, (C) disease or predation, (D) inadequacy of existing regulatory mechanisms, or (E) other natural or man-made factors. Collectively, I refer to these factors as "threats." In addition to reviewing the best available information on threats to Harrisson's dogfish, I considered demographic risks to the species, similar to approaches described by Wainwright and Kope (1999) and McElhany et al. (2000). The approach of considering demographic risk factors to help frame the evaluation of extinction risk has been used in many NMFS status reviews, including: Pacific salmonids, Pacific hake, walleye pollock, Pacific cod, Puget Sound rockfishes, Pacific herring, scalloped hammerhead sharks and black abalone (see http://www.nmfs.noaa.gov/pr/species/ for links to these reviews). In this approach, the collective condition of individual populations is considered at the species level according to four demographic viability risk criteria: abundance, growth rate/productivity, spatial structure/connectivity, and diversity. These viability criteria reflect concepts that are well founded in conservation biology and that individually and collectively provide strong indicators of extinction risk. Using these concepts, as well as their links to the threats discussed above, I estimated the likely overall extent of extinction risk faced by Harrisson's dogfish. Because species-specific information (such as current and historical abundance) is sparse, and levels of historical fishing effort on the species and subsequent removals are unknown or uncertain, quantitative models depicting likelihood of extinction are unavailable.

Recommendations as to whether the species should be listed as threatened or endangered were not part of this analysis. Rather, scientific conclusions about the overall risk of extinction faced by the species under present conditions and in the foreseeable future were based on an evaluation of the species' demographic risks and threats. Determination of the ESA listing status of each species is a decision that includes the above analyses as well as consideration of the certainty of implementation and effectiveness of future conservation efforts, the certainty of effectiveness of existing conservation efforts, as well as other management considerations.

Demographic Risks

Due to the lack of information on the species' life history and ecology (such as factors that contribute to fertilization and recruitment success, reproductive and courting behaviors, and general movement behaviors), significant uncertainties exist surrounding the levels of risk posed by the demographic factors and are discussed below.

Abundance

Because species-specific historical and current abundance estimates are not available, Williams et al. (2013a), with input from, and review by, AFMA, stakeholders, and the Independent Gulper Shark Scientific Working Group (SWG), estimated the relative carrying capacity (K) and depletion rates of Harrisson's dogfish using habitat as a proxy for biomass. Detailed information on the data sources and methods can be found in Williams et al. (2013a). Below is a brief summary of the results from this effort.

Carrying Capacity (K)

Using the entire range of Harrisson's dogfish, estimates of K per habitat segment were calculated from fisheries-independent data sources (including the FRV *Kapala* survey data discussed above, and surveys conducted by CSIRO using the FRV *Soela*), inferred using habitat correlations, or inferred from adjacent segments and population scale estimates. Results showed that estimated pre-fishery (pre-1980) densities for Harrisson's dogfish were highest from Central NSW to northeast Victoria, and off the seamounts (see Figures 12 and 13). These areas have the highest relative K, historically supporting the largest populations of Harrisson's dogfish (Figure 14).

