Dusky Sea Snake
(Aipysurus fuscus)

5-Year Review:
Summary and Evaluation


Photo Credit: Sanders *et al*., 2014

National Marine Fisheries Service
Office of Protected Resources
Silver Spring, MD
September 2020

5-YEAR REVIEW

Dusky sea snake (*Aipysurus fuscus*)

Table of Contents

List of Figures

5-YEAR REVIEW

Dusky sea snake (*Aipysurus fuscus*)

1. GENERAL INFORMATION

1.1. Reviewers

Lead Regional or Headquarters Office:
Grace Carter, Office of Protected Resources, Hollings Scholar
Heather Austin, Office of Protected Resources, (301) 427-8422

1.2. Methodology used to complete review

A 5-year review is a periodic analysis of a species' status conducted to ensure that the listing classification of a species currently listed as threatened or endangered on the List of Endangered and Threatened Wildlife and Plants (List) (50 CFR 17.11 – 17.12) is accurate. The 5-year review is required by section 4(c)(2) of the Endangered Species Act of 1973, as amended (ESA) and was prepared pursuant to the joint National Marine Fisheries Service (NMFS) and U.S. Fish and Wildlife Service's 5-year Review Guidance and Template (NMFS and USFWS 2018). The NMFS Office of Protected Resources (OPR) conducted the 5-year review. We updated information from the status review (Manning, 2014) based on peer-reviewed publications, government and technical reports, theses, and personal communications. We gathered information through July 2020. The information on the dusky sea snake (*Aipysurus fuscus)* biology and habitat, threats, and conservation efforts was summarized and analyzed based on ESA section 4(a)(1) factors (see Section 2.3) to determine whether a reclassification or delisting may be warranted (see Section 3.0).

NMFS initiated a 5-year review of the dusky sea snake and solicited information from the public on July 7, 2020. One public comment was received and incorporated as appropriate in this review.

1.3. Background

1.3.1. FRN Notice citation announcing initiation of this review

FR Notice: 85 FR 40622, July 7, 2020

1.3.2. Listing History

<u>Original Listing</u>
FR Notice: 80 FR 60560
Date listed: October 2015
Entry listed: Dusky Sea Snake (*Aipysurus fuscus*)
Classification: Endangered

1.3.3. Associated rulemakings

Not Applicable

1.3.4. Review History

The initial status review (Manning, 2014) concluded that the dusky sea snake is at a high risk of extinction and recommended its classification be ‘endangered.’

1.3.5. Species Recovery Priority Recommendation

Not Applicable

1.3.6. Recovery Plan or Outline

Not Applicable -- It was determined that a recovery plan would not benefit the conservation of this species because its range occurs entirely under the jurisdiction of other countries. The United States has no authority to implement actions needed to recover this species.

2. Review Analysis

2.1. Application of the 1996 Distinct Population Segment (DPS) policy

2.1.1. Is the species under review a vertebrate?

__x__**Yes**
_____**No**

2.1.2. Is the species under review listed as a DPS?

_____**Yes**
__x__**No**

2.1.3. Was the DPS listed prior to 1996?

_____**Yes**
_____**No**

2.1.3.1. Prior to this 5-year review, was the DPS classification reviewed to ensure it meets the 1996 policy standards?

_____**Yes**
_____**No**

2.1.3.2. Does the DPS listing meet the discreteness and significance elements of the 1996 DPS policy?

_____**Yes**
_____**No**

2.1.4. Is there relevant new information for this species regarding the application of the DPS policy?

_____Yes
__x__No

2.2. Recovery Criteria

Not Applicable

2.2.1. Does the species have a final, approved recovery plan containing objective, measurable criteria?

_____Yes
_____No

2.2.2. Adequacy of recovery criteria.

Not Applicable

2.2.2.1. Do the recovery criteria reflect the best available and most up-to date information on the biology of the species and its habitat?

