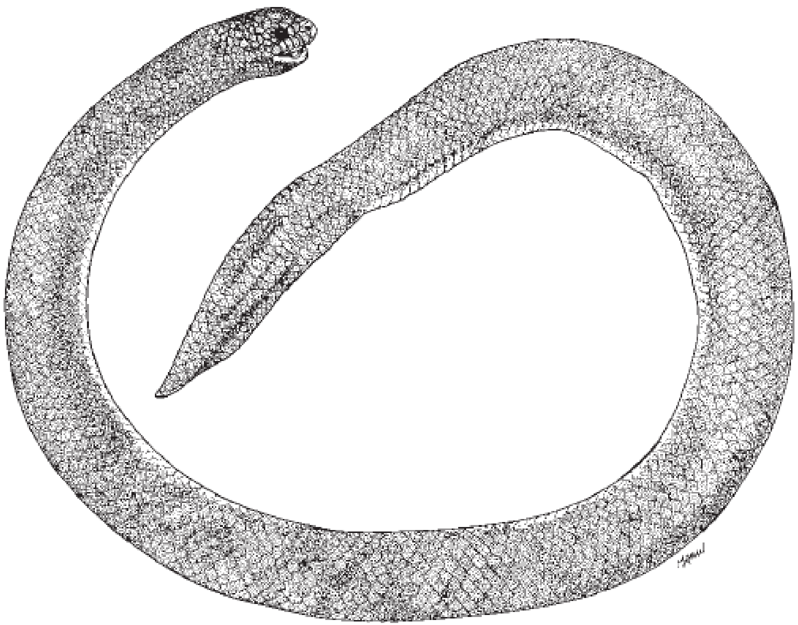
ENDANGERED SPECIES ACT
STATUS REVIEW REPORT for the DUSKY SEA SNAKE

Aipysurus fuscus



Rasmussen, 2001

AUGUST, 2014

NATIONAL MARINE FISHERIES SERVICE

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

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Executive Summary

This report was produced in response to a petition received from WildEarth Guardians on July 15, 2013, to list 81 marine species as endangered or threatened under the Endangered Species Act (ESA). Three of the petitioned species were sea snakes. The National Marine Fisheries Service (NMFS) evaluated the petition to determine whether the petitioner provided substantial information as required by the ESA to list these species. On November 6, 2013, NMFS announced in the *Federal Register* that the petition did present substantial information that listing may be warranted for one of the three sea snakes, *Aipysurus fuscus*, commonly referred to as the dusky sea snake; and NMFS requested information on this species from the public (78 FR 66675). Subsequently, NMFS initiated a status review of this species, which I document in this report. This draft report summarizes available data and information on the dusky sea snake and presents an evaluation of the species' status and extinction risk.

A. fuscus is a marine snake endemic to a small number of coral reefs offshore of Western Australia in the Timor Sea. Declines in this species have been observed at multiple reefs, and its absence in repeated surveys strongly suggests it has been extirpated from a large percentage of its historic range. No abundance estimates are available for this species, but the current range is estimated to be no more than 262 km^2. Causes for the observed declines are unknown, but potential threats include climate change, loss of live coral reef habitat, and hybridization with the congener, *A. laevis*. Although the habitat of the dusky sea snakes receives substantial protection from human disturbance through national and international mechanisms as well as through natural isolation, the species has nonetheless undergone declines at multiple reef locations. Remaining reef populations are relatively fragmented, and high rates of hybridization have been documented across the range. Given the demographic risks, the threat of hybridization, and the potential threats of climate change and coral loss, I conclude that the dusky sea snake currently faces a high risk of extinction.

INTRODUCTION

Scope and Intent of the Status Review

On July 15, 2013, NMFS received a petition from WildEarth Guardians to list 81 species of marine organisms as endangered or threatened species under the Endangered Species Act (ESA). After evaluation of the petition, NMFS found that the petition presented substantial scientific information that listing of the dusky sea snake under the ESA may be warranted (78 FR 66675; November 6, 2013). If a petition is found to present substantial scientific or commercial information that the petitioned action may be warranted, NMFS is required to promptly commence a status review for the particular species to help determine whether the petitioned action is warranted (16 U.S.C. §1533(b)(3)(A)). This report documents the status review for the dusky sea snake in response to the petition and the 90-day finding.

The ESA requires that listing determinations be made on the basis of the best scientific and commercial data available, after taking into consideration any efforts by any State or foreign nation, or any political subdivision of a State or foreign nation, to protect the species (16 U.S.C. §1533(b)). In order to compile the best available data on this species, I conducted an extensive literature search and contacted several researchers for reprints of relevant papers I could not otherwise obtain. As announced in the 90-day finding, NMFS also solicited the public for relevant data and information from November 6, 2013, through January 6, 2014. Relevant information submitted from the public and extracted from my literature search is incorporated into this status review.

After compiling the best available data, I completed a thorough review of the biology, population status and future outlook for this species. This status review includes an analysis of threats to the species and makes conclusions regarding the extinction risk of the species. The intention of this status review report is to provide a thorough and accurate review and analysis of the available information to support a determination about whether this species warrants protection under the ESA. Information presented in this draft report is subject to revision in response to peer and public comments as well as to any new data that become available.

Section 3 of the ESA (16 U.S.C. §1532) defines the term "endangered species" as "any species which is in danger of extinction throughout all or a significant portion of its range." The term "threatened species" is defined as "any species which is likely to become an endangered species within the foreseeable future throughout all or a significant portion of its range."

For the purpose of the extinction risk analysis, the term “foreseeable future” in the ESA’s definition of “threatened” was defined as the timeframe over which threats can be reliably predicted to impact the biological status of the dusky sea snake. In considering an appropriate “foreseeable future” timeframe, I considered both the life history of the dusky sea snake and whether I could project the impact of the particular threat. In the risk assessment section of this report, I do not define a specific “foreseeable future” due to uncertainty regarding threats and life history parameters of the species.

Types of data that are important to the evaluation of extinction risk include: 1) current abundance relative to historical abundance and carrying capacity of the habitat; 2) spatial and temporal distribution of the species; 3) trends in abundance; 4) natural and human-influenced factors that affect survival and abundance; 5) possible threats to genetic integrity; and 6) recent events (e.g., El Niño event or a change in management actions) that have predictable, short-term consequences on the abundance of the species. Additional risk factors, such as disease prevalence or changes in life history traits, may also be considered in evaluating risk to populations.

Summary of the Listing Petition

The petition states that the dusky sea snake is in decline and that protection under the ESA is necessary to prevent its extinction. In support of the request to list this sea snake under the ESA, the petition relied mainly on the International Union for Conservation of Nature (IUCN) assessment of this species, which is currently classified as “endangered” on the Red List. The petition summarizes available survey data that indicate the relative abundance of the species has declined significantly since 1998. The species also appears to have a very limited range, fragmented populations, and restricted dispersal. The petition acknowledges that the causes for the observed declines in dusky sea snake abundance are not clear, but it also states that climate change poses an “extreme threat” to the continued existence of this species. Elevated sea surface temperatures and coral bleaching are identified in the petition as particular consequences of climate change that are resulting in degradation of the dusky sea snake’s habitat; however, data to support these statements was not provided. The petition also states that existing regulatory protections, which includes a nature reserve within the species’ historical range, are not sufficient to protect this species from the global threat of climate change.

Summary of Information Received

NMFS received comments from four parties in response to the request for relevant information on the dusky sea snake. One commenter supported the listing of the “species” discussed in the 90-day petition finding (78 FR 66675; November 6, 2013) but did not provide any substantive scientific or commercial data to inform this status review. A second commenter provided data and information relevant to the hagfish species that were included in WildEarth Guardian’s petition and did not discuss sea snakes. A third commenter asserted that there is insufficient information to support listing the dusky sea snake as threatened or endangered under the ESA, and that such a listing would not provide a meaningful conservation benefit for this species. Lastly, the petitioner submitted comments in support of listing the dusky sea snake and provided four additional references.

LIFE HISTORY AND ECOLOGY

Classification and Distinctive Characteristics

The dusky sea snake, *A. fuscus*, is a valid taxonomic species within family Elapidae, a very diverse family of venomous snakes. The vast majority of marine snakes belong to subfamily, Hydrophiinae, which includes about 17 genera and 62 species. This ecologically diverse subfamily is considered to have undergone relatively recent radiation, sharing a common terrestrial ancestor only about 6-13 million years ago (Sanders *et al*. 2013a). Genus *Aipysurus* contains seven species, six of which are restricted to Australasian waters.

Scientific Classification

Kingdom	Animalia
Phylum	Chordata
Subphylum	Vertebrata
Class	Reptilia
Order	Squamata
Suborder	Serpentes
Family	Elapidae
Subfamily*	Hydrophiinae
Genus	*Aipysurus*
Species	*fuscus*

* The clade Hydrophiinae could also be called Hydrophiidae.

The dusky sea snake is completely aquatic and displays many adaptations for its marine existence. Like all sea snakes, it has a paddle-like tail for swimming; and, like all marine reptiles, it has a salt gland, which allows it to secrete salt (Dunson, 1975). The salt gland, however, may not be sufficient for maintaining osmotic balance, and consumption of fresh water may also be required (Lillywhite *et al*., 2014). Despite their aquatic existence, sea snakes lack gills and must surface to breathe air. Dive durations vary by species but most species typically stay submerged for about 30 minutes and some for 1.5 -2.5 hours (Heatwole and Seymour, 1975). Maximum dive depth for dusky sea snakes is unknown, but co-occurring members of this genus are considered "shallow" and "intermediate" depth species that dive no deeper than 20 m or 50 m, respectively (Heatwole and Seymour, 1975). Sea snakes are also capable of cutaneous respiration whereby oxygen diffuses from sea water across the skin into the blood and carbon dioxide is diffused across the skin into the water. The degree to which sea snakes are capable of this varies with species and temperature, and more specific information is lacking for the dusky sea snake.

Aipysurus fuscus is brown, blackish-brown, or purplish-brown and may have pale cross-bands on its sides. It has wide ventral scales and diamond-shaped body scales that are smooth and imbricate (i.e., overlapping). Imbricate scales probably help protect the snake from abrasion on sharp corals. There are generally 19 scale rows around the neck; 19 around the mid-body; and 155 to 180 ventral scales

The head of *A. fuscus* Guinea (2012), showing the brown body coloration.

(Rasmussen, 2001). There are 6 to 8 maxillary teeth behind the poison fangs. Average adult length may be around 60 cm (Cogger, 1975) and maximum total length is 98 cm (Lukoschek *et al*., 2010). The dusky sea snake has potent venom and is referred to as a "defensive biter," meaning it will bite when restrained or captured (Heatwole, 1975a). Unprovoked attacks by sea snakes in general are extremely rare (Heatwole, 1975a).

Range and Habitat Use

The dusky sea snake is a benthic, coral reef-associated species endemic to the shallow (<15 m deep), emergent reefs of the Sahul Shelf off the coast of Western Australia in the Timor Sea, between Timor and Australia. These reefs are relatively isolated and lie at the edge of the continental shelf over several hundred kilometers from the mainland. Smith (1926) notes that although the type specimen had been reported to come from Sulawesi (formerly, Celebes), Indonesia, it had been confused with *A. laevis*, which can be clearly distinguished from *A. fuscus* based on scale-rows and ventral counts. Given the known distribution of *A. fuscus* and the fact that no other specimens have ever been collected outside of the Australian reefs in the Timor Sea, the report from Sulawesi has been widely discounted (Cogger, 1975; Lukoschek *et al*., 2010, citing Tschudi 1837).

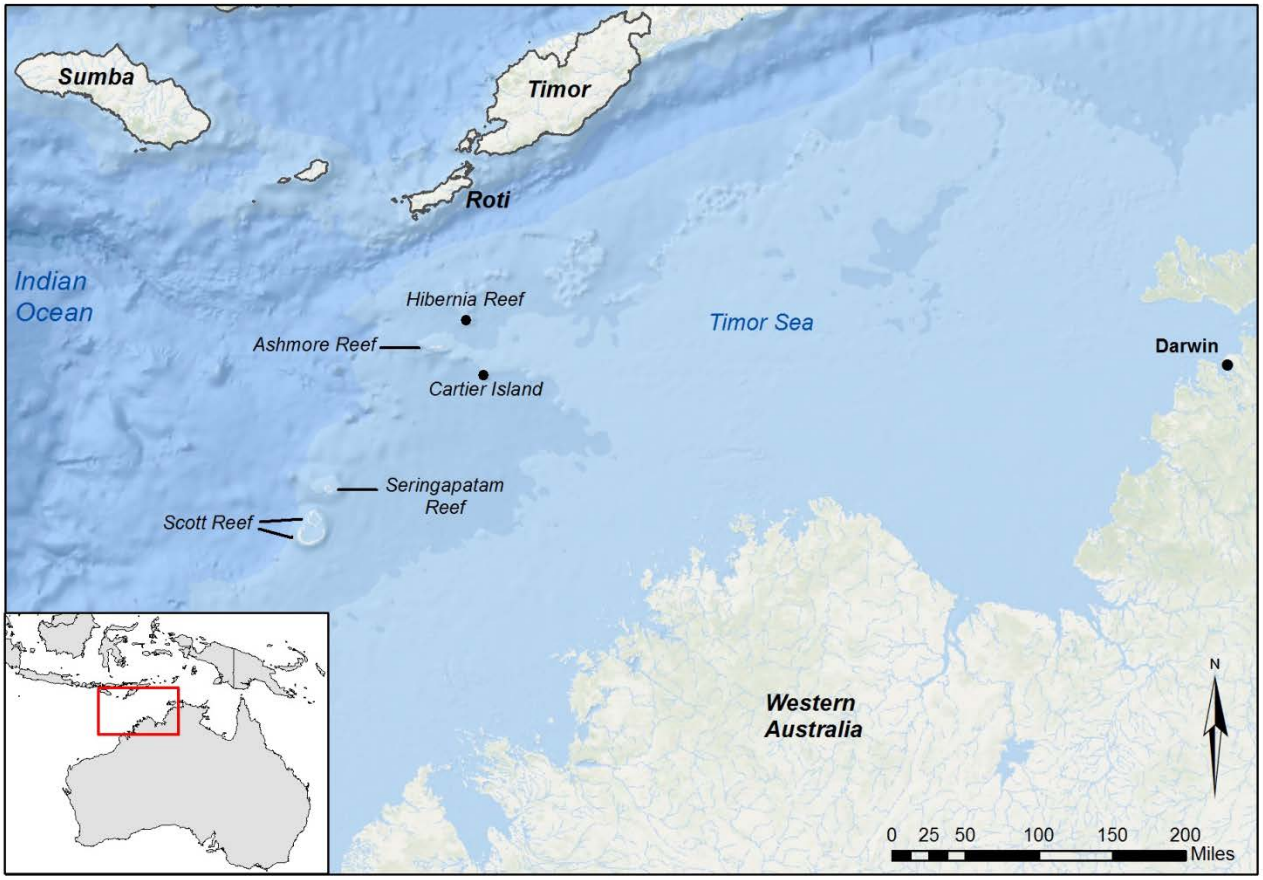


Figure 1. Reefs within the historical range of *A. fuscus* include Ashmore, Hibernia, Scott (North and South) and Seringapatam Reefs.