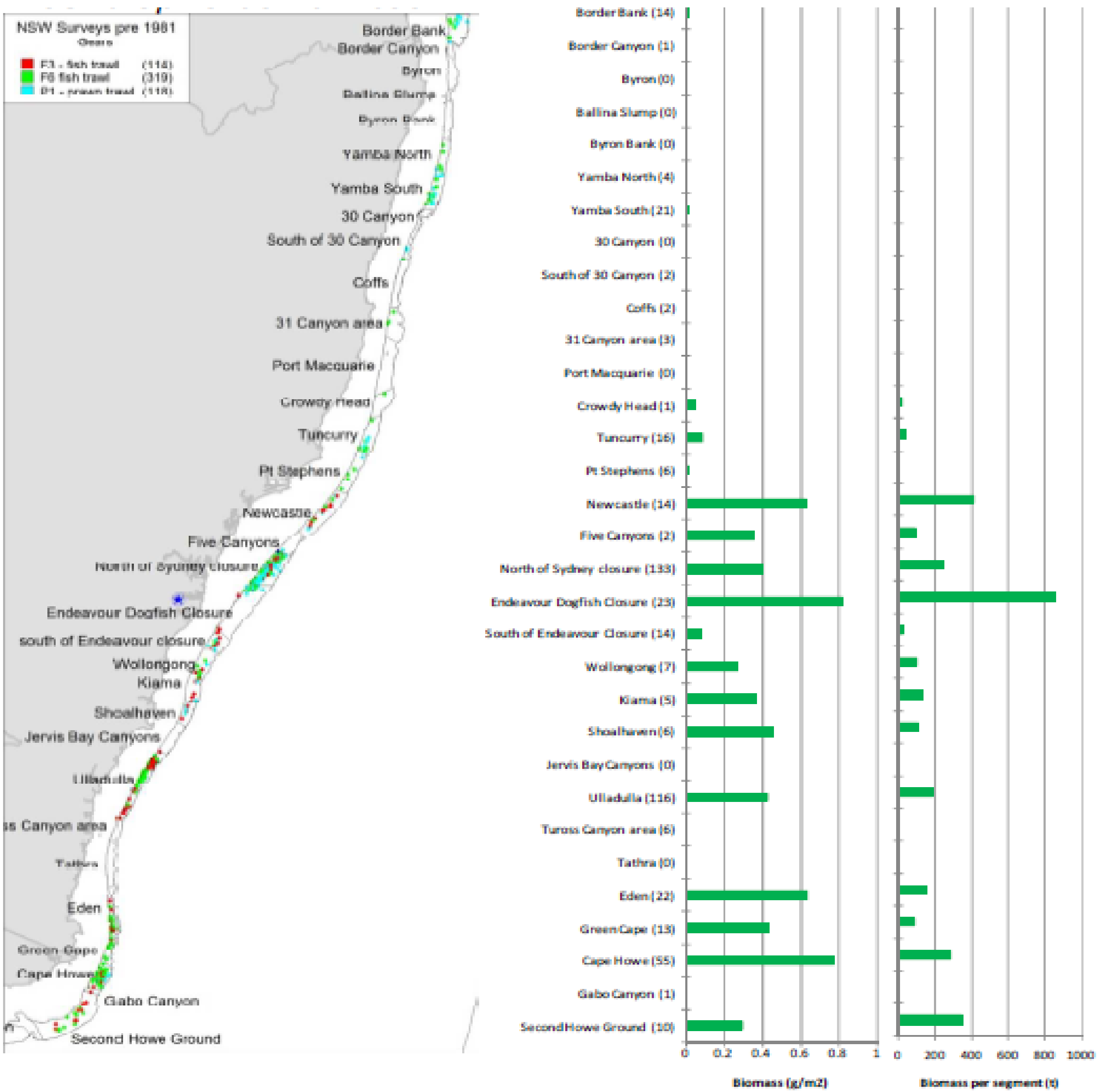

Figure 12. Estimates of pre-fishery Harrisson's dogfish biomass density (g/m^2) and biomass per segment (t) in NSW. Numbers in parentheses denote number of samples (source: Williams et al. 2013a).