_____Yes
_____No

2.2.2.2. Are all of the 5 listing factors that are relevant to the species addressed in the recovery criteria (and is there no new information to consider regarding existing or new threats)?

_____Yes
_____No

2.2.3. List the recovery criteria as they appear in the recovery plan, and discuss how each criterion has or has not been met, citing information.

Not Applicable

2.3. Updated Information and Current Species Status

2.3.1. Biology and Habitat

2.3.1.1. New information on the species' biology and life history:

Snakes have evolved to thrive in a multitude of environments, including water. About 362 snake species utilize aquatic environments, with 70 species being considered sea snakes (Murphy, 2012). Fossil evidence suggests that snakes first inhabited oceanic environments in the Cretaceous Period (Murphy, 2012). Of the marine snakes, there are eight oviparous sea krait species that lay their eggs on land and at least 60 species of ovoviviparous true sea snakes (Ukuwela, 2013). While they are often referred to as viviparous, true sea snakes birth live young in the water (Ukuwela, 2013). True sea snakes, of the subfamily Hydrophiinae, are unique among reptiles in that they spend their entire lives in the ocean. Hydrophiinae is composed of 62 species across 17 genera (Manning, 2014). Members of this subfamily are mostly found in the Indian and Pacific Oceans around reefs, estuaries, and sea grass beds no deeper than 100m (Ukuwela, 2013). The only exception to this is the yellow-bellied sea snake, which resides in pelagic environments and ambushes prey that mistake it for driftwood (Guinea, 2013). The range of true sea snakes has historically excluded the Atlantic Ocean, most likely because the formation of the Isthmus of Panama five million years ago took away any warm water passage into the Atlantic Ocean (Ukuwela, 2013).

Aquatic snakes have a variety of adaptations that allow them to successfully move through water. They have laterally compressed bodies to be used as a paddle and valvular nostrils located more dorsally (Murphy, 2012). In addition to locomotion, the paddle-like tail is assumed to help with maintaining position in the water column with increased buoyancy, as freshwater aquatic snakes do not have this feature (Murphy, 2012). True sea snakes are able to rid themselves of dead skin and parasites by rubbing against coral or by twisting their body into a tight knot and squeezing through the coils (Guinea, 2013). Australia is most likely the origin site for true sea snakes (Ukuwela, 2013), and northwest Australia is currently home to the most biodiverse group of *Aipysurus* sea snakes (Udyawer *et al.*, 2020). Sea snakes have enough venom to cause a human fatality, but interactions with humans in Australian waters are mostly restricted to trawl fishermen and shell divers (Rasmussen *et al.*, 2014). True sea snakes have salt glands to regulate electrolytes, but still require access to freshwater (Gillett, 2017). Freshwater is most commonly obtained by surfacing during rainstorms (Guinea, 2013). Another adaptation of sea snakes is the ability to obtain oxygen through cutaneous respiration. This allows them to uptake oxygen from surrounding sea water through their skin and permits longer dive lengths (Udyawer *et al.*, 2016c). Up to 23% of oxygen intake can be from cutaneous respiration (Udyawer *et al.*, 2016c). The rate of oxygen consumed in this manner has not been found to be affected by sea water temperature or sea snake activity level, unlike the rate of oxygen consumed by pulmonary respiration (Udyawer *et al.*, 2016c).

The two main lineages of true sea snakes are the *Aipysurus* and *Hydrophis* clades (Ukuwela, 2013). Hydrophine sea snakes are a diverse group of snakes that tend to spend their nights on the surface (Guinea, 2013). The less diverse group, *Aipysurus*, is made of true sea snakes that live in shallow, benthic, coral ecosystems (D'Anastasi *et al*., 2016a). *Aipysurus* sea snakes are characterized by their large body scales and wide ventral scales (Anon, 2015). *Aipysurus* species sleep on the sea floor and are not attracted to night lights, making them difficult to document during night surveys (Guinea, 2013). Six of the seven *Aipysurus* species live only in Australian waters (Manning, 2014). Members of this genus are mostly found in coral reef habitats and tend to have fragmented populations (Udyawer *et al*., 2020). There are considerable knowledge gaps associated with sea snakes due to their infrequent encounters and lack of focused research.