The Timor Sea is considered a 'hot spot' of sea snake diversity and is home to about one quarter (~14 of 62) of the world's hydrophiine sea snakes (Lukoschek *et al*., 2013). The Timor Sea region experiences an arid, tropical monsoonal climate (Hale and Butcher, 2013). Monsoonal conditions dominate from about December to May, and cyclones are relatively common within the region. Geologically, this area is also high in oil and gas reserves with active hydrocarbon seeps (Hale and Butcher, 2013). Tides are semi-diurnal, and with spring tides of over 4.5 m, a relatively high degree of tidal flushing occurs (Commonwealth of Australia, 2002).

Within the Timor Sea, the dusky sea snake has been reported or observed at several reefs, including Ashmore, Scott, Seringapatam and Hibernia Reefs (Figure 1). However, individual surveys have not consistently recorded dusky sea snakes at all of these locations. In transect surveys conducted by Minton and Heatwole (1975) over several weeks during December 1972–January 1973 at Ashmore, Scott, and Hibernia Reefs and Cartier Island, dusky sea snakes were recorded at Scott and Ashmore reefs only. Extensive surveys conducted more recently at Ashmore Reef, where dusky sea snakes were once relatively common, have located no specimens (Table 1). Lukoschek *et al.* (2010) estimated that the area of occurrence of dusky sea snakes is probably less than 500 km^2.

During their surveys, Minton and Heatwole (1975) observed dusky sea snakes in shallow water (< 10 m) as well as in the 12 to 25 m depth-zone. They were observed in areas of moderate to heavy coral growth, but they were also observed to congregate in sandy-bottomed gullies and channels (Minton and Heatwole, 1975). Guinea and Whiting (2005) reported that dusky sea snakes were commonly seen over sandy substrate on the flooding tide, and they were more commonly observed in low tide surveys (versus high tide surveys).

The most well-studied of the Sahul Shelf reefs is Ashmore Reef, which is also the largest of the five isolated reefs in the Timor Sea and has the highest diversity of hermatypic (reef-building) and non-hermatypic corals (Hale and Butcher, 2013; Figure 2A). Ashmore Reef has a total area of about 227 km^2, ~73.3 km of reef edge, and three islands (West, Middle and East Island; Figure 2A; Skewes *et al*., 1999). Over 750 species of fish have been recorded at Ashmore Reef; gobies and wrasses, which are the predominant prey items for the dusky sea snake, are among the most species rich groups (Hale and Butcher, 2013). The other reefs within the range of the dusky sea snake are smaller and have different configurations of reef, lagoon and channel habitat (Figure 2). Hibernia Reef, which lies about 42 km northeast of Ashmore Reef, has no dry land and becomes fairly exposed at low tide (Figure 2B). Hibernia Reef has a total area of about 11.5 km^2 and a reef-edge length of about 22 km (Skewes *et al*., 1999). The two reef areas that comprise Scott Reef (Figure 2C) have a total area of about 250 km^2 and a combined reef edge length of 248 km (Skewes *et al*., 1999). The much smaller Seringapatam Reef that lies just north of Scott Reef has a total area of 55 km^2 and a reef-edge length of about 46 km (Figure 2C; Skewes *et al*., 1999). Scott and Seringapatam Reefs rise very steeply up about 400 -500 m from the seabed but very little remains exposed at high tide. Cartier Island is an unvegetated sand cay in a platform reef that has a total area of about 11 km^2 and edge length of 12.2 km (Figure 2D; Skewes *et al*., 1999). The combined area of these reef systems is approximately 555 km^2 (Skewes *et al*., 1999).

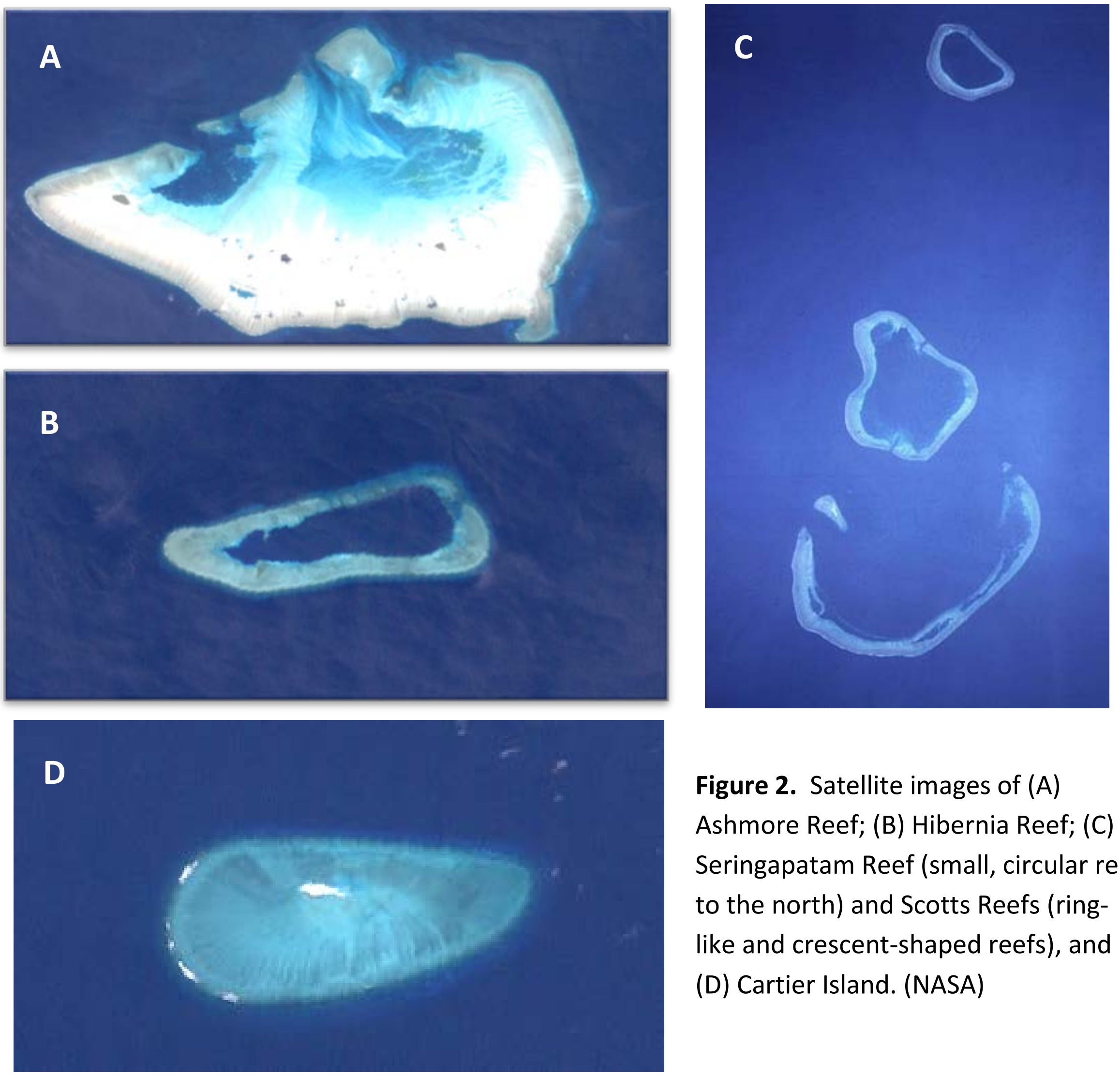


Figure 2. Satellite images of (A) Ashmore Reef; (B) Hibernia Reef; (C) Seringapatam Reef (small, circular reef to the north) and Scotts Reefs (ring-like and crescent-shaped reefs), and (D) Cartier Island. (NASA)

Sea snakes have patchy distributions and can be found in very dense aggregations in certain locations within their ranges (Heatwole, 1997). This patchiness complicates efforts to understand habitat use patterns, as seemingly suitable habitat can remain unoccupied. The temporal stability of "patches" was evaluated for the closely related congener, the olive sea snake (*A. laevis*) and another elapid sea snake, the turtleheaded sea snake (*Emydocephalus annulatus*) on over a dozen reefs in the southern Great Barrier Reef by Lukoschek *et al*. (2007a), but the presence/ absence patterns were fairly complex and had no clear source-sink or metapopulation dynamics. On a smaller spatial scale, distributions of snake fauna on Australian reefs appear to be influenced by water depth, substrate type (e.g., sand, reef), and feeding strategies (McCosker, 1975; Heatwole, 1975b). Based on an analysis of prey diversity and feeding specialization, McCosker (1975) stated that the absence or relative rarity of some *Aipysurus* species from various reefs of the Sahul Shelf did not appear to be related to a lack of suitable prey species but might instead be related to a lack of specific, shallow inner-reef habitat. Other biotic factors, such as limited juvenile dispersal, may also contribute to the observed patchy distributions (Lukoschek *et al*., 2007a). Overall, however, causative factors for observed distributions are not completely understood.

Home-range size and site fidelity of individual dusky sea snakes has not been evaluated. However, movements of its closest relative, the olive sea snake, *A. laevis* (Lukoschek and Keogh, 2006), have been studied at two sites near the southern end of the Great Barrier Reef. Using ultra-sonic transmitters, Burns and Heatwole (1998) tracked the movements of 11 adult olive sea snakes for 6-9 days and computed an estimated home-range size of 1,500-1,800 m^2. Home-ranges of the monitored sea snakes overlapped to various extents (5.5 - 86.6% overlap), but no aggressive or territorial behaviors were observed between individual snakes (Burns and Heatwole, 1998). Observations of individual sea snakes also revealed that while adult olive sea snakes at these particular locations have small home-ranges, they do not return to any one particular crevice or hiding location within the reef (Burns and Heatwole, 1998). Based on this study, it appears that movement of adults is very limited and longer distance dispersal might be due only to passive transport, such as by currents and storms. However, it should be noted that this study was very short in duration, and movements of adults may differ at other locations where the quality or stability of the habitat may be substantially different than in this particular study.

A longer duration study was conducted by Lukoschek and Shine (2012) on the turtle-headed sea snake, *Emydocephalus annulatus*, a species within the nine-species *Aipysurus* lineage and with a partially overlapping range with *A. fuscus*. Results of their 8-year mark recapture study indicated that two adjacent bays (< 1.15 km apart) in New Caledonia contain essentially discrete populations of turtle-headed sea snakes despite the snakes' ability to easily swim between the bays and despite no obvious break in suitable reef habitat (Lukoschek and Shine, 2012). Genetic analysis (11 microsatellite loci; n= 136 snakes) indicted a significant degree of genetic divergence of the two populations (F_{ST}=0.008, $p < 0.01$), supporting the finding that there is low dispersal and restricted gene flow between the two populations (Lukoschek and Shine, 2012). Overall, these studies both suggest that these sea snake species remain within fairly small home ranges and undergo limited dispersal. It is very plausible that *A. fuscus* shares this behavior; however, studies are needed to evaluate adult and juvenile *A. fuscus* habitat use and movement.

Diet and Feeding

The dusky sea snake preys mainly on labrid (e.g., wrasses) and gobiid (e.g., gobies) fishes and to a lesser extent, fish eggs (McCosker, 1975). Food competition among sympatric sea snakes may be minimal. Examinations of diet composition for sympatric sea snakes have shown very little diet overlap (McCosker, 1975; Voris and Voris, 1983). Comparison of diets of nine hydrophiid sea snakes species from Ashmore Reef, in particular, indicated that while there is overlap in prey types at the family and genus levels, there was no overlap in prey types at the species level (McCosker, 1975).

Feeding behavior of dusky sea snakes has not been thoroughly investigated. During surveys at Ashmore Reef, Guinea and Whiting (2005) noted that they commonly saw dusky sea snakes over sand bottom habitat and watched one snake actually force its head and about 15% of its body into the sand. However, because it emerged without a prey item (Guinea and Whiting, 2005), it's unclear whether this was foraging or some other behavior.

Like their terrestrial relatives, sea snakes swallow their prey whole and therefore must have some strategy for subduing them. McCosker (1975) hypothesized that the highly toxic venom of sea snakes is probably more of a feeding adaptation than a defensive one. Often taken as support of this hypothesis is the example of the marbled sea snake, *A. eydouxii*, which is an obligate fish egg-eater. This species, which has no need to subdue its prey, lacks fangs, has greatly atrophied venom glands, and has venom with 40-100 times lower toxicity than that of other *Aipysurus* species (Li *et al*., 2005).