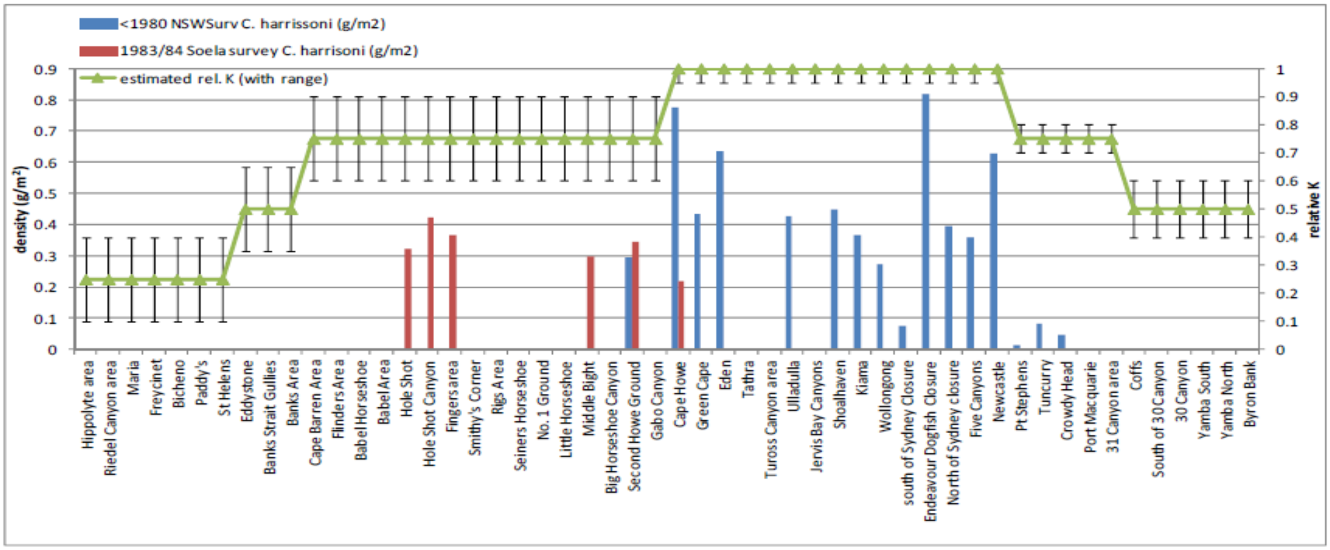

Figure 13. Pre-fishery density (g/m^2) and relative carrying capacity (K) of Harrisson's Dogfish based on trawl survey catches from research fishery surveys conducted pre-1980 and in 1983/84. K assumes a catchability by trawl of 1(source: Williams et al. 2013a).

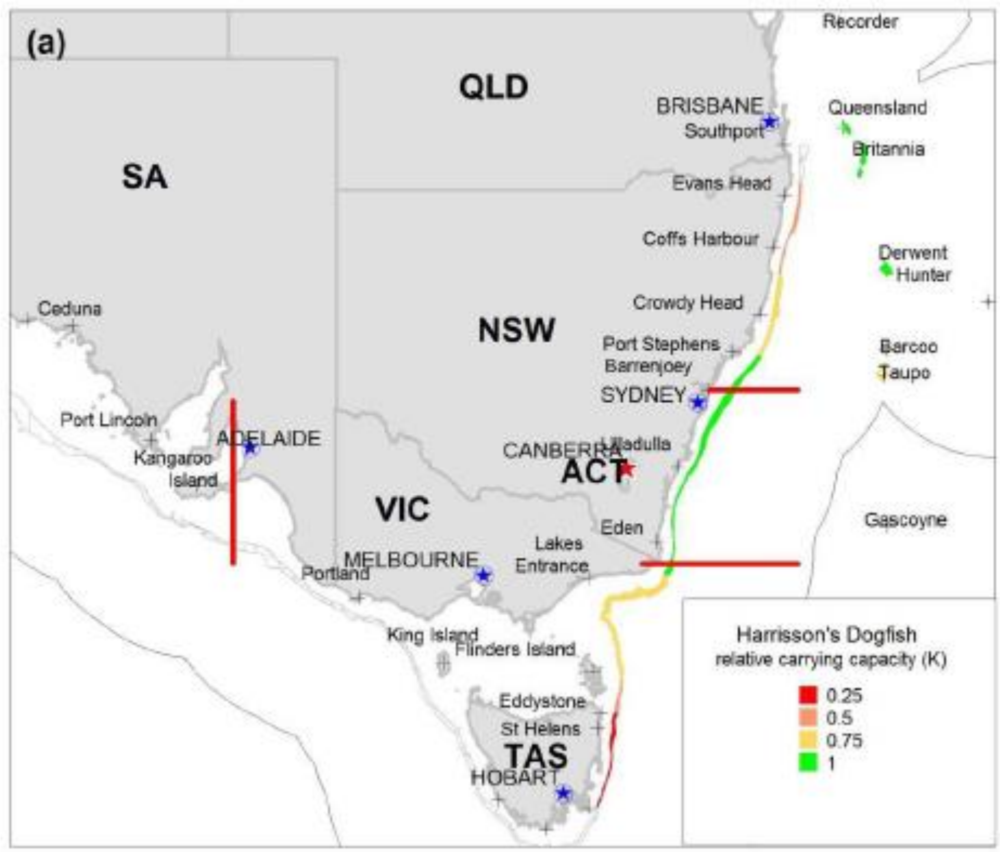

Figure 14. Map of the spatial distribution of the estimated pre-fishery relative carrying capacity (K) for Harrisson's dogfish. Red lines separate subregions based on fisheries and jurisdictional boundaries. K assumes a catchability by trawl of 1(source: Williams et al. 2013a).