Aipysurus fuscus (Tschudi, 1837), the dusky sea snake, is a relatively small brown or purple-brown sea snake with a few faint cross-bands (Anon, 2015). It is a species native to northwest Australia that is currently listed as 'Endangered' under the International Union for Conservation of Nature (IUCN) Red List due to its fragmentation and decreasing population trends (Lukoschek *et al*., 2010). Like all true sea snakes, *A. fuscus* is a predatory, ovoviviparous, fully-marine reptile (D'Anastasi *et al*., 2016a). It conceives and bears young fully underwater. Based on data from similar species, the lifespan for *A. fuscus* is most likely 10 years with maturity first being reached at approximately 3-4 years of age (Lukoschek *et al*., 2010). It is most often sighted alone or as a pair (Anon, 2015). It can be challenging to identify sea snakes down to the species level, and sightings of the olive sea snake, *Aipysurus laevis*, often are mistaken for *A. fuscus*. The difference between these species is that *A. fuscus* has 155 or more ventral scales and fewer than 21 scale rows around midbody (Rasmussen *et al.,* 2014).

The type specimen for *A. fuscus* was found in Sulawesi, however it is likely that this individual was of mistaken identity because there is no evidence of *A. fuscus* residing in this location (Lukoschek *et al.,* 2010). Currently, *A. fuscus* has a very limited recognized range. Individuals have been historically recorded residing at Ashmore Reef, Scott Reef, and Hibernia Reef within the Timor Sea off the coast of northwest Australia. These reefs are on the Sahul Shelf and are no deeper than 15 m in the areas in which *A. fuscus* resides (Manning, 2014). Like most sea snakes, *A. fuscus* is not endemic to pelagic environments. A 2015 survey of the Timor Sea reefs only found the species on Scott Reef (D'Anastasi *et al.*, 2016b). Concern for conservation of sea snakes in the Timor Sea has been sparked by reports of recent declines (Udyawer *et al.*, 2016a). A major concern for this species is that it has not been seen at Ashmore Reef since 2005 (Lukoschek *et al.*, 2013). It is possible that *A. fuscus* has suffered from a population decline of 70% or more since 1998 (Lukoschek *et al*., 2010).

Many *Aipysurus* sea snakes exhibit diet specialization. Many marine snakes tend to be egg-eating or eel-eating specialists, and it is common for sea snake species to only consume fish from one or two families (Voris and Voris, 1983). There are over 56 fish families that are consumed by sea snakes, with gobies and eels being prevalent prey items (Voris and Voris, 1983). Prey are swallowed whole, so even sea snake species that are considered generalists choose fish that are within a certain size or age class (Voris and Voris, 1983). Evaluations of stomach content reveal *A. fuscus* to prey mainly on Gobiidae and Labridae fishes, as well as fish eggs (Voris and Voris, 1983). *A. fuscus* is venomous and has 6 to 8 teeth behind its fangs (Manning, 2014). It may stick its head or tongue into a crevice or substrate to locate prey

(Anon, 2015). The specialist tendencies of *A. fuscus* make it well adapted to living on the reef, but susceptible to changes in ecosystem.

In tracking behavior, members of the species have been seen resting, swimming, or foraging between reef and sand (D'Anastasi *et al.*, 2016b). Hard coral reef ecosystems are the only ecosystem in which *A. fuscus* has been found, and therefore appear necessary for its survival. Reports within the last five years mostly confirm what is already accepted and documented within the status review about the life history and biology of *A. fuscus*. There continues to be a knowledge gap for much of the ecology and biology of this species due to its absence in appearance during video surveys and its tendency to chase away divers.