The olive sea snake, *A. laevis*, which is most closely related to the dusky sea snake, apparently relies on odor to hunt for fish in coral and rock crevices (Heatwole *et al*., 1978; as cited in Burns and Heatwole, 1998). Olive sea snakes (*A. laevis*) have been observed to feed both during the day and at night, mainly at the bottom edge of the reef and along the vertical reef face (Burns and Heatwole, 1998). Olive sea snakes were also observed to interrupt their foraging activities about every 16 minutes on average to make quick assents to breathe at the surface for several seconds. While not feeding or breathing, the snakes were observed to rest or hide in or under coral (Burns and Heatwole, 1998).

Growth and Reproduction

Maximum total length of dusky sea snakes is 98 cm (Lukoschek *et al*., 2010). Reported growth rates for sea snakes range from 0.07 – 1.0 mm per day and decline with age (Heatwole, 1997); however, growth for dusky sea snakes has not been documented. Among marine snakes, females are often larger than males and take longer to reach sexual maturity (Heatwole, 1997; Fry *et al*., 2001).

Longevity of dusky sea snakes is unknown, but may be about 15 years based on what has been reported for the olive sea snake, *A. laevis* (Burns, 1984, as cited in Heatwole, 1997). Lukoschek *et al.* (2010) assumed a maximum lifespan of about 10 years. Lukoschek *et al.* (2010) also assumed age at first maturity to be about 3-4 years and generation time to be around 5 years.

Aipysurus fuscus is a viviparous sea snake - meaning embryos develop internally and young undergo live birth. Because this species never ventures on land, mating occurs at sea and young are born alive in the water. For eight of nine species of sea snakes studied by Lemen and Voris (1980), the number of embryos was positively correlated with female body size. Cogger (1975) indicated that within the *Aipysurus* genus, the number of young per female is small - usually less than four – and that young are relatively large at birth. In a study by Fry *et al*. (2001) that included data for three *Aipysurus* species, mean clutch size (± 1SE) ranged from 3.6 (± 0.3) for *A. eydouxii* to 6.5 (± 1.8) for *A. laevis* (In this study, snout-vent lengths (SVL) of *A. eydouxii* females ranged from 39.2 – 85.0 cm, and SVL lengths of *A. laevis* females ranged from 71.2 – 130.0 cm.)

Timing and seasonality of the dusky sea snake's breeding cycles are unknown. Olive sea snakes, however, exhibit synchronous breeding in the spring (October) and have a 6-month gestation period (Heatwole, 1997). Given the relatively long gestation period, it's thought that female olive sea snakes breed every other year (Heatwole, 1997). While the example of the closely related olive sea snake may serve as a reasonable proxy for the dusky sea snake, it should be noted that breeding cycles of other sea snakes vary (Heatwole, 1997). Gestation length for a given species may even be affected by temperature (Fry *et al*., 2001).

Little is known about the juvenile life stage of dusky sea snakes. Observations of newborn olive sea snakes, *A. laevis*, indicate that juveniles are relatively secretive and probably hide in the coral reefs for their first year (Zimmerman and Shohet, 1994; as cited in Lukoschek *et al*., 2007a).

Abundance and Population Structure

There are no historical or current population estimates for the dusky sea snake. However, multiple reefs have been surveyed repeatedly, and although survey methodologies have varied, the data provide some indication of population trends for some locations. For Ashmore Reef in particular, the survey data provide a strong indication of severe population decline and possible extirpation (Table 1).

Among reefs within the range of the dusky sea snake, Ashmore Reef is the most heavily surveyed, both in terms of the number of sea snake surveys and in terms of individual survey effort. This reef has historically had high sea snake species diversity and abundance. Smith (1926) indicates that a collection of over 100 snakes that had recently been obtained for him from Ashmore Reef included 27 dusky sea snakes, and that many more snakes could have been collected. This anecdotal information suggests that dusky sea snakes were once fairly common at Ashmore Reef. Guinea and Whiting (2005) surveyed Ashmore Reef in 1994, 1996, and 1998, and found that *A. fuscus* was the second-most common species during low-tide surveys across the three years of the study. During these surveys, a total of 12 dusky sea snakes and an overall percent composition of 15.4% were recorded for *A. fuscus* (Guinea and Whiting, 2005). Rigorously designed surveys were later conducted by Lukoschek *et al.* (2013), who also standardized the survey data for Ashmore Reef by calculating the number of "snakes captured per day," so they could compare abundance data from their surveys to previously published studies. Their analysis revealed declines in sea snake diversity, total sea snake abundance, and *A. fuscus* abundance in particular (Figure 3). Although reported catch rates for *A. fuscus* are highly variable among studies, the species has not been recorded in any surveys conducted at Ashmore Reef after 2005 despite considerable survey effort (Lukoschek *et al*., 2013; Table 1).

Surveys at Hibernia Reef have not consistently detected *A. fuscus*; and the most recent surveys, conducted in 2012 and 2013, have failed to detect any dusky sea snakes despite extensive survey effort (Guinea, 2013; Table 1). In 2005, when dusky sea snakes were observed at Hibernia Reef, their relative abundance was fairly low (e.g., 5.7% of the sea snakes captured; Guinea, 2013). While dusky sea snakes may currently be absent from this reef, it is difficult to evaluate the extent to which this would represent a decline in overall abundance.

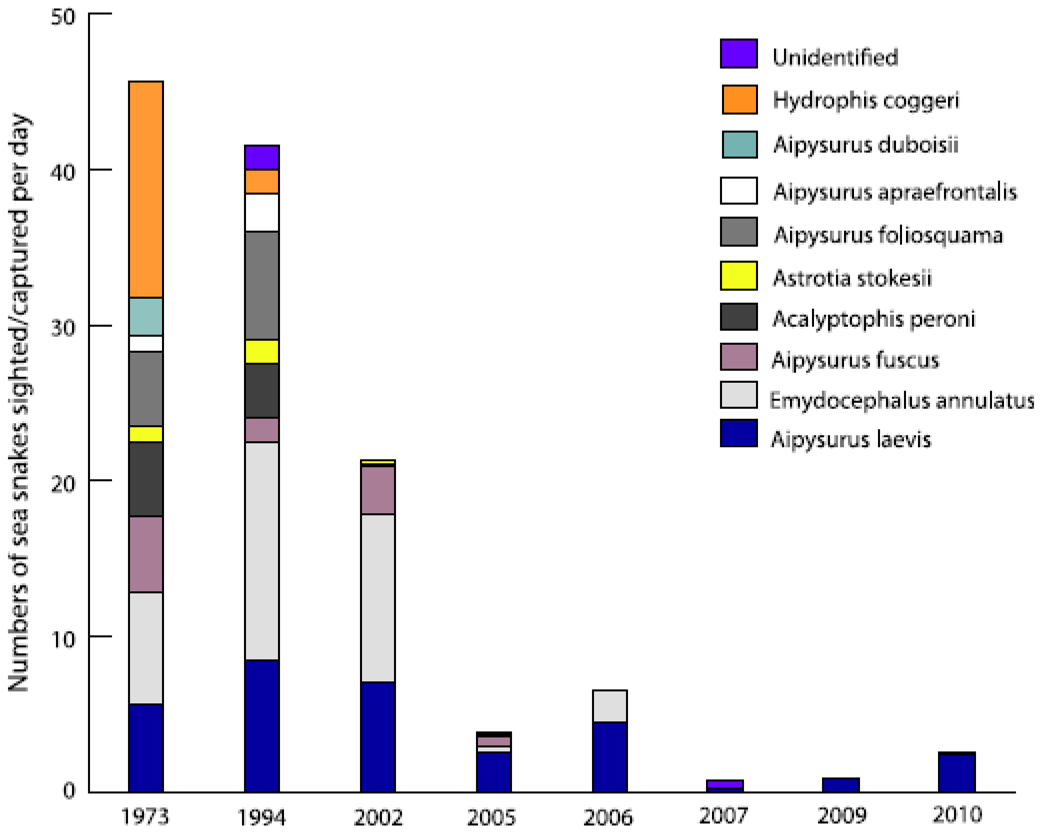


Figure 3. Standardized survey data for sea snakes surveys conducted at Ashmore Reef using various methods. *Aipysurus fuscus* is absent in the survey data after 2005. (From Lukoschek *et al*., 2013). Widespread bleaching events occurred at Ashmore Reef in 1998 and 2003.

Although their relative abundance varies across surveys, dusky sea snakes have been consistently observed at Scott Reef (Table 1). Guinea (2012) visited Scott Reef in February, 2006, and reported that 75% of the sea snakes observed (n=36) comprised olive (*A. laevis*) and turtle-headed sea snakes (*Emydocephalus annulatus)*. Third in abundance was the dusky sea snake, which made up 15% of the total sea snake sightings (Guinea, 2013). The reef was surveyed again in September, 2006; and, at that time, dusky sea snakes comprised 6% of the sea snakes observed (n=3) and were the fourth-most abundant species (Guinea, 2013). On a third visit to the reef in November 2006, a total of 37 snakes were observed, 80% of which were olive and turtle-headed sea snakes. The remaining 20% consisted of two species, dusky sea snakes and Dubois's sea snakes *(A. duboisii;* Guinea, 2013). (Precise numbers were not reported in the cited reference.) Portions of Scott Reef were surveyed again in 2012 and 2013, and dusky sea snakes made up 3.2% and 7.4% of the total sightings respectively for each year (Guinea, 2013). While these data are suggestive of a decline, they cannot necessarily be interpreted as a population decline for dusky sea snakes at Scott Reef given the variability with survey design and effort.

Abundance data for the remaining reefs are extremely limited and difficult to interpret. Environment Australia (Department of the Environment and Heritage) includes Cartier Island as part of the dusky sea snake's range, (Commonwealth of Australia, 2002), and Cogger (1975) indicates there are historical records from Cartier Island. However, dusky sea snakes are absent in surveys of Cartier Island in 1972/73, 2005, and 2013 (Table 1). Dusky sea snakes were reported in the two most recent surveys of Seringapatam Reef, albeit at relatively low abundances (Table 1).

Structure and connectivity of populations of *A. fuscus* have not been studied directly. Analysis of the genetic structure of the olive sea snake (*A. laevis*) across its Australian range, which extends from Shark Bay, Western Australia to the southern Great Barrier Reef, indicates a complex pattern of structure and connectivity (Lukoschek *et al*., 2007b). In this study, researchers analyzed mitochondrial DNA (mtDNA) from 354 olive sea snakes collected from 14 locations across three large regions of Australia. Within the Western Australia region, samples were collected at Hibernia, Scott, and Ashmore reefs and Cartier Islet. Analysis of molecular variance using haplotype frequencies and percent sequence divergence indicated strong, statistically significant population subdivision at all levels (regional, within region, and within location; Lukoschek *et al*., 2007b). However, comparisons among locations within the Western Australia region were not all significant. Specifically, Scott Reef, which lies farthest from the other Timor Sea reefs (Figure 1) was differentiated from Ashmore and Cartier based on *F*-statistics (a measure of genetic divergence) and estimated divergence times, and estimated migration rates were low; yet, the same pattern was not true for Scott and Hibernia reefs, which had the highest migration rates in this region and low *F*-statistics (Lukoschek *et al*., 2007b)). Despite the conflicting results, the authors concluded that the data supported the hypothesis that deep-water expanses, such as those that surround the reefs of the Timor Sea, limit dispersal (Lukoschek *et al*., 2007b). They further concluded that gene flow among the reefs of the Timor Sea is low, and that olive sea snakes at these reefs have been diverging for some time (Lukoschek *et al*., 2007b).

A subsequent study by Lukoschek *et al.* (2008), in which the same 354 olive sea snakes were genotyped for five microsatellite DNA loci, indicated a mixture of little to high genetic differentiation among the Timor Sea reef populations (F_{ST} = 0 - 0.185). The F_{ST} value was only statistically significant for the pairwise comparison of Scott and Ashmore Reef.

Table 1. Survey information and relative abundance data for *A. fuscus* by reef. Survey methodologies and measurement of relative abundance varied across surveys. Data are reported as the number of dusky sea snakes counted and their percentage of the total number of snakes captured during the particular reef survey. (Note: Some authors/ references consider Seringapatam Reef to be a part of Scott Reef; and although the precise location is unclear, the Minton and Heatwole (1975) survey at Scott Reef is considered here under "Scott Reef.")