Depletion

Williams et al. (2013a) estimated depletion rates of Harrisson's dogfish, expressed as the proportion of K that is remaining, in two ways. The first way (D1) calculated depletion based on a qualitative analysis using interpretations of current abundance data, historical effort distribution, knowledge of sub-regional scale patterns of removals, recent survey data, and knowledge of depletion rates in time series data off NSW. The second method (D2), which was a more conservative approach, assigned relative levels of depletion to habitat segments based on the cumulative historical effort for all demersal gears (but did not incorporate patterns of removals). Williams et al. (2013a) cautioned that the D2 method should be used only as a "reality check" and that the D1 method provides the best estimates of depletion. Table 1 presents the results of the depletion analyses.

Table 1. Area standardized estimated level of depletion of Harrisson's Dogfish (source: Williams et al. 2013a).

Harrisson's Dogfish (*C. harrissoni*)		Total area (km²)	D_1	D_2	Depletion lower limit	Depletion upper limit	Estimate qualifiers
Population scenario 1	Single population (margin & seamounts)	22,765	0.21	0.23	0.11	0.31	Overall depletion estimate strongly influenced by assumed low depletion on seamounts. Overall estimate is area standardised, but relative population sizes on margin and seamounts are unknown.
Population scenario 2	Continental margin population	19,674	0.11	0.14	0.04	0.20	Depletion on margin influenced by uncertainty about level of cumulative effort on the slope off northern NSW
	Seamount populations	3,091	0.75	0.75	0.50	1	Population abundance on seamounts, and connectivity between seamounts, and with margin, all unknown
Subregions	**Fisheries sectors / jurisdiction**						
	South of NSW border - Commonwealth	8,441	0.11	0.14	0.06	0.17	D_2 likely to underestimate depletion due to removals by targetted fishery off eastern Bass Strait (see Figure 6)
	NSW border to Barrenjoey - Comm. & NSW	5,062	0.06	0.06	0.02	0.11	Consistent with independent estimate (Graham et al. 2001)
	North of Barrenjoey - NSW	6,172	0.16	0.20	0.04	0.32	Uncertainty about level of cumulative effort on the slope may affect both estimates

Overall, Harrisson's dogfish is estimated to be at 21% of its virgin (pre-fishery) population size (with a lower limit of 11% and upper limit of 31%). When the continental and seamount stocks are examined separately, the resultant depletion estimates provide a stark comparison of the effects of historical trawling. For the continental margin population, which experienced significant trawling from the 1970s through 1990s, depletion is estimated to be 0.11 (with a lower limit of 0.04 and upper limit of 0.2) or, in other words, the continental margin population is estimated to be at 11% of its virgin population size. On the other hand, the seamount population is estimated to be at 75% of its pre-fishery population size (with a lower limit of 50% and upper limit of 100%). When broken out by sub-region fishery sector/jurisdiction, depletion is greatest within the historically heavily trawled areas off southern NSW (from Barrenjoey to NSW border; see Figure 15). This area has been substantially fished by Commonwealth trawl & NSW line and other demersal gears (Figure 15), with the Harrisson's dogfish population estimated to be only 6% of K (Table 1).