2.3.1.2. Abundance, population trends (e.g. increasing, decreasing, stable), demographic features (e.g., age structure, sex ratio, family size, birth rate, age at mortality, mortality rate, etc.), or demographic trends:

While it is known that the *A. fuscus* population has undergone a gradual decline in population, there is no information regarding a current population size or the change in its abundance over the past five years. There is uncertainty regarding *A. fuscsus* adundance. Ashmore Reef historically demonstrated high sea snake diversity and high *A. fuscus* abundance (Manning, 2014). It is the largest and most studied of all Timor Sea Reefs (Manning, 2014). However, a dramatic drop in sea snake numbers on Ashmore was noticed in the early 2000s, with a trend of decreasing abundance and diversity since then (Guinea, 2013). There has been a complete lack of sightings of the Ashmore Reef population of *A. fuscus* since 2005 (Lukoschek *et al.*, 2013).

A documented population on the Scott Reef complex remains. *A. fuscus* has historically been reported at this location. The Scott Reef complex is composed of Scott Reef North, Scott Reef South, and Seringapatam Reef (Speed *et al.*, 2019). Manta board surveys have been used on Timor Sea reefs to estimate sea snake abundance. This type of survey consists of a researcher grabbing onto to a piece of plywood that is being towed by a boat; the researcher wears a snorkel and a camera recorder on their helmet (Guinea, 2013). In the manta board surveys mentioned in this report, the researcher had a graphite pencil to mark observations on the plywood and would capture unidentifiable individuals for skin biopsies and photographs (Guinea, 2013). Manta surveys on Scott Reef were often accompanied by standard snorkel and boat surveys. A 2006 manta board survey of the Scott Reef complex, excluding Seringapatam Reef, found 3 out of 52 sea snakes to be *A. fuscus* (Guinea, 2013). A 2012 manta board survey of the entire Scott Reef complex revealed 3 out of 107 sampled sea snakes to be *A. fuscus* (Guinea, 2013). A 2013 manta board survey of the entire complex found 7 out of 117 sampled sea snakes to be *A. fuscus* (Guinea, 2013). In a 2015 study that used a combination of survey methods, 4 out of 27 sea snakes found on Scott Reef were determined to be *A. fuscus* (D'Anastasi *et al.*, 2016b). But, unlike previous surveys, the 2015 study surveyed but did not find *A. fuscus* at Seringapatam Reef (D'Anastasi *et al.*, 2016b). It is possible that total sea snake abundance is declining on Scott Reef as well. A study that conducted sampling rounds across five years revealed only one species, which was sighted at a less frequent rate, in its most recent survey of Scott Reef in 2014 (**Figure 1**; Udyawer and Heupel, 2017).