Reef	**Year**	***Method***	***A. fuscus* Abundance Data**	**Reference**
Ashmore	1972/73	*Snorkel transect surveys, high and low tides*	37 snakes (10% of total)	Minton and Heatwole, 1975
Ashmore	1994	*Boat-based and on-foot transect surveys, low tide*	3 snakes (9.7% of total)	Guinea and Whiting, 2005
Ashmore	1996	*Boat-based and on-foot transect surveys, low tide*	3 snakes (23.1% of total)	Guinea and Whiting, 2005
Ashmore	1998	*Boat-based and on-foot transect surveys, low tide*	6 snakes (17.6% of total)	Guinea and Whiting, 2005
Ashmore	2002	*Snorkel, SCUBA, manta-tow, and on-foot surveys; day; all habitat types*	31 snakes (14.6% of total)	Lukoschek *et al.*, 2013
Ashmore	2006	*Snorkel, SCUBA, on-foot surveys; all habitat types and water depths*	0 snakes	Lukoschek *et al.*, 2013
Ashmore	2009	*SCUBA; all habitat types*	0 snakes	Lukoschek *et al.*, 2013
Ashmore	2010	*Manta-tows, SCUBA; all habitat types*	0 snakes	Lukoschek *et al.*, 2013
Ashmore	2012	*Manta-board and snorkel surveys*	0 snakes	Guinea, 2013
Ashmore	2013	*Manta-board and snorkel surveys; boat surveys on falling tide*	0 snakes	Guinea, 2013
Cartier	1972/73	*Snorkel transect surveys, high and low tides*	0 snakes	Minton and Heatwole, 1975
Cartier	2005	*Manta-board surveys*	0 snakes	Guinea, 2013
Cartier	2013	*Manta-board and snorkel surveys*	0 snakes	Guinea, 2013
Hibernia	1972/73	*Snorkel transect surveys, high and low tides*	0 snakes	Minton and Heatwole, 1975
Hibernia	2005	*SCUBA*	2 snakes (5.7% of total)	Guinea, 2013
Hibernia	2012	*Manta-board and snorkel surveys*	0 snakes	Guinea, 2013
Hibernia	2013	*Manta-board, snorkel and on-foot surveys; spotlight search at night*	0 snakes	Guinea, 2013
Seringapatam	2006	*Snorkel surveys*	0 snakes	Guinea, 2013
Seringapatam	2012	*Manta-board and snorkel surveys*	1 snake (2.2% of total)	Guinea, 2013
Seringapatam	2013	*Manta-board and snorkel surveys; spotlight search at night*	1 snake (2.8% of total)	Guinea, 2013
Scott	1972/73	*Snorkel transect surveys, high and low tides*	5 snakes (13% of total)	Minton and Heatwole, 1975
Scott	2006	*Manta-board surveys*	7 snakes (15% of total; Feb.); 3 snakes (6% of total; Sep.)	Guinea, 2013
Scott	2012	*Manta-board and snorkel surveys*	2 snakes (3.2% of total)	Guinea, 2013
Scott	2013	*Manta-board and snorkel surveys; spotlight search at night*	6 snakes (7.4% of total)	Guinea, 2013

Whether the patterns of genetic structure observed for olive sea snakes apply to dusky sea snakes is uncertain. However, it is plausible that a pattern of relatively low gene flow among some reef populations holds true for the dusky sea snakes, because deeper water could be expected to present the same barrier to dispersal as it does for the more widely distributed olive sea snake. Furthermore, as discussed previously, available evidence for related species indicates very limited adult dispersal. Thus, while far from conclusive, the available information suggests that connectivity of dusky sea snake populations, at least among some reefs, may be relatively low.

ASSESSMENT OF EXTINCTION RISK

Approach to Evaluating 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: destruction or modification of habitat, overutilization, disease or predation, inadequacy of existing regulatory mechanisms, or other natural or man-made factors. Collectively, I simply refer to these factors as "threats." In addition to reviewing the best available data on threats to the dusky sea snake, I considered demographic risks to the species in a manner 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 consideration of extinction risk has been used in many 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. In addition to the demographic risk factors, I considered the threat factors listed in section 4(a)(1) of the ESA. Based on all of this information I describe the likely level of extinction risk faced by the dusky sea snake.

Because information on the dusky sea snake is sparse and often non-quantitative, I use qualitative risk categories to characterize the four demographic viability criteria: very low, low, moderate, and high. In addition, because threats to the dusky sea snake are so poorly understood, I characterized the relative likelihood (as very low, low, medium, or high) that potential or assumed threats are contributing to the decline in abundance of *A. fuscus.* I do not make recommendations as to whether the species should be listed as threatened or endangered. Rather, I draw conclusions about the overall risk of extinction faced by the species under present conditions and in the foreseeable future based on an evaluation of the species' demographic risks and threats.

According to the ESA, the determination of whether a species is threatened or endangered should be made on the basis of the best scientific information available regarding its current status, after taking into account efforts being made to protect the species. During the extinction risk assessment, likely or possible effects of conservation measures are taken into account to the extent they are reflected in metrics of population or species viability. Conservation measures that have not yet been implemented or shown to be effective are taken into account in a separate process by NMFS prior to proposing any listing determinations. In the last part of this section, I summarize the conservation efforts that are currently in place and that may be benefiting the dusky sea snake so that NMFS can consider them before making a listing determination.

Analysis of the ESA Section 4(A)(1) Factors

In this section, I examine possible threats to the dusky sea snake and the likelihood of a negative impact of these threats on the species. Causes for observed declines in dusky sea snakes are not known, so the discussion below focuses not only on the potential harm to dusky sea snakes as a result of each possible threat but also on the strength of evidence that each threat is actually impacting dusky sea snakes. The information does not allow an assessment of the magnitude of the effect of any threat on the species abundance or other demographic factors, but establishing the likelihood that a threat is contributing to decline helps in determining overall extinction risk. To assist in the interpretation of the species' status, I evaluated both current and historical, potential threats to dusky sea snakes.

The likelihood that each particular threat is contributing the observed loss or decline of dusky sea snakes is summarized at the end of this section (Table 2) according a qualitative scale:

> **(1)** Very low – meaning it is very unlikely that the particular threat contributes or will contribute to the decline of the species;
> **(2**) Low - meaning it is unlikely that the particular threat contributes or will contribute to the decline of the species;
> **(3)** Medium - meaning it is likely the particular threat contributes or will contribute to the decline of the species; and,
> **(4)** High - meaning it is highly likely that the particular threat contributes or will contribute to the decline of the species.

Present or threatened destruction, modification or curtailment of habitat or range

Aipysurus fuscus is highly dependent on coral reefs for prey and shelter. Loss of live coral cover is a possible mechanism contributing to the decline of dusky and other sea snake species at places such as Ashmore Reef. This hypothesis is plausible given the dusky sea snake's relationship with coral reefs, but as discussed below, it is not clearly supported by the documented patterns of coral and sea snake abundances.

Coral reefs of the Sahul Shelf experienced widespread bleaching in response to El Nino events in 1998 and 2003. During the 1998 event, water temperatures rose rapidly and remained above normal for two months (NOAA, 2013). This event is the most extreme temperature anomaly recorded at Scott Reef to date (NOAA, 2013) and resulted in a greater than 80% loss of hard and soft coral cover (Smith *et al*., 2008). This translated into a reduction of live coral coverage to a total of roughly 10%. No recovery of hard corals was observed in the first three surveys following the 1998 event, but a significant increase of 6.4% was observed between 2002 and 2004 (Smith *et al*., 2008) – indicating that recovery was underway and that the 2003 El Nino event had little impact on Scott Reef. Initial increases in coral cover were driven by the growth of remnant corals, and recruitment rates of corals remained well below normal for 6 years following the disturbance (Gilmour *et al*., 2013). Coral recruitment following the event was extremely limited due to the degree of isolation of Scott Reef, which lies about 250 km from other reefs in the region (Gilmour *et al*., 2013). Six years after the 1998 event (by 2004), the hard corals had partially recovered to 40% of their pre-bleaching cover, the soft corals showed no sign of recovery, and community composition of corals remained significantly altered (Smith *et al*., 2008). Within 12 years after the event (by 2010), coral cover, recruitment, community composition, and generic diversity were similar to pre-bleaching years (Gilmour *et al*., 2010). Several other moderate disturbances, including two cyclones, occurred during this time period and may have slowed the rate of recovery to some extent (Gilmour *et al*., 2013). Available sea snake survey data, spanning 1972 – 2013, do not appear to indicate a major decline in abundance of dusky sea snakes at Scott Reef, which were relatively common during the surveys conducted by Guinea (2012) in 2006. However, the large gap in these survey data for 1973-2006 could conceal any shorter-term patterns.

Ashmore Reef experienced bleaching in 1998 and again to an apparently greater extent in 2003 (Lukoschek *et al*., 2013). There are no estimates of coral coverage prior to 1998, so the extent of coral loss is not quantified. Widespread mortality of corals occurred as a result of the 2003 bleaching event, and average live coral coverage was reduced to 10% (Kospartov *et al*., 2006; as cited in Lukoschek *et al*., 2013). Surveys conducted in 2005 and 2009, indicate that recovery of corals at Ashmore Reef was rapid but delayed by about 7 years (Ceccarelli *et al*., 2011). The annual geometric rate of increase for hard corals was calculated as 30.4% and 21.6% for soft corals for during 2005- 2009 (Ceccarelli *et al*., 2011). Overall, there has been an eight-fold increase in hard coral coverage from 1998 to 2009 (Hale and Butcher, 2013), with all of the recorded recovery occurring after 2005. Survey data suggest complete loss of dusky sea snakes at Ashmore Reef after 2005 (Table 2).

In their review of existing data, Lukoschek *et al*. (2013) show that sharp declines in total sea snake abundance and species diversity occurred at Ashmore Reef following both the 1998 and 2003 bleaching events (see Figure 3). These patterns are consistent with the hypothesis that loss of live corals affected reef-associated sea snakes as a whole. However, Lukoschek *et al*. (2013) argue that loss of corals does not explain changes in sea snake abundance and diversity at Ashmore Reef, because they consider the 1998 bleaching event to have had little impact at Ashmore and the most pronounced declines in sea snake abundance and diversity occurred prior to the 2003 bleaching event. This conclusion is hard to fully support, because as noted above, data to indicate the extent of coral loss following the 1998 bleaching event are lacking.

Understanding of the relationship between live coral coverage and dusky sea snake abundance requires more detailed information regarding coral species composition, habitat complexity, and coral and prey fish resiliency relative to both bleaching events. Significant losses of live coral will almost certainly result in changes in community composition for those benthic fish species that rely on the corals for food and shelter (Pratchett *et al*., 2008). As discussed by Hale and Butcher (2013), coral cover was low at Ashmore Reef following the 1998 El Nino event, which also led to shifts in community composition of corals and possible indirect effects on sea snake prey species. An analysis of such indirect effects is required before drawing firm conclusions that the 1998 disturbance had no effect on sea snakes at Ashmore Reef. However, at this time, because a clear or consistent pattern does not emerge given the available data on dusky sea snake abundances at Ashmore and Scott reefs in relationship to the two bleaching events, I cannot conclude that this particular threat is contributing to the decline of the dusky sea snake.

The reefs where dusky sea snakes are found lie more than several hundred kilometers offshore and thus receive a considerable degree of protection from human activities and land-based sources of pollution. Despite this remoteness, the reefs may experience some degradation as a result of vessel traffic. Anchor damage, pollution from contaminated bilge water, and marine debris are among the potential issues identified at Ashmore Reef, which experiences a relatively high level of traffic from Indonesian fishers, yachts, merchant ships, and illegal entry vessels (Whiting, 2000; Lukoschek *et al*., 2013). The mechanisms for and extent to which these boat-based habitat threats are impacting dusky or any other sea snake species of the Timor Sea reefs is unknown. Protection of habitats at both Ashmore Reef and Cartier Island has likely improved since their designation as protected areas in 1983 and 2000, respectively, under the National Parks and Wildlife Conservation Act 1975 (which was later replaced by the Environment Protection and Biodiversity Conservation Act 1999).

The extensive oil and gas industry activity in this region may also be a possible source of disturbance affecting dusky sea snakes and their habitat (Figure 4). Exploration and extraction activities within the Ashmore Platform began in 1968 (Geoscience Australia, 2012) and are expected to continue for some time given the significant resources within this region. Ashmore Reef and Cartier Islands lie about 50-80 km west of the main offshore wells in the Timor Sea, and the closest exploration wells are 36 km away (Russell *et al*., 2004). However, Scott Reef lies directly above a significant portion of the Torosa Resevoir, where drilling for natural gas is expected to commence in 2017 (Woodside Energy LTD, 2013). The development of a floating liquefied natural gas facility (FLNG) in this area will mean increased vessel traffic and potential light, sound, and chemical pollution. The area is also expected to experience minor subsidence or compaction as the gas is removed (Woodside Energy LTD, 2013). Whether and the degree to which any of these threats will impact dusky sea snakes is not yet known.

Unfortunately, extremely limited information also exists regarding the toxic effects of oil exposure on sea snakes. Oil spills, which occur more frequently as a result of vessel or pipeline incidents rather than exploration and drilling activities (www.amsa.gov.au), have also not occurred very often in this region.