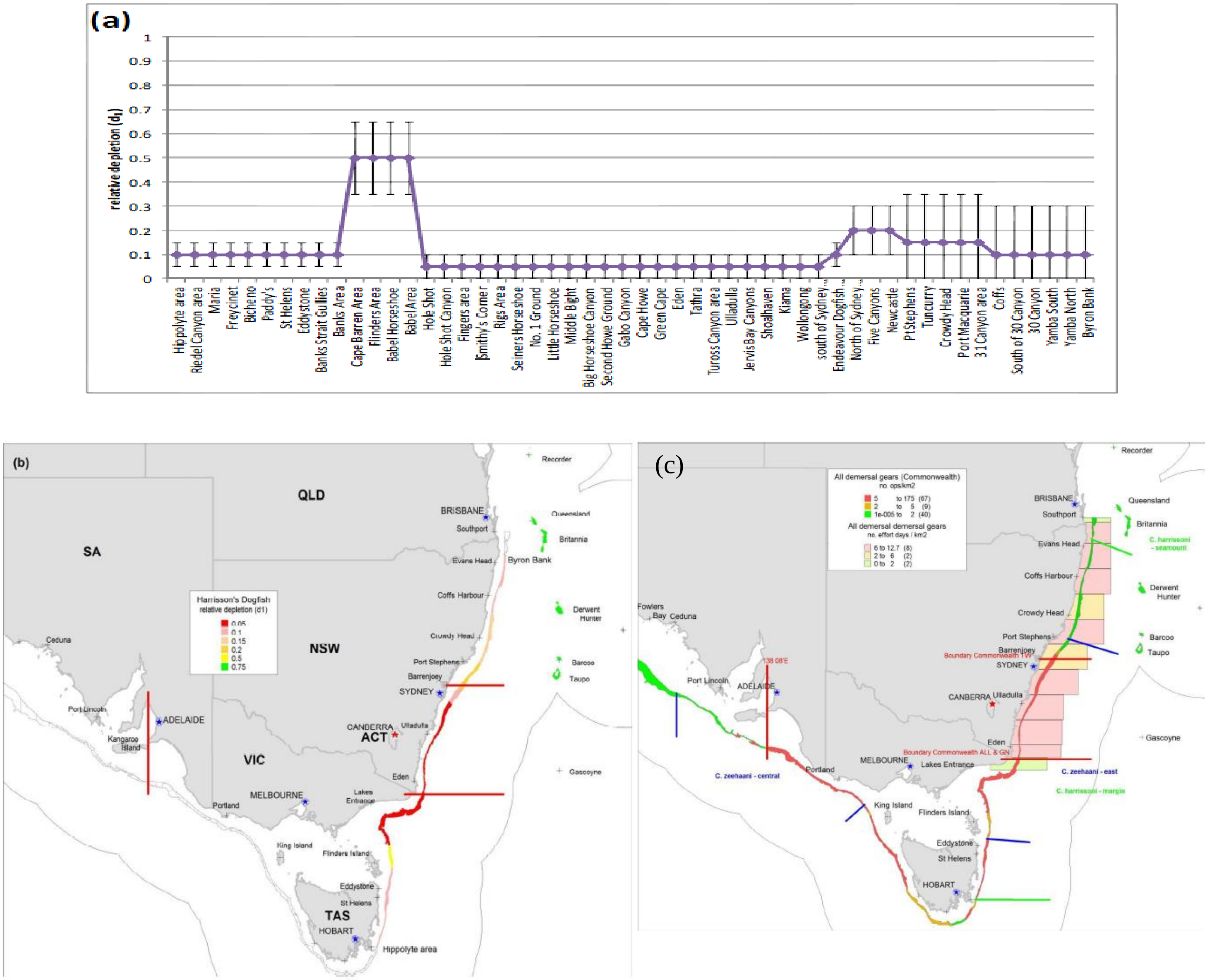

Figure 15. Spatial distribution of the estimated relative depletion (D1) for the continental margin population of Harrisson's dogfish and demersal gear fishing effort. (a) Graph depicting the D1 estimates and the upper and lower limits reflecting uncertainties in the data; (b) map showing the spatial depletion distribution; (c) map showing fishing effort distribution for all demersal gears. Red lines mark subregions based on fisheries/jurisdiction boundaries. Green lines mark the endpoints of the core habitat range for Harrisson's dogfish. (Blue lines mark end points of core habitat range for Southern dogfish). (Source: Williams et al. 2013a).