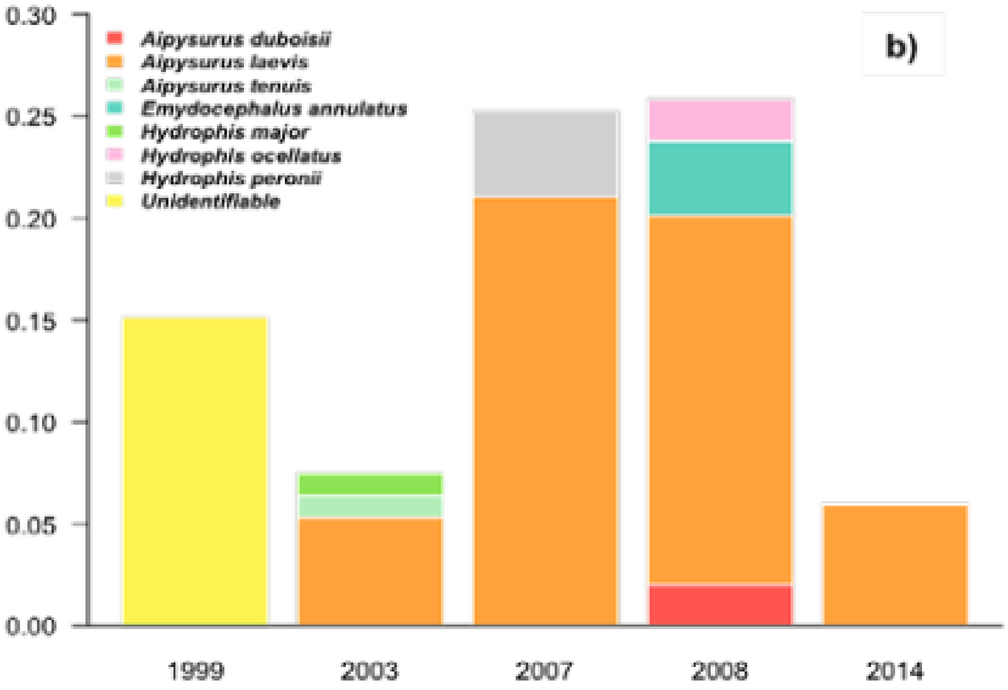

Figure 1. The number of snakes seen per minute at BRUVS across five different years on Scott Reef. 2014 revealed only one species, which was found at a less frequent rate. This study identified no *A. fuscus*, demonstrating its elusiveness when attempting to survey with BRUVS (Udyawer and Heupel, 2017).

Smaller populations have been recorded outside of Ashmore and Scott Reef. Divers surveyed Hibernia Reef in 2005 and recorded 35 sea snakes, two of which were *A. fuscus* (Guinea, 2013). When Guinea (2013) returned in 2012 and 2013, no *A. fuscus* was identified at Hibernia Reef. Cartier Island has historically shown a record of *A. fuscus*, however, the evidence suggesting a population here is very limited. Additionally, manta board surveys conducted at Cartier Island in 2012 and 2013 did not result in any *A. fuscus* sightings (Guinea, 2013).

There are no historical estimates for population size of *A. fuscus* (Manning, 2014). The species has not been consistently detected in Timor Sea studies. Between 1999 and 2016, multiple sources and survey methods recorded 1849 sea snakes in northwest Australia (**Figure 2**; Udyawer *et al.*, 2016a). The few *A. fuscus* individuals that were seen resided in two distinct locations that were not clearly identified. Another study that used baited remote underwater video stations (BRUVS) between 1999 and 2014 on Scott Reef (**Figure 1**) revealed no *A. fuscus* sightings (Udyawer and Heupel, 2017). This reflects the challenge of documenting abundance in this species.