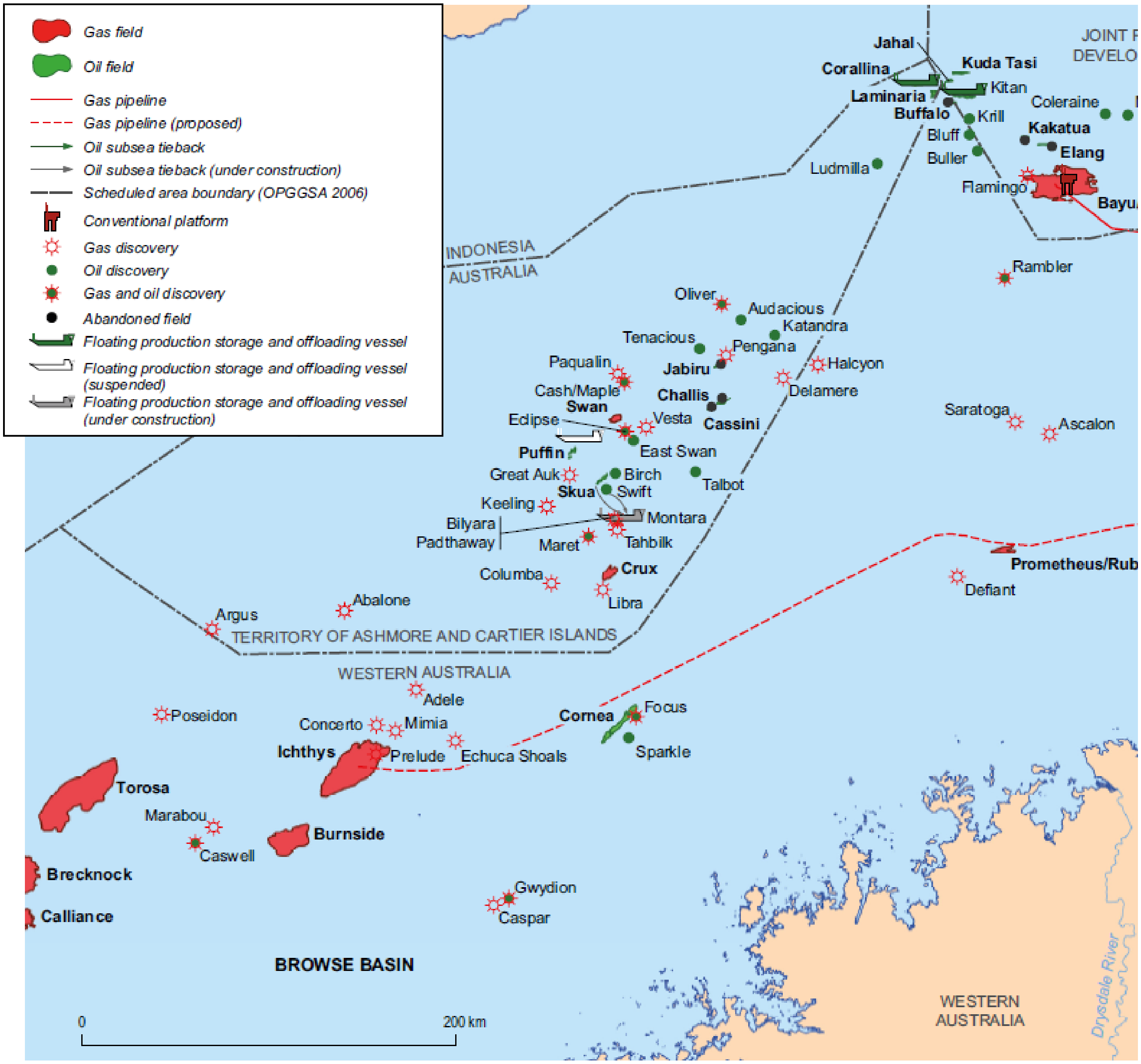


Figure 4. Locations of petroleum production facilities, hydrocarbon accumulations and current and proposed pipeline infrastructure within and around the Ashmore and Cartier Island area (Geoscience Australia, 2012).

In August 2009, the West Atlas oil rig on the Montara Well exploded and began uncontrollably leaking oil and gas into the Timor Sea for 74 days until the well was finally capped in November 2009 (Figure 5). Considered one of the worse oil-related spills to have ever occurred in Australia, the Montara leak was analogous in nature to the Deepwater Horizon disaster of April 2010 in the Gulf of Mexico. In an effort to rapidly assess impacts to multiple taxa, Watson *et al*. (2009) conducted ship-based transect surveys in areas around the Atlas drilling platform in

September 2009. They did not observe or identify any dusky sea snakes; however, they did observe “lethargic sea snakes lying in thick oil (i.e. not moving much when approached, unable to dive)” and collected a dead horned sea snake (*Acalyptophis peronii*) from oil-affected waters for further analysis (Watson *et al*., 2009). The necropsy report indicated that this snake was in good physical condition with no visible external or internal pathologies, and no oil was detected in swab samples of the skin (Gagnon and Rawson, 2010). Chemical analysis of tissues clearly indicated that exposure to crude oil occurred through ingestion of prey and not through inhalation (Gagnon and Rawson, 2010). *A. peronii* is considered more of a diet specialist than the dusky sea snake and primarily consumes burrowing gobiids (McCosker, 1975; Voris and Voris, 1983). Because they saw no physical damage to the gut structure and no contamination of the tissues, Gagnon and Rawson (2010) concluded it was unlikely that oil ingestion was the primary cause of death. Tests for presence of chemical dispersants used during the spill-response were not conducted.

A necropsy was also performed on a dead, sea snake landed by a commercial fisherman operating in the vicinity of the West Atlas spill on September 14, 2009 (Gagnon, 2009). This specimen was identified as *Hydrophis elegans*, which is a relatively widespread and abundant species that preys on eels and other fishes (McCosker, 1975; Voris and Voris, 1983). The necropsy indicted that the snake had fed recently and that the stomach contents were contaminated with oil (Gagnon, 2009). Relatively high levels of polycyclic aromatic hydrocarbons (PAHs) were also detected in the lungs, trachea and muscle tissue (Gagnon, 2009). Neither of two dispersant chemicals used to treat the spill were detected in lung samples (Gagnon, 2009). The necropsy report concluded that the likely cause of death for this specimen was exposure to petroleum hydrocarbons (Gagnon, 2009).

In 2012 and 2013, Guinea (2013) conducted surveys to evaluate the potential impacts of the Montara leak on species of marine reptiles (Figure 5; Guinea, 2013). Potentially impacted areas surveyed included Ashmore Reef, Cartier Island and Hibernia Reef; Scott and Seringapatam reefs were also surveyed as control reefs (Guinea, 2013). The extensive survey efforts of Guinea (2013) did not indicate any impact of the hydrocarbon release on the marine reptiles (sea turtles and sea snakes) of the potentially affected reefs. Of the reefs surveyed, Hibernia Reef and Cartier Island had the highest sea snake density; however, no sea snakes were observed at Ashmore Reef, where sea snake abundance and diversity had already declined to very low levels prior to the 2009 incident (Guinea, 2013). Overall, I conclude that, while there are likely to be acute impacts to sea snakes in response to major spills, it is unlikely that pollution stemming from oil and gas industry activities has contributed to the observed declines of the dusky sea snake.

The habitat-related threats discussed in this section are expected to continue well into the future. Coral bleaching, while not yet completely understood, has been most strongly linked to unusually warm sea surface temperatures as a causative factor (Glynn, 1993). Given that El Nino and its associated warming of equatorial Pacific Ocean waters is a natural and reoccurring climate phenomenon, coral bleaching in response to sufficiently strong El Nino events will continue. Furthermore, because climate warming as a consequence of CO_2 emissions is expected to continue (IPCC, 2013), and elevated sea surface temperatures are expected to rise at an accelerated rate (Lough *et al.*, 2012), loss of corals through bleaching events is expected to increase. The expansion of oil and gas exploration and extraction in Australia's Northwest Marine Region may also result in an increased risk of oil spills and additional pressure on dusky sea snakes.

Figure 5. Location of reefs surveyed in the Timor Sea by Guinea (2012-2013) relative to the West Atlas oil rig. Ashmore Reef and Cartier Island are 167 km west-north-west and 108 km west from the Montara well, respectively. Seringapatam Reef is 296 km south-east from the Montara well and far from modeled oil trajectories (Australian Government, Department of the Environment; Guinea, 2013).

Overutilization for commercial, recreational, scientific, or educational purposes

Sea snakes have been harvested for their meat, organs and skin for centuries. Most of the commercial exploitation occurs in Japan and the Philippines, and most of the meat consumption occurs in Southeast Asia (Heatwole, 1997). Sea snakes are not consumed for food in Australia but are used for leather products, which have been sold in markets and souvenir shops there for over 30 years (Marsh *et al.*, 1994; Heatwole, 1997). Harvesting sea snakes in Australia for leather-making began on a small scale, but by 1977 had expanded into a commercial enterprise (Heatwole, 1997). The main source of sea snakes for leather-making is from by-catch in commercial trawl fisheries, and commercial harvest of sea snakes is authorized under several licenses issued to prawn trawlers operating on the east coast of Queensland and in the Gulf of Carpentaria (Marsh *et al.*, 1994; Heatwole, 1997). This harvest, therefore, occurs well outside the range of the dusky sea snakes. There is no directed Australian fishery for any sea snakes species; and although Indonesians have fished on the Timor Sea reefs since the early 18th century, there is no evidence that they have been engaged in harvest of sea snakes (Hale and Butcher, 2013; Lukoschek *et al.,* 2013).

At least 18 species of sea snakes are taken as bycatch in Australia's commercial prawn trawls, and mortality rates for incidentally caught sea snakes may be as high as 48.5% in the absence of bycatch reduction devices (BRDs; Ward, 1996; Wassenberg *et al*., 2001). The only trawl fishery that operates within the range of the dusky sea snake is the North West Slope Trawl Fishery (NWSTF). The Australian Fisheries Management Authority (AFMA) reports that the NWSTF, which targets three scampi species (lobsters), is a low effort fishery with a very low level of bycatch and no documented interactions with threatened, endangered, or protected species (AFMA, 2012). The NWSTF is also a deep-water fishery, and thus unlikely to encounter dusky sea snakes. Reef-associated sea snakes are not frequently captured in commercial trawls (Fry et al., 2001; Lukoschek *et al*., 2007a; Lukoschek *et al*., 2013).

Some olive sea snakes have been taken illegally from the Great Barrier Reef Marine Park for use in the aquarium trade (Marsh *et al*., 1994); however, information is lacking on the extent of such illegal harvest. I have no information to indicate such illegal harvest is posing a threat to dusky sea snakes, which occur at far fewer and more remote reefs and at lower densities than olive sea snakes.

Illegal fishing by Indonesian vessels has occurred at Ashmore Reef; however, this fishing has largely targeted trepang (sea cucumbers), trochus snails, reef fishes, adult sea turtles and bird eggs (Whiting, 2000). No harvest of any biota is currently allowed at Ashmore Reef beyond subsistence fishing for finfish in the small portion of the reef that is open to the public (Figure 9); and finfish may only be caught for immediate consumption or consumption within one day's sailing time. There are no documented cases of illegal harvest of sea snakes, and increased enforcement presence at Ashmore Reef has also led to the decline of this illegal fishing (Whiting, 2000; Lukoschek *et al*., 2013). There is no information to suggest sea snake harvest is occurring at other reefs within the range of the dusky sea snake.

In conclusion, there is no evidence to indicate that either direct harvest or incidental capture is posing a threat to this species. There is also no evidence to suggest that fishing-related mortality has contributed to the observed declines in dusky sea snakes. Lastly, there is no indication that fishing pressure or targets are expected to change in the future such that fisheries interactions would pose a future threat to this species. Fisheries-related management is discussed further below (see "Inadequacy of existing regulatory mechanisms" section).

Disease or predation

There are no documented outbreaks of any diseases in dusky or any other sea snakes in the wild (Lukoschek *et al*., 2013). Furthermore, there are no reports of sick or diseased sea snakes during over a decade of surveying at Ashmore Reef (Lukoschek *et al*., 2013). However, there is the potential for the introduction of various pathogens via ballast and bilge water of fishing vessels, recreational boats, merchant vessels, and illegal entry vessels that visit the area (Russell *et al*., 2014).

Documented sea snake predators include bony fishes, sea eagles, sharks, and salt water crocodiles (Heatwole, 1975c; Davenport, 2011). Tiger sharks (*Galeocerda cuvieri*), in particular, appear to have an ecologically significant role as a sea snake predator; whereas, other co-occurring shark species do not appear to consume any snakes (Heatwole, 1975c; Davenport, 2011). In a study on bar bellied sea snakes (*Hydrophis elegans*) in Shark Bay, Australia, Kerford *et al*. (2008) found that shark predation may mediate habitat use of the sea snake, which selected refuge habitats (seagrass beds) during high tides when tiger shark presence is elevated. After having encountered a high percentage of sea snakes with scarring or missing tails, Heatwole (1975c) examined 593 specimens of 19 sea snake species collected from Ashmore Reef and other areas to analyze the incidence and type of injury. Heatwole (1975c) examined 37 specimens of *A. fuscus* and found that 10.8% had conspicuous tail injuries that appeared consistent with an attack from a fish, and 2.7% had body scars that appeared consistent with an attack by a bird. The majority (32 snakes) of the *A. fuscus* specimens had no obvious injury. Although it is uncertain whether the observed injuries were in fact caused by predation attempts, it is likely that *A. fuscus* commonly experiences predation and is depredated by more than one type of predator. Given the information available, it is not possible to interpret whether the seemingly high percentage of snakes bearing these scars indicates a low success rate on the part of the predators or instead indicates a fairly high predation rate. No additional information on predation of *A. fuscus* is available and there are no data to suggest the level of predation on dusky sea snakes has contributed to the observed declines in their abundance.

In conclusion, I do not consider disease or predation to be posing a threat to the dusky sea snake such that they have contributed to the observed decline in abundance of this species. Predictions of how these threats may impact dusky sea snakes in the foreseeable future would be based largely on speculation; thus, I make none at this time.

Inadequacy of existing regulatory mechanisms

Dusky sea snakes, along with all of Australia's hydrophiine sea snakes, are listed under the Commonwealth Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act). This listing means that a permit is required to authorize any killing, injuring, taking, trading, keeping or moving of a dusky sea snake. The EPBC Act also requires that surveys be conducted for listed marine species. There are no recovery plans in place for any sea snake species (www.environment.gov.au/topics/biodiversity/threatened-species-ecological-communities/recovery-plans).

Two of the five main reefs within the dusky sea snake's historical range - Ashmore Reef and Cartier Island - are protected reserves. Ashmore Reef National Nature Reserve was established in 1983 under the National Parks and Wildlife Conservation Act 1975 (a predecessor to the EPBC Act) and later listed as a Ramsar Site in 2000 under the Ramsar Convention, which is an intergovernmental treaty on sustainable use of wetlands. Cartier Island, a former British Air Force bombing range, was designated as a Marine Reserve in 2000. These two Reserves cover a combined area of 750 km^2 and are both assigned to IUCN (The International Union for Conservation of Nature) category Ia – strict nature reserve. IUCN category Ia areas are protected to preserve biodiversity and maintain the areas for the benefit of scientific research. Human access to such areas is tightly controlled and limited. A small section of Ashmore Reserve is managed as IUCN category II – national park (Figure 7). Such areas are managed to protect ecosystems and biodiversity, and while still restricted, human visitation is not as limited as for category Ia areas. Under the EPBC Act, no person may "kill, injure, take, trade, keep or move a member of a native species" within any Reserve without a permit (Commonwealth of Australia, 2000). No fishing or harvest of any biota is allowed within the Reserves with the limited exception of finfish fishing within the category II area of Ashmore, and as long as the fish are used for relatively immediate consumption.