In addition, Williams et al. (2013a) plotted depletion of Harrisson's dogfish as a function of cumulative trawl effort for a number of habitat segments along the continental margin (Figure 16). The authors found that even low levels of trawl effort per unit area can lead to fast and high rates of depletion. This is in accordance with findings from the fishery-independent studies by

Graham et al. (1997, 2001), which indicated a > 99 % decline in Harrisson's dogfish abundance from 1976 to 1997.

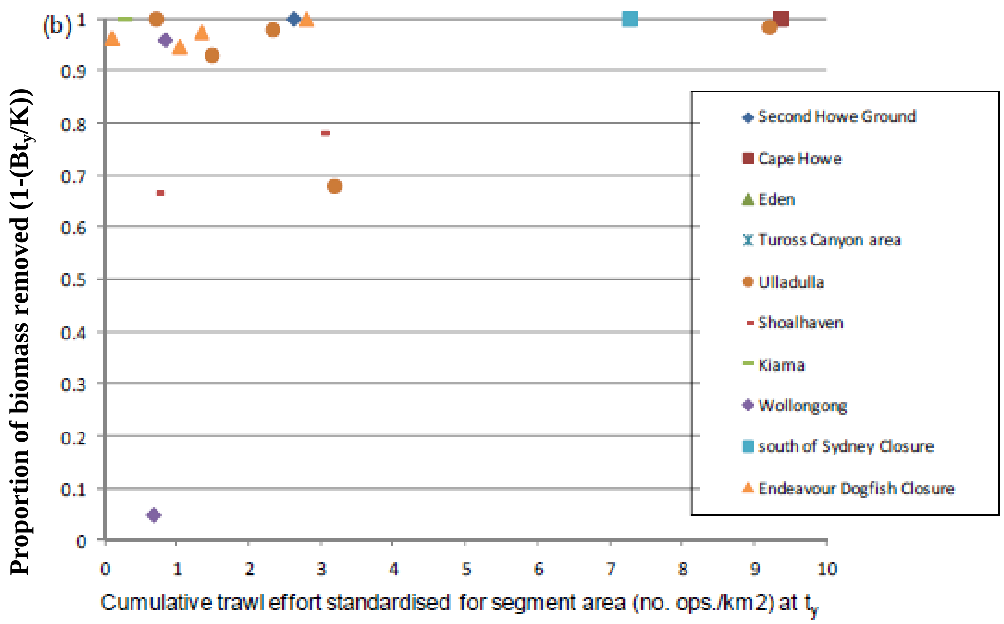

Figure 16. Depletion estimates of Harrisson's dogfish as a function of trawl effort between the Endeavour Dogfish Closure habitat segment and the Second Howe Ground habitat segment (source: Williams et al. 2013a).

As mentioned previously, the relationship between the severely depleted continental slope population and the less depleted seamount population is still unresolved, as are their respective current abundance levels and proportional contribution to the entire species as a whole. In other words, it is unknown whether the abundance levels of the less depleted seamount populations are adequate to maintain important biological and ecological functions and protect the entire species from risk of extinction. Given these uncertainties, and consideration of the species' life history, evaluation of the best available information indicates that the overall Harrisson's dogfish population has suffered substantial declines with current abundance levels that are likely inadequate to protect the species from being influenced by stochastic or depensatory processes throughout its entire range.

Growth Rate/Productivity

Although little is known about the specific biology of *C. harrissoni*, available data indicate that *Centrophorus* species, in general, exhibit life history characteristics (such as low fecundity, late maturity, slow growth rates, and long population doubling times) that increase their vulnerability to depletion and limit their ability to recover from overexploitation. Based on the data, it appears that both males and females of *C. harrissoni* do not reach reproductive maturity until they have grown to around 88% of their maximum size. For females, it means that they would have to be able to survive 23-36 years before being able to reproduce, and for males this number has been estimated between 15 and 34 years. In addition, females have an extremely low fecundity, with litter sizes of only two pups (and occasionally just one). Due to these life history characteristics, deep-water *Centrophorus* species have been suggested as possibly the least productive of the chondrichthyan fishes (Kyne and Simpfendrofer 2007). This extremely low productivity significantly increases the extinction risk of the species by hindering its ability to quickly rebound from threats that decrease its abundance (such as overutilization).