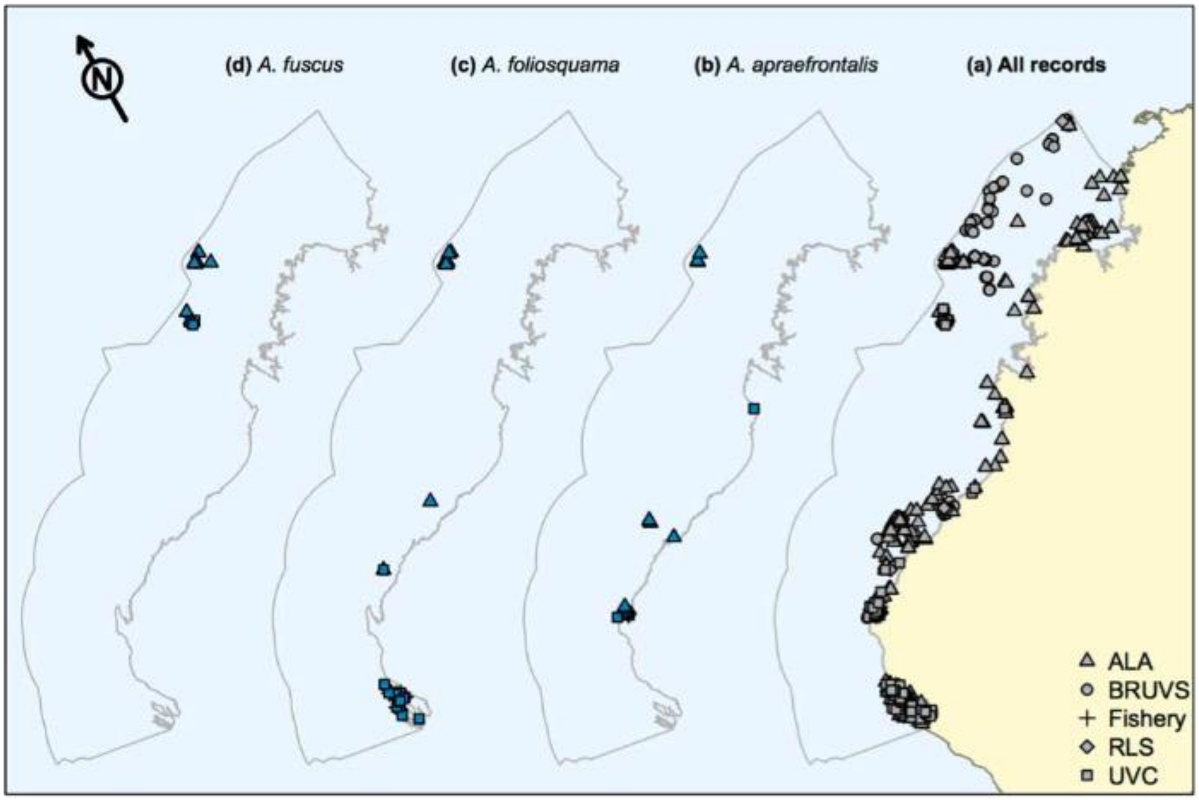

Figure 2. Plots of the two locations in which *A. fuscus* was seen between 1999 and 2016 collected by Atlas of Living Australia, BRUVS, Western Australian Department of Fisheries trawl surveys, Reef Life Survey program, and previous scientific surveys (Udyawer *et al*., 2016a).

It can be challenging to get accurate estimations of abundance. BRUVS have had limited success in documenting *A. fuscus* (Udyawer and Heupel, 2017). These stations often do not produce identifications on the species level due to low resolution and visibility (Udyawer *et al.*, 2016a). Testing for genetic bottlenecks within a population are sometimes used to asses population growth or decline. However, they have historically been unreliable and did not provide significant results when conducted on *A. fuscus* and other sea snakes at Ashmore Reef (Lukoschek, 2018b). A demographic survey would most likely provide a better estimation for population size and trends.

Environmental DNA (eDNA), the genetic material shed into an animal's surrounding medium, can be analyzed in a water sample to survey population trends; this method is sometimes used in studying fish biodiversity (Udyawer *et al.*, 2018). A study that aimed to determine the best way of evaluating aquatic snake populations in California found eDNA analysis less effective than trapping in detecting species presence (Rose *et al.*, 2019). There is no information about this technique being used to survey sea snakes in the Timor Sea. Considering eDNA can be effectively used for other animal species, developing techniques to efficiently test for sea snake eDNA would be an important step in monitoring sea snake populations. Tests such as eDNA analysis could be supplemented with in-water or remote camera surveillance to provide more accurate information on abundance. Overall, more research is needed to more accurately estimate current numbers.

2.3.1.3. Genetics, genetic variation, or trends in genetic variation (e.g., loss of genetic variation, genetic drift, inbreeding, etc.):