Since the early 18th century, Indonesian fishers have visited and fished reefs within the Timor Sea, mainly in search of trepang, trochus, turtle, shark fin, and reef fishes (Commonwealth of Australia, 2002). In 1974, a Memorandum of Understanding (MOU) was established between Australia and Indonesia that set out arrangements by which traditional fishers may access resources in Australia's territorial sea. Because of its shape, the area covered by this MOU is often referred to as the MOU Box (Figure 9). The MOU Box, which covers an area of about 50,000 km^2, includes the five main reefs where the dusky sea snake occurs (Skewes *et al*., 1999; Figure 9). The marine resources within this area are managed by the Australian Government, and traditional fishing by Indonesian fishers is allowed. However, as discussed above, certain restrictions apply within the Marine Reserves. Traditional Indonesian fishers may access parts of the Ashmore Reserve for shelter, freshwater and to visit grave sites; and, as mentioned previously, fishing is prohibited in both the Cartier Island and Ashmore Marine Reserves with the limited exception for fishing for immediate consumption within the category II area of the Ashmore Reserve.

Within the MOU Box, surveys indicate severe depletion of the commercially valuable target species, especially trepang, trochus and small shark species (Skewes *et al*., 1999). Catch data and quantitative estimates of fishing pressure are very limited, but surveillance information indicates that fishing pressure has increased despite the declines of target species (Skewes *et al*., 1999). While some illegal fishing at Ashmore Reef is believed to be occurring, significant populations of these target species remain at Ashmore as a result of the fishing restrictions within the Reserve (Skewes *et al*., 1999). There is no evidence that sea snakes have been targeted by Indonesian fishers (Hale and Butcher, 2013; Lukoschek *et al*., 2013). There are also no known connections between the depletion of the targeted species, some of which may themselves be predators on sea snakes (e.g., sharks), to the decline of dusky sea snakes.

As discussed previously, prawn trawling poses a threat to sea snakes generally. During 1990 alone, an estimated 81,080 (±13,666, 95% CI) sea snakes were captured in the Northern Prawn Fishery (NPF; Ward, 1996b), which operates off northern Australia and harvests banana and tiger prawns. Up to almost half of the incidentally captured sea snakes may drown or be crushed by the weight of the catch, although mortality rates vary by species (Wassenberg *et al*., 2001; Milton, 2001). In 2000, use of turtle excluder devices (TEDs) and bycatch reduction devices (BRDs) became mandatory in the NPF to reduce the bycatch of multiple taxa (Brewer *et al*., 2006). The effectiveness of BRDs in reducing bycatch of sea snakes has been shown to differ significantly depending on the type and location of the BRD in the trawl; and when optimally configured, BRDs can dramatically reduce sea snake bycatch (Brewer *et al*., 2006; Milton *et al*., 2009). In addition to mandatory BRDs, a dramatic decline in fishing effort and reduced size of the NPF fishing fleet since 2004 have also contributed to reducing sea snake bycatch (Milton *et al*., 2009). In a recent risk assessment for 14 species of sea snakes, no species appeared to be at risk of overfishing or to be at risk of extinction over the long term as a result of overfishing given fishing effort in the NPF during 2004-2006 (Zhou *et al*., 2012). In the NWSTF, which as discussed above operates within the range of *A. fuscus*, both fishing effort and observer coverage have been too low to rigorously evaluate the level and nature of bycatch occurring in this fishery (AFMA, 2012). However, in two separate ecological risk assessments on the NWSTF, no interactions with any protected species were detected, and detailed bycatch data for 2000-2008 do not include any sea snakes records (Emery *et al*., 2008; AFMA, 2012). Thus, there is no indication that inadequate regulatory mechanisms of the NWSTF are contributing to the decline of *A. fuscus*. If effort in this fishery increases, then additional observer coverage and bycatch monitoring would be required (AFMA, 2012). Overall, I do not consider the regulatory measures addressing bycatch of sea snakes in Australian trawl fisheries to be inadequate such that they pose a threat to *A. fuscus*, and they are unlikely to have contributed to the observed decline of *A. fuscus.*

Sea snake products have been traded internationally since the 1930s (Marsh *et al*., 1994), but no species is currently listed under CITES (the Convention on International Trade in Endangered Species of Wild Fauna and Flora). Australia's Wildlife Protection Act 1982 restricts the export of sea snake products out of Australia (Marsh *et al*., 1994). There are no data to suggest that the dusky sea snake is threatened by past, present or future trade.

According to the Australia's Department of Sustainability, Environment, Water, Population and Communities (DSEWPC) 2012 Report Card for marine reptiles listed under the EPBC Act, pollution from offshore oil rigs and operations is a potential concern for sea snakes (DSEWPC, 2012). This report also states that Australia has a strong system for regulating the oil and gas industry and that this system was strengthened further in the wake of the Montara oil spill. Details on how any particular processes or regulations were strengthened are not provided in this report. Although oil spills pose a potential threat to the health and status of the dusky sea snake, oil spills are relatively rare, and I do not have information to indicate that the existing regulatory mechanisms are inadequate or that they have contributed to the decline of this species.

Climate change also poses potential threats to dusky sea snakes. Possible threats to sea snakes stemming from anthropogenic climate change include elevated sea surface temperature, ocean acidification, and increased coral bleaching events. Impacts of climate change on the marine environment are already being observed in Australia and elsewhere (Poloczanska *et al*., 2012; Melillo *et al*., 2014), and the most recent IPCC assessment provides a high degree of certainty that human sources of greenhouse gases are contributing to global climate change (IPCC, 2013). Ocean temperatures around Australia have increased by 0.68°C since 1910-1929 (Poloczanska *et al*., 2012), and carbon dioxide inputs have lowered ocean pH by 0.1 units since 1750 (Howard et al., 2009). Australia and other countries have responded to climate change through various international and national mechanisms. Australia signed on to the Kyoto Protocol in 2007 and has active domestic and international programs to lower greenhouse gas emissions (www.climatechange.gov.au/). In Australia, there appear to be no specific actions to address potential climate change effects on marine reptiles beyond monitoring (Fuentes *et al*., 2012). Because climate change related threats have not been clearly or mechanistically linked to decline of dusky sea snakes, the adequacy of existing or developing measures to control climate change threats is not possible to fully assess, nor are sufficient data available to determine what regulatory measures would be needed to adequately protect this species from climate change. While it is not possible to conclude that the current efforts have been inadequate such that they have contributed to the decline of this species, I do conclude that, if regulatory mechanisms are not strengthened, dusky sea snakes are likely to be negatively impacted by climate change given the predictions of widespread and potentially permanent damage to coral reefs in Australia (IPCC, 2013). Additional discussion of whether and to what extent dusky sea snakes may be negatively affected by climate change is presented in the section below regarding other natural or human threats.

Overall, I do not find substantial evidence to indicate that dusky sea snakes are threatened by the lack of adequate regulatory mechanisms. Beyond the direct protection they receive through their listing under the EPBC Act, dusky sea snakes receive additional direct and indirect protection within the Ashmore Reef and Cartier Island Marine Reserves. These Reserves comprise about 43% of the total reef area and about 21% of the total reef-edge length across the five main reefs within their range. As neither direct harvest nor bycatch are demonstrated to threaten dusky sea snakes, the adequacy of existing fishing regulations and bycatch reduction mechanisms is largely irrelevant. Oil spills are rare and unpredictable, and I have no information to indicate that spills and other oil and gas industry activities pose a threat as a consequence of inadequate management. The largest potential gap in existing regulatory mechanism may be for threats related to climate change. Evidence to demonstrate that dusky sea snakes have declined as a consequence of impacts to their coral reef habitat is limited, but this is a plausible threat to the species. Evidence to indicate that elevated water temperatures poses a threat to dusky sea snakes is even more limited (and is discussed further below). Predictions of worsening damage to coral reefs, however, increase the likelihood that dusky sea snakes will be negatively affected if efforts to curb global warming are not strengthened.

Other natural or human factors affecting its continued existence

Elevated sea surface temperature as a consequence of climate change has been proposed as a possible threat to sea snakes. The IUCN assessment for *A. fuscus*, suggests that climate-induced increases in water temperature may actually exceed the upper lethal limit for *A. fuscus* and thereby pose a threat to the species (Lukoschek *et al*., 2010). Sea snakes, like all reptiles, are ectotherms and thus to a great extent are physiologically affected by temperature. On a large geographic scale, the distribution of sea snakes is considered to be dictated by ocean temperatures: sea snakes generally do not occur in waters below about 18 ^{o}C (Davenport, 2011). Most sea snakes can tolerate temperatures up to a mean of about 39-40 °C, but tolerances may vary with the size of the snake and the rate of temperature change (Heatwole *et al*., 2012). Also, although sea snakes are able to dive to avoid extreme temperatures of surface waters, they have limited capacity to acclimate and cannot thermoregulate (Heatwole *et al*., 2012).

Sea surface temperatures vary seasonally within the Timor Sea. The highest recorded oceanic water temperature in the Ashmore region is 31°C, and the highest recorded lagoon water temperature is 35.4°C (Commonwealth of Australia, 2002). These temperatures are below the assumed upper lethal temperature limit for dusky sea snakes; but Australia's average ocean temperatures have increased by over half a degree since 1910-1929, and the rate of warming has accelerated since the mid-20th century (Poloczanska *et al*., 2012). Experiments to measure the thermal tolerances of *A. fuscus* have not been conducted, and I have no available data to indicate that water temperature has had a direct negative impact on dusky sea snakes such that it has contributed to the observed decline of this species. Given the thermal tolerances for other sea snakes and the ocean temperatures currently experienced by *A. fuscus* at present, it is very unlikely that elevated ocean temperature has been a source of mortality. However, it is plausible that a continuation of the observed rate of ocean warming would - in the distant future - result in negative physiological consequences for *A. fuscus*.

Hybridization and introgression have recently been identified by Sanders *et al*. (2014) as a threat to the continued existence of *A. fuscus*. Hybridization, or the production of viable offspring through the crossing of genetically distinct taxa or groups, occurs in the wild for about 10% of animal species (Mallet, 2005). Hybridization can lead to introgression, or the integration of foreign genetic material into a genome. The conservation concern in this particular case is that reproductive barriers between *A. laevis* and *A. fuscus* appear to be breaking down and potentially allowing *A. fuscus* to undergo reverse speciation.

The dusky sea snake co-occurs with the closely related olive sea snake, *A. laevis*, throughout its range; and the two species are thought to have shared a common ancestor approximately 500,000 years ago (Sanders *et al*., 2013b). The olive sea snake is a relatively abundant and much more widely distributed species compared to the dusky sea snake. Although similar in appearance, the two species can be distinguished based on body scale rows, body size, and color pattern. Sanders *et al.* (2014) analyzed 11 microsatellite markers for *A. fuscus* and *A. laevis* across four reefs (Ashmore, Hibernia, Scott and Seringapatam) to assess inter-specific gene flow and introgression. Results of their genetic analyses indicate significant and asymmetric gene flow, with higher rates of introgression from *A. laevis* into the smaller *A. fuscus* population (Sanders *et al.*, 2014). A high frequency of hybrids was also found at each of the four reefs included in the study area. Forty-three percent of the snakes sampled (n=7) at Ashmore, 55% of the snakes sampled (n= 42) at Scott Reef, and 42% of the snakes sampled (n=12) at Seringapatam Reef were identified as hybrids (Sanders *et al.,* 2014). At Hibernia Reef, 95% of the snakes sampled (n=19) were hybrids (Sanders *et al.*, 2014). Phenotypically, the majority of hybrids resembled the olive sea snake (Sanders *et al.*, 2014). Regardless of whether it reflects a natural evolutionary process or is somehow human-caused, the high rates of hybridization of *A. fuscus* with another species across its range may lead to the eventual disappearance of this taxonomic species.

Table 2. Summary of possible threats to *A. fuscus* and relative strength of the evidence indicating these may be operative threats on *A. fuscus*. Threats are organized by their appropriate ESA section 4(a)(1) category. Characterizations of the relative likelihood (very low, low, medium, high) that a particular threat is contributing or will contribute to the observed decline in abundance of *A. fuscus* are explained further in the text above.

	Threat	Likelihood
Habitat	Loss of live corals	low
	Pollution from oil and gas development-related activity	low
Overutilization	Bycatch	very low
	Direct harvest	very low
	Illegal fishing	very low
Disease or Predation	Predation	very low
	Disease	very low
Inadequate regulations	Direct harvest (legal and illegal)	very low
	Bycatch	very low
	Trade	very low
	Oil and gas industry	low
	Climate change	medium
Other	Lethal water temperatures	medium
	Hybridization	high

(1) Very low – meaning it is very unlikely that the particular threat contributes or will contribute to the decline of the species; **(2)** Low - meaning it is unlikely that the particular threat contributes or will contribute to the decline of the species; **(3)** Medium - meaning it is likely the particular threat contributes or will contribute to the decline of the species; and, **(4)** High - meaning it is highly likely that the particular threat contributes or will contribute to the decline of the species.