Spatial Structure/Connectivity
Harrisson's dogfish is endemic to Australia and possibly also New Zealand. It is found on the continental margin as well as on seamounts. At this time, it is not known whether the Australian seamount and continental populations mix or the level of connectivity between individual seamount populations. Limited inter-population exchange would reduce the recovery potential for depleted local populations and may increase the risk of extirpations and possibly lead to extinction.

Although Harrisson's dogfish is considered to be at 99% of its original range on the Australian continental margin, its distribution within this range is likely patchy and possibly severely fragmented due to its historical population decline. The estimated extent of occurrence for Harrisson's dogfish is 22,603 km^2 and its area of occupancy is approximately 18,197 km^2 (see Figure 17) (TSSC 2013).

Figure 17. Historical (orange + green) and current (green) extent of occurrence of Harrisson's dogfish in the Australian EEZ (Williams et al. 2012a).

Historically, sites that supported breeding activities may have been common along the Australian eastern continental margin, with mature males and females observed within the three *Kapala* survey grounds off the NSW coast (Andrew et al. 1997; K. Graham, personal communication). However, the significant trawling and subsequent depletion of the population has led to severely fragmented populations and appears to have disrupted or completely eliminated previously established breeding areas. South of Sydney, there is now only one known potential breeding site of Harrisson's dogfish, based on the presence of both mature females and mature males, and it is located in the Flinders Research Zone.

Additionally, many sites where Harrisson's dogfish are observed contain predominantly mature males, with only a few sites documenting higher numbers of females and juveniles (Graham and Daley 2011). This spatial sexual segregation may increase the extinction risk of the species if the sexes are subject to different levels of exploitation by spatially focused fishing. Although the movement behavior of Harrisson's dogfish is not currently known, a study that electronically tracked a closely related species, *C. zeehaani*, inside a fishery closure off South Australia found that most females remained within the study site, whereas the males were more likely to be non-residents, leaving the fishery closure and failing to return over the duration of the study period (15 months) (Daley et al. 2014). Hence, the patchy distribution, and potential movement and residency behavior, pose a significant risk to the species' continued existence because declines in the viable populations, or even declines in the fragmented populations of mature males (such as when outside of fishery closures) or mature females, will likely result in decreased reproductive success. This patchy distribution also makes the species more susceptible to local extirpations from environmental and anthropogenic perturbations or catastrophic events. Given the species' extremely low productivity and depleted overall abundance estimates, further decreases in mature individuals of the population could translate to drastic declines for the species as a whole.

Diversity

The loss of diversity can increase a species' extinction risk by decreasing a species' capability of responding to episodic or changing environmental conditions. This can occur through a significant change or loss of variation in life history characteristics (such as reproductive fitness and fecundity), morphology, behavior, or other adaptive characteristics. It is likely that Harrisson's dogfish is at risk from a loss of diversity based on the fact that many of the remaining populations are small, fragmented, and possibly isolated. Due to their size and isolation, these populations may be at an increased risk of random genetic drift and could experience the fixing of recessive detrimental genes that could further contribute to the species' extinction risk (Musick 2011).

<u>Analysis of overall extinction risk</u>

It is clear that the species faces current demographic risks that significantly increase its susceptibility to extinction. The species has suffered substantial declines as a result of historical overutilization and is estimated to be at 21% of its total virgin population size (with even lower estimates for the continental margin population – 11%). In areas where historical trawling effort on the continental slope was highest and most extensive (i.e., from Barrenjoey to the eastern Bass Strait, which also correspond to the highest pre-fishery biomass estimates of Harrisson's dogfish, see Figures 9-12), depletion estimates are drastically low, ranging from only 5% to 10% (of virgin population size) (Figure 12). Due to this decline, the species currently occupies only 39% of its range (or 18,197 km^2). Based on observations of the species from fishery-independent studies, the population is currently fragmented, with only three identified remnant populations that are thought to be viable (due to presence of mature males, females, and/or juveniles within the area).