According to genetic signatures from samples collected in 2002, no demographic contraction was seen in the Ashmore Reef population of *A. fuscus* before its decline, unlike the other two prominent sea snake species in the region, *A. laevis* and *Emdocephalus annulatus* (Lukoschek, 2018b). However, *A. fuscus* did demonstrate lower genetic diversity compared to these other sea snakes possibly due to a smaller population before decline (Lukoschek, 2018b). Before the disappearance of *A. fuscus* from Ashmore Reef, inbreeding depression and non-random mating were seen in the species (Lukoschek, 2018b). A previous study had found sea snakes on Timor Sea reefs to have high hybridization rates with 55% of sampled individuals from Scott Reef being classified as hybrids of *A. fuscus* and *A. laevis* (Sanders *et al.*, 2014). This raised great concern over the future of the *A. fuscus* species. However, the hybridization of sea snakes in the Timor Sea has been challenged by a more recent study that analyzed samples taken from Ashmore Reef around the time of the decline of *A. fuscus*. Samples taken in 2002 showed only 2 out of 83 sea snakes on Ashmore Reef to be possible hybrids (Lukoschek, 2018b). Samples taken in 2010 showed no evidence to suggest *A. fuscus* hybridized with other species of sea snakes on Ashmore reef (Lukoschek, 2018b). Additionally, the hypothesis that hybridization is occurring on Scott Reef due to difficulty of finding a mate does not align with the absence of hybridization within the declining populations of Ashmore Reef (Lukoschek, 2018b). This study suggests a lower risk of reverse speciation than previously thought but does not necessarily point to a more positive outlook for the species (Lukoschek, 2018b).

Analysis of haplotype frequency and sequence revealed species within *Aipysurus* to have clearly defined clades and different haplotypes depending on region (Lukoschek, 2018a). Additionally, sea snake populations that are now in the Timor Sea likely diverged from those on the Great Barrier Reef and Gulf of Carpentaria around the same time period as the emergence of the Torres Strait Land bridge, suggesting this physical boundary was the mechanism for divergence (Lukoschek, 2018a).

2.3.1.4. Taxonomic classification or changes in nomenclature:

There are no changes to taxonomic classification:
Kingdom: Animalia
Phylum: Chordata
Subphylum: Vertebrata
Class: Reptilia
Order: Squamata
Suborder: Serpentes
Family: Elapidae
Subfamily: Hydrophiinae
Genus: *Aipysurus*
Species: *fuscus*

Marine snakes were most likely a sister group to burrowing snakes. Unlike terrestrial and arboreal snakes, burrowing snakes would have been exposed to increased salinities during storm surges and high tides (Murphy, 2012). True sea snakes demonstrated rapid adaptive radiation and grew diverse partly due to sea level changes and physical barriers that arose during the Pleistocene (Ukuwela, 2013). All true sea snakes belong to the subfamily Hydrophiinae and are classified into two genera: *Aipysurus* and *Emydocephalus*. All *Aipysurus* species are ovoviviparous, and the genus suffers from patchy distributions and reduced population sizes (Lukoschek, 2018a). *A. fuscus* and several other species diverged from the West Australian Coast sea snakes between 178,000 and 526,000 years ago (Lukoschek, 2018a). *A. fuscus* separated from its sister taxon, *A. laevis*, about 500,000 years ago (Lukoschek, 2018a).

2.3.1.5. Spatial distribution, trends in spatial distribution (e.g. increasingly fragmented, increased numbers of corridors, etc.), or historic range (e.g. corrections to the historical range, change in distribution of the species' within its historic range, etc.):

The limited recognized range of *A. fuscus* consists of Ashmore, Scott, and Hibernia off the northern coast of Australia (Manning, 2014). Ashmore Reef consists of three vegetated sand cays and a sandbar along the 25 km of reef (Guinea, 2013). There are no reports of a current population of *A. fuscus* at Ashmore Reef. The Scott Reef system most likely holds the largest current population of *A. fuscus*. It is about 260 km from Australia's mainland and is composed of Scott Reef South, Scott Reef North, and Seringapatam Reef (Speed *et al.*, 2019). Sitting on the Sahul Shelf, Scott Reef is a system of three atolls surrounded by water that can reach 1000 m in depth; it is about 300 km from the mainland of Australia (Green *et al.*, 2019). The rims of Scott Reef sit 0.3 to 1.2 m below mean sea level, so during low tide the only exchange between the lagoons and the open ocean is through narrow channels for

North Reef and Seringapatam Reef and a 2 km wide channel for South Reef (Green *et al.*, 2019).