Demographic Risks

Below I summarize various demographic risks to the viability of *A. fuscus*. As mentioned previously, I conducted a qualitative assessment of the overall status of the species using four demographic viability risk criteria: abundance, population growth rate/productivity, spatial structure/connectivity, and diversity. The relative likelihood that each particular demographic factor contributes in a significant way to the extinction risk of the species is characterized according to the following scale:

> (1) Very low – meaning it is very unlikely that the particular factor contributes or will contribute significantly to the risk of extinction;
> (2) Low - meaning it is unlikely that the particular factor contributes or will contribute significantly to the risk of extinction;
> (3) Moderate - meaning it is likely the particular factor contributes or will contribute significantly to risk of extinction; and,
> (4) High - meaning it is highly likely that the particular factor contributes or will contribute significantly to the risk of extinction.

(Note: I use the term "significantly" here as it is generally defined – i.e., in a sufficiently great or important way as to be worthy of attention.)

Abundance

There are no historical or current abundance estimates for *A. fuscus*, and available relative abundance data (Table 1 and Figure 3) largely obscure temporal (e.g., seasonal, day/ night) and spatial (e.g., reef proximity, water-depth) patterns, which can greatly affect sea snake abundance estimates (Guinea and Whiting, 2005). However, the available survey data strongly suggest that dusky sea snakes have disappeared from Ashmore Reef, which - based on reef area data reported in Skewes *et al*. (1999) - represents about 40% of their historical reef habitat. Extirpation from this reef would represent a substantial change in the species' distribution and abundance.

Given its absence in recent, extensive surveys, dusky sea snakes are either rare or no longer present at Hibernia Reef (Guinea, 2013). Of 19 snakes sampled at Hibernia Reef by Sanders *et al*. (2014), none were classified as "pure" *A. fuscus*, and 95% of the snakes sampled were assigned as hybrids. Similarly, relative abundance of *A. fuscus* at Seringapatam Reef and Cartier Island is also low or the species may not be present at these reefs (Table 1). While *A. fuscus* has been reported at Seringapatam Reef (Table 1), examination of museum specimens and recent genetic analyses of 12 snakes collected in 2012 and 2013 by Sanders *et al*. (2014) indicate that none were *A. fuscus* (Sanders, pers. comm., May 20, 2014). Of the 12 snakes collected by Sanders *et al*. (2014) in 2012 and 2013, 7 were *A. laevis*, 5 were hybrids, and all 12 had *A. laevis* phenotypes. No additional data are available for Cartier Island.

A. fuscus has consistently been the third or fourth-most abundant sea snake at Scott Reef (north and south reefs); however, present abundance is unclear given the available data and recent information regarding hybridization with *A. laevis* (Sanders *et al*., 2014).

The loss of populations or potentially very low abundances of dusky sea snakes at several reefs (e.g., Ashmore, Seringapatam, and Hibernia Reefs) has increased the fragmentation of the species and increased the likelihood of hybridization with the more dominant olive sea snake. Overall, the available information indicates that current abundances are highly likely to be contributing to the extinction risk of the species.

Population Growth Rate/ Productivity

Although information on dusky sea snake reproduction is fairly speculative, reproductive output is assumed to be low to moderate for dusky sea snakes, which may reach maturity at ~3-4 years and produce a small number of young (~4 or fewer) every other year (Heatwole, 1997; Lukoschek *et al.,* 2010). The IUCN assessment for this species reports an estimated population decline of at least 70% since 1998 (Lukoschek *et al*., 2010); however, it is unclear how this estimate was derived and whether it applies range-wide as implied or to Ashmore Reef only (see Elfes *et al*., 2013). While the true rate of decline is unknown, the available data on relative abundance and hybridization rates suggest the species is declining throughout its range, and there is no information to suggest such a trend would reverse. The limited, available evidence is therefore suggestive of negative population growth. Given the available information, it is likely that the low population growth rate is contributing to the risk of extinction for this species.

Spatial Structure and Connectivity

The dusky sea snake has a restricted and patchy distribution. The maximum range area is currently estimated to be only 262 km^2 (Sanders *et al*., 2014). This estimate assumes *A. fuscus* is extirpated from Ashmore Reef and does not occur at Seringapatam Reef. The two other reefs – Hibernia and Scott Reef - are separated by about 260 km of mostly deep water (>200 m) habitat (Sanders *et al*., 2014; Figure 5). Lukoschek *et al*. (2010) estimate the dusky sea snake's area of occupancy to be less than 500 km^2.

Direct data on connectivity among dusky sea snake reef populations are not available. As discussed earlier, information on connectivity among sea snake reef populations comes mainly from a tracking study and genetic data for *A. laevis*, which is a closely related, but much more common and widely distributed species than *A. fuscus*. The short-term (6-9 days) tracking study on *A. laevis* suggests that adults of this species have a small home range (1,500-1,800 m^2) and undergo limited active dispersal (Burns and Heatwole, 1998). Results of that study are somewhat supported by analyses of microsatellite DNA by Lukoschek *et al*. (2008), which indicate that two of the most distant Timor reef populations of *A. laevis* are significantly diverged (Fst = 0.048). However, the degree of divergence of other reef populations was not significant, and there was no clear isolation-by-distance relationship (Lukoschek *et al*., 2008).

Overall, based on the available information for the olive sea snake and the fact that dusky sea snakes are viviparous and lack a dispersive larval phase, I assume that connectivity of *A. fuscus* may be limited among some reefs within the region. Limited inter-population exchange would reduce the recovery potential for local populations that have experienced severe declines or have been lost. I conclude this demographic factor is likely to contribute to the extinction risk of the species. Additional research on this topic is needed for *A. fuscus*.

Diversity

As discussed earlier, recent genetic evidence indicates high rates of hybridization between *A. fuscus* and *A. laevis* at all four reefs where dusky sea snakes were thought to still occur (Sanders *et al*., 2014). The high rates of hybridization and the asymmetric gene flow, with higher rates of introgression from *A. laevis* into the smaller *A. fuscus* population, suggest that *A. fuscus* is undergoing reverse speciation (Sanders *et al.*, 2014). Thus, hybridization is highly likely to contribute to the extinction risk of the dusky sea snake.

Table 3. Summary of demographic risk factors for *A. fuscus* and relative strength of the evidence indicating these factors are posing an extinction risk for the species. Characterizations of the relative likelihood (very low, low, medium, high) that a particular factor is contributing in a significant way to the extinction risk of the species are explained further in the text above.

Demographic Risk	Likelihood
Abundance	high
Growth rate/ productivity	moderate
Spatial structure and connectivity	moderate
Diversity	high

CONSERVATION EFFORTS

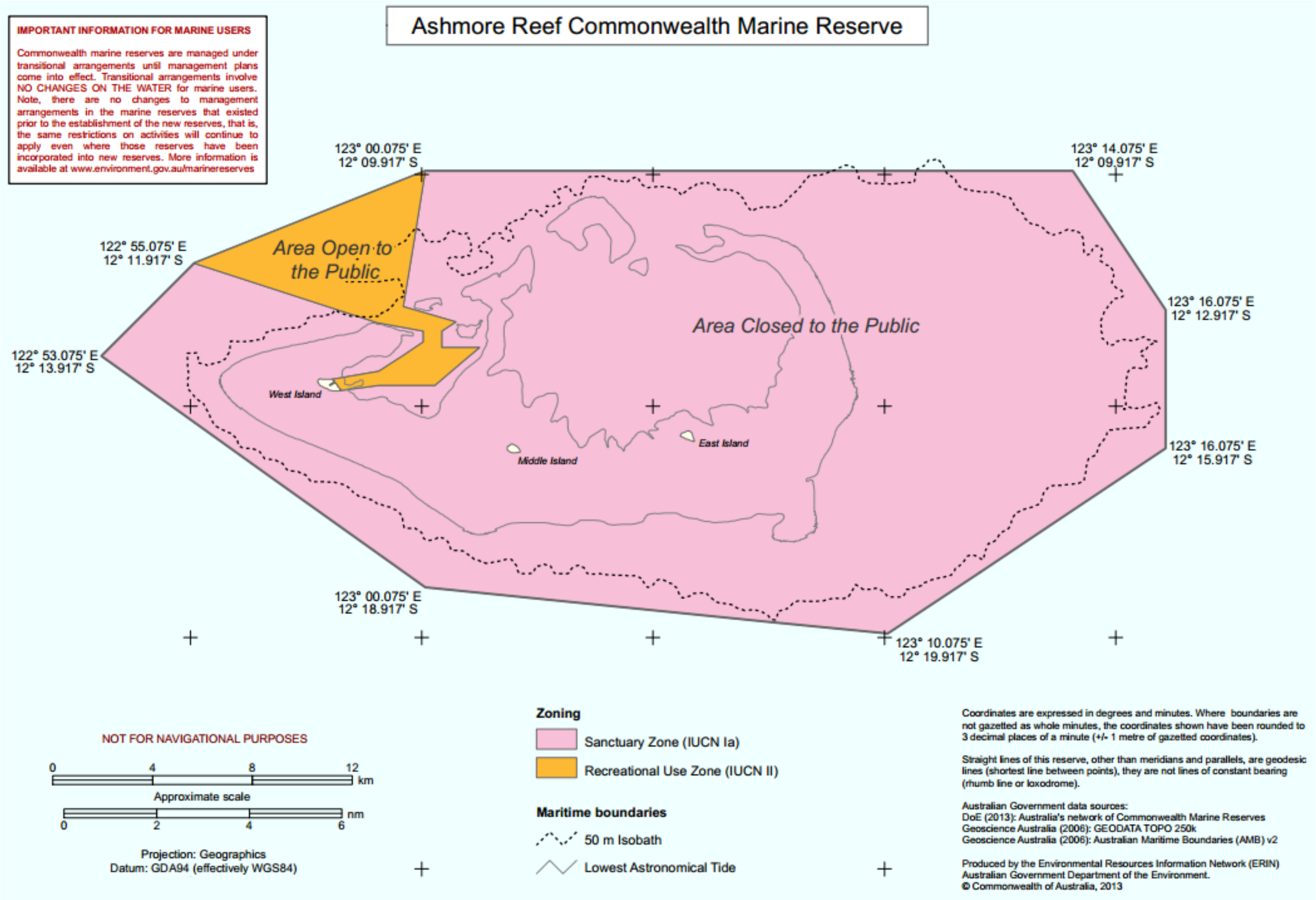
Section 4(b)(1)(A) of the ESA requires the Secretary of Commerce to take into account "…efforts, if any, being made by any State or foreign nation, or any political subdivision of a State or foreign nation, to protect such species…". The ESA therefore directs NMFS to consider all conservation efforts being made to conserve the species. The joint USFWS and NMFS Policy on Evaluation of Conservation Efforts When Making Listing Decisions ("PECE Policy", 68 FR 15100; March 28, 2003) further identifies criteria for determining whether formalized conservation efforts that have *yet to be implemented or to show effectiveness* contribute to making listing unnecessary, or to list a species as threatened rather than endangered [emphasis added]. An analysis of such conservation efforts is not included in this status review, but will be addressed in the 12-month finding or proposed rule in response to the petition to list this species under the ESA. Conservation efforts that are already being made and that may be having a positive influence on the status of *A. fuscus* are inherently considered in the assessment of the demographic risks to the species. The following section provides a synopsis of those conservation efforts already in place.

Commonwealth Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act)

As mentioned previously, all of Australia's hydrophiine sea snakes are listed and protected under the Commonwealth Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act). Under the EPBC Act, it is illegal to kill, injure, take, trade, or move dusky sea snakes in Commonwealth waters without a permit (DSEWPC, 2012a). The EPBC Act also requires that surveys be conducted for listed marine species. There are no conservation plans in place for any sea snake species (Lukoschek *et al*., 2007a). However, sea snakes are identified as a "conservation value" in Australia's North-west Marine Bioregional Plan (DSEWPC, 2012b). Marine bioregional plans are meant to improve the way decisions are made under the EPBC Act, particularly with respect to balancing protection of marine biodiversity with the sustainable use of natural resources. The North-west Plan identifies activities that may affect sea snakes and thus require prior approval. National heritage places are also listed and protected under the EPBC Act. Ashmore, Scott, and Seringapatam reefs are all listed on Australia's Commonwealth Heritage List; and under the EPBC Act, approval must be obtained before any action takes place that could have a significant impact on the national heritage values of these areas.

Protected Areas

As discussed earlier in this report (see "Inadequacy of Existing Regulatory Mechanisms"), several area protections have been extended directly and indirectly to coral reefs within the dusky sea snakes' range. The Ashmore Reef National Nature Reserve was established in 1983 under the National Parks and Wildlife Conservation Act 1975, a predecessor to the EPBC Act and later renamed the Ashmore Commonwealth Marine Reserve. This Reserve includes 583 km^2 of sandy islands, coral reefs and surrounding waters up to 50 m deep (Commonwealth of Australia, 2002). Due to its zoning as an IUCN category Ia area, the Reserve is almost completely closed to the general public (Figure 7). Permits may be issued to authorize visits for tourism or recreation, and there are 1-2 visits per year by commercial tourism vessels to view wildlife (Hale and Butcher, 2013). About 15-20 recreational yachts make visits each year (Hale and Butcher, 2013). Indonesians have fished this site for centuries and subsistence fishing is allowed in only the category II portion of the reserve (Figure 7; Hale and Butcher, 2013). No commercial fishing is allowed in any part of the Reserve. The relatively pristine state of the site makes it attractive for the long-term monitoring and other scientific projects that are conducted there (Hale and Butcher, 2013). Since the late 1980's, Environment Australia (EA) contracted a private vessel and crew to undertake on-site management at the Reserve; however, as of 2000, Australian Customs Service took over this responsibility (Whiting, 2000). Enforcement of protections at the Reserve depends largely on the presence of Customs officials, which is not quite continuous (Whiting, 2000; Lukoschek *et al*., 2013).