Although the species' biological characteristics have allowed it to successfully thrive in the past (as demonstrated by density levels from the 1970s), under the current scenario of severely fragmented populations, questionable population viability, and low abundance, the species' natural life history traits are presently threatening its continued existence. Already, the species is at a high risk of extinction from depensatory processes, with current levels of abundance and spatial fragmentation potentially insufficient to support mate choice, fertilization and recruitment success. Even if these fragmented populations demonstrate successful mating, the species has extremely low fecundity (2-3 year gestation period resulting in 1 to 2 pups), slow growth rates, and late maturity, all of which contribute to a long population doubling time and hence extremely slow recovery from overexploitation. In fact, the SWG (2012) estimated a recovery time for *C. harrissoni* of 85.5 years, and for closely related members of the Centrophoridae, estimated time for recovery exceeds 75 years (Irvine et. al 2012). Due to its already severely depleted status, the species' natural life history traits are inhibiting population recovery and placing the species' current and future viability into question.

Environmental and anthropogenic perturbations or catastrophic events are also likely to lead to local extirpations and possibly total extinction, especially if the event resulted in a loss of any of the three critical source populations. Given the apparent spatial structuring of the species, with males dominating the majority of sites and only a few sites containing possibly resident mature females, the catastrophic event or environmental perturbation need not even wipe out the entire viable population. A simple reduction in the numbers of individuals at a certain site could prevent population replacement. The loss of a site primarily dominated by females would likely portend drastic declines in population viability and could lead to extirpations. Similarly, loss of a site primarily dominated by males may also decrease reproductive success. In addition, the fact that the species recovery time exceeds 80 years, there is a high likelihood that even a single catastrophic event, such as an oil spill, may occur and affect recovery in the foreseeable future. Thus, although more information is needed regarding the level of connectivity between the Australian seamount and continental margin populations, and the New Zealand individuals, the current size and fragmentation of populations significantly increases the species' susceptibility to extirpations from environmental and anthropogenic perturbations or catastrophic events throughout its range.

Based on the above considerations, any additional mortality on the species is likely to further exacerbate its risk of extinction. Therefore, activities that target or even incidentally catch Harrisson's dogfish would result in overutilization of the species and present a threat to the species existence. To address this threat, AFMA and NSW implemented a zero retention limit for Harrisson's dogfish in 2013; however, it is unclear whether this regulation will also decrease catch discards that have resulted in significant levels of fishing mortality for these populations (Wilson et al. 2009; Wilson et al. 2010; Woodhams et al. 2011). In 2009, observed catch discards for gulper sharks (*C. harrissoni, C. moluccensis, C. zeehaani*) in all sectors of the SESSF fishery was reported at 3 t. In 2010, observed discards decreased to 22 kg (Woodhams et al. 2012) but increased in 2011 and 2012 to 1.2 t (Woodhams et al. 2013). The maximum sustainable harvest rate of gulper sharks is thought to be < 5%, even as low as 1% of their virgin biomass (Forrest and Walters 2009). Although retaining any catch is now prohibited, Harrisson's dogfish may still be incidentally caught and discarded, a level of harvest that is currently unsustainable given the species' demographic risks. Based on the recent observed discard rates, and evidence that even low levels of fishing effort can lead to rapid and high depletion of the species (see Figure 13), this incidental fishing mortality is considered a threat to the species that significantly increases its risk of extinction.

In conclusion, based on the best available data, there has been a severe decline in the overall population of Harrisson's dogfish as a result of overutilization by commercial fisheries and further exacerbated by the species' natural biological vulnerability to overexploitation. At this time, it is uncertain whether the inadequacy of existing regulatory measures also poses a threat to the species as many of the current regulatory measures have only recently been implemented and their effect on the species has yet to be seen. NMFS will evaluate the likelihood of effectiveness of these regulatory mechanisms in improving the status of Harrisson's dogfish before making its listing decision.

Due to the aforementioned threats and demographic risks, and taking into account uncertainties regarding the connectivity between the seamount and continental margin populations, I conclude that the Harrisson's Dogfish is presently at a high risk of extinction throughout all of its range because the species is at or near a level of abundance, productivity, spatial structure, and diversity that make it likely to be influenced by stochastic or depensatory processes. Overall, these threats place the current viability of the species into question.

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