Although there have been some cases of misidentification, *A. fuscus* is not endemic to Western or northeast Australia (D'Anastasi *et al.*, 2016b). Some historical reports indicate Cartier Island part of *A. fuscus*' range, however there is no evidence of this species at this location in recent surveys (Manning, 2014). A challenge of observing sea snakes at Hibernia Reef and Cartier Island is that due to the tide cycle, the survey period is shortened to 2 to 3 hours (Guinea, 2013). Cartier Island, a Marine Protected Area, is a reef with a sand cay near the center of it (Guinea, 2013). Hibernia reef sits 30 nautical miles northeast of Ashmore Reef (Guinea, 2013). Its sandbar is exposed during low spring tides, and it has a steep drop-off of 100 m (Guinea, 2013).

An individual was recently sighted for the first time in a location outside of the recognized range. It was found in Heywood Shoal (**Figure 3**), which is not a protected area but was modeled as a suitable habitat for the species (Udyawer *et al.*, 2020). The individual was verified as *A. fuscus* through genetic testing (Udyawer *et al.*, 2020).

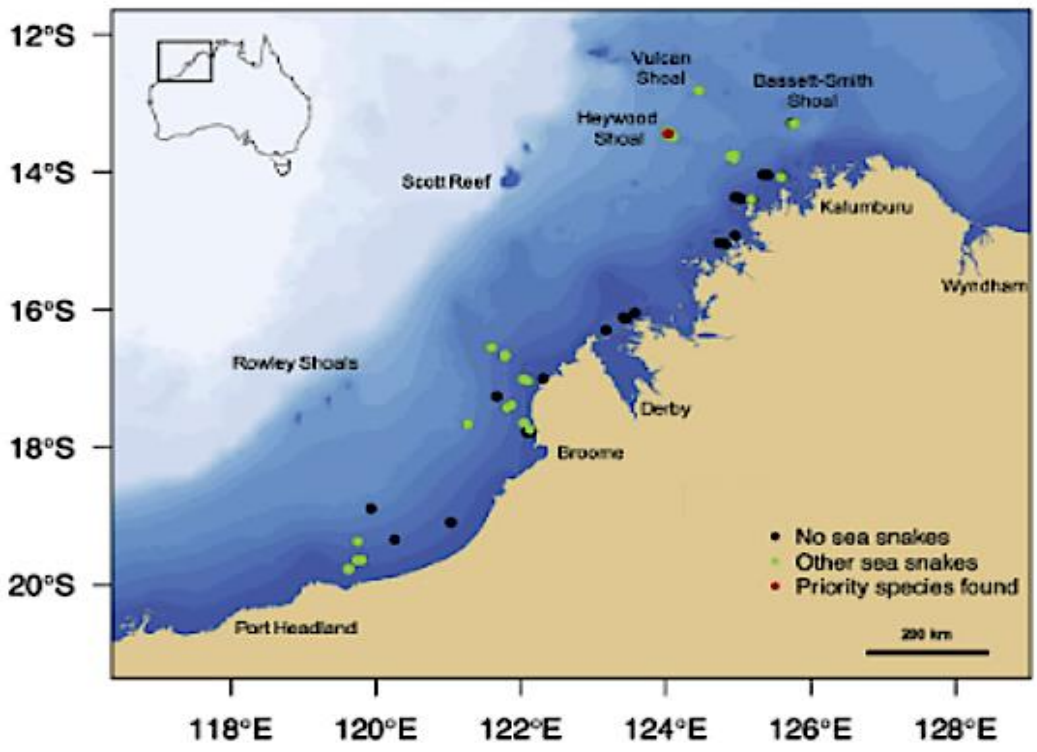

Figure 3. Map of northwest Australia that depicts the proximity of Scott Reef to Heywood Shoals, where an individual *A. fuscus* was sighted for the first time (Udyawer et al., 2