IMPORTANT INFORMATION FOR MARINE USERS

Commonwealth marine reserves are managed under transitional arrangements until management plans come into effect. Transitional arrangements involve NO CHANGES ON THE WATER for marine users. Note, there are no changes to management arrangements in the marine reserves that existed prior to the establishment of the new reserves, that is, the same restrictions on activities will continue to apply even where those reserves have been incorporated into new reserves. More information is available at www.environment.gov.au/marinereserves

Coordinates are expressed in degrees and minutes. Where boundaries are not gazetted as whole minutes, the coordinates shown have been rounded to 3 decimal places of a minute (+/- 1 metre of gazetted coordinates).

Straight lines of this reserve, other than meridians and parallels, are geodesic lines (shortest line between points), they are not lines of constant bearing (rhumb line or loxodrome).

Australian Government data sources:
DoE (2013): Australia's network of Commonwealth Marine Reserves
Geoscience Australia (2006): GEODATA TOPO 250k
Geoscience Australia (2006): Australian Maritime Boundaries (AMB) v2

Produced by the Environmental Resources Information Network (ERIN)
Australian Government Department of the Environment.
© Commonwealth of Australia, 2013

Figure 7. Map of the Ashmore Reef Commonwealth Marine Reserve showing area designated as category Ia (pink area), which is closed to the public. The West Island Lagoon and portions of the West Island (gold area) are assigned to category II and are open to the public. (Map from Australian Government Department of the Environment: http://www.environment.gov.au/topics/marine/marine-reserves/north-west/ashmore-activities).

The area that comprises the Ashmore Reserve was also designated as a Ramsar Site in October 2002. The Convention on Wetlands of International Importance, which was signed in Ramsar, Iran in 1971 and is often referred to as the "Ramsar Convention," came into force in 1975 and established a framework for national efforts and international cooperation in support of the conservation, management and "wise use" of wetlands and their resources. "Wise use" is defined as "the maintenance of [a wetland's] ecological character, achieved through the implementation of ecosystem approaches, within the context of sustainable development" (see Ramsar Handbook: http://www.ramsar.org). In Australia, Ramsar Sites receive protection under the EPBC Act: any action that will have or is likely to have a significant impact on a Ramsar Site requires and environmental assessment and approval. The EPBC Act also sets forth national standards for managing, planning, monitoring, involving the community, and conducting environmental assessments to insure consistent compliance with the Ramsar Convention.

Cartier Island Commonwealth Marine Reserve, which was designated in 2000 under the EPBC Act (and previously named Cartier Island Marine Reserve), is completely closed to the public. No commercial or recreational fishing is allowed. General access and several other activities such as scientific research, photography and tourism, may be allowed with prior approval from the Director of National Parks is issued under the EPBC Act (see http://www.environment.gov.au/topics/marine/marine-reserves/north-west/cartier-activities).

Australia–Indonesia Memorandum of Understanding of 1974 (MOU Box)

The bilateral agreement that established the "MOU Box" is officially known as the Australia–Indonesia Memorandum of Understanding regarding the Operations of Indonesian Traditional Fishermen in Areas of the Australian Fishing Zone and Continental Shelf – 1974. The rectangular tract of marine waters within Australia's Exclusive Economic Zone subject to this MOU and subsequent agreements between Australia and Indonesia covers an area of about 50,000 km^2 and includes Scott and Seringapatam Reefs, Browse Island, and Ashmore and Cartier Islands (Figure 9). The agreement recognizes access rights of traditional Indonesian fishers and the long history of traditional Indonesian fishing in the shared waters to the north of Australia, but as discussed previously, fishing is no longer allowed at Ashmore Reef and Cartier Island with the exception of limited fishing within the category II section at the Ashmore Reserve.

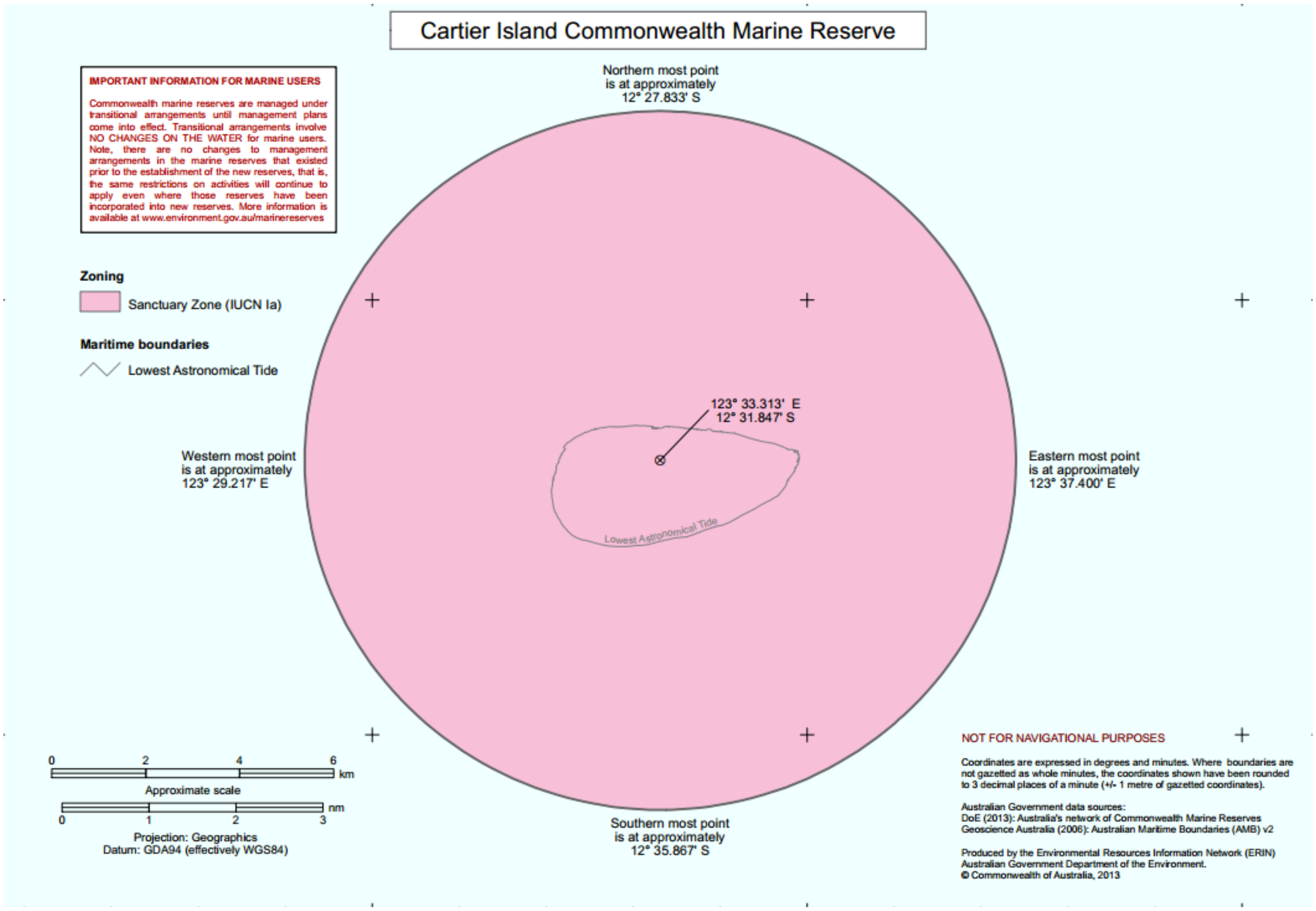


Figure 8. Map of Cartier Island Commonwealth Marine Reserve with the boundaries of the IUCN category Ia area (pink), which is closed to the public.

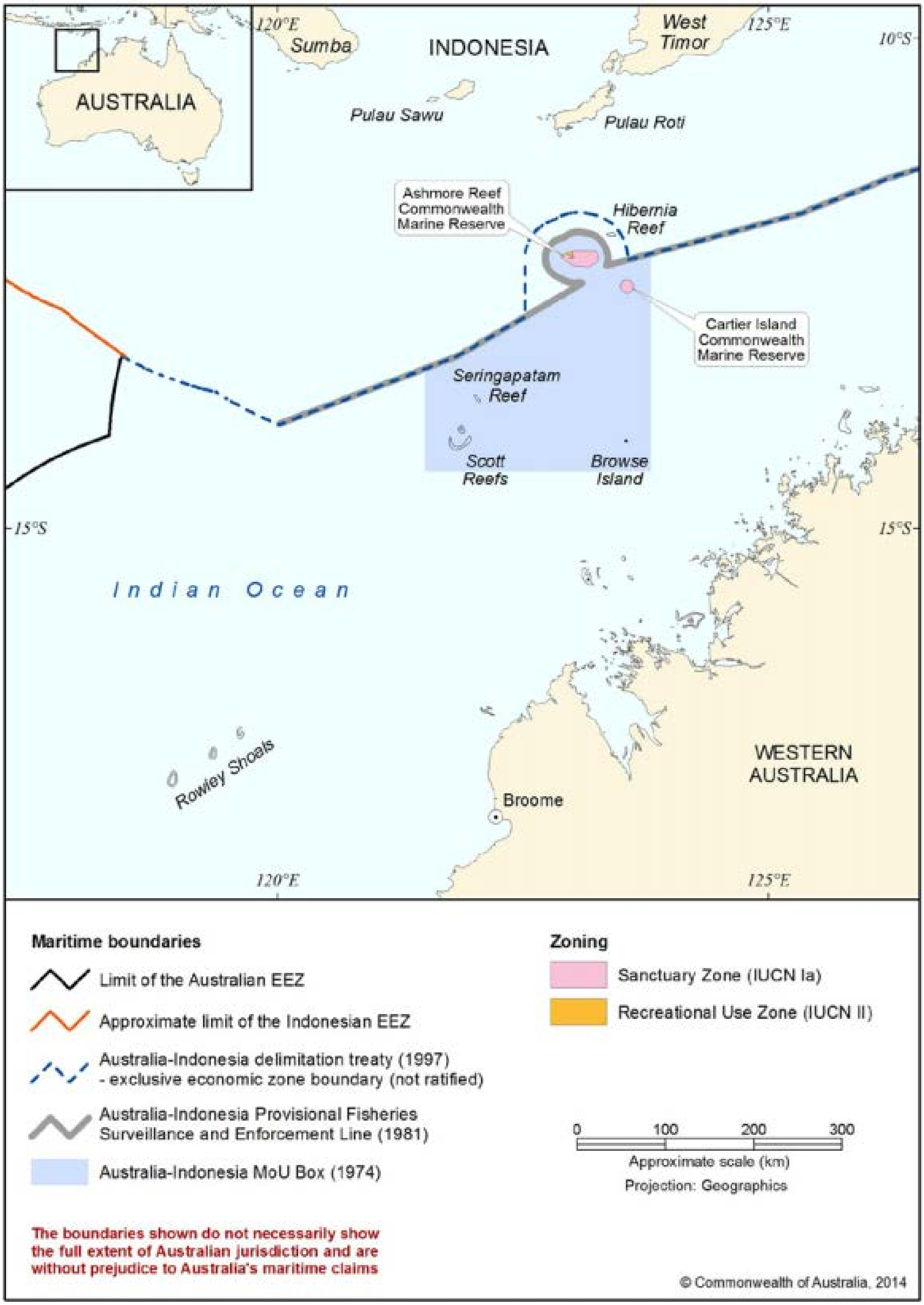


Figure 9. Location of Ashmore Commonwealth Marine Reserve, Cartier Island Marine Reserve, and the MOU Box.

Bycatch Reduction Devices (BRDs)

Because sea snakes are listed under the EPBC Act, all Australian fisheries are required to demonstrate that direct and indirect interactions with sea snakes are sustainable (Zhou *et al*., 2012). BRDs and turtle excluder devices (TEDs) are required in the prawn trawl fishery to minimize bycatch mortality and help conserve protected species. Trawls take over a dozen species of sea snakes (Heatwole 1997; Wassenberg *et al*., 2001; Zhou *et al*., 2012), and in the absence of a BRD, an estimated 48.5% of all incidentally captured sea snakes will die (Wassenberg *et al*., 2001). Zhou *et al*., 2012 estimated fishing mortality rates, maximum sustainable fishing mortality, and minimum sustainable fishing mortality for the Northern Prawn Fishery, and concluded that no sea snake species appeared to be at risk of extinction at fishing levels of 2004-2006, which is significantly lower that the level of effort in previous decades (Zhou *et al*., 2012). The only trawl fishery that operates within the range of the dusky sea snake is the North West Slope Trawl Fishery (NWSTF). As discussed earlier, there have been no documented interactions of this fishery with any sea snake species (AFMA, 2012).

SYNTHESIS AND CONCLUSION

Accurate and precise data for many demographic characteristics of dusky sea snakes are lacking. However, the best available data do provide multiple lines of evidence to support a conclusion that this species is currently facing a high risk of extinction. The observed loss of dusky sea snakes from Ashmore Reef, which constitutes about 40% of the historical reef habitat, indicates a contraction of an already limited range for this species. Loss of dusky sea snakes from Ashmore Reef and low relative abundances elsewhere, coupled with high rates of hybridization throughout the range and a presumed low rate of dispersal, suggest that the species is in decline and unlikely to recover without intervention. Existing regulatory mechanisms also seem unlikely to prevent further decline of this species. Decades of protections at Ashmore Reef, while maintaining this as a relatively pristine reef (Hale and Butcher, 2013), have not prevented the severe decline and likely extirpation of dusky sea snakes there. The threat of hybridization is beyond the scope of existing protections. The interaction of low and/or declining abundance, limited dispersal, and high rates of hybridization all suggest a high risk of extinction in the near term. Thus, following consideration of the best available data summarized in this report, I conclude that the dusky sea snake, *A. fuscus*, is currently at high risk of extinction throughout its historical range.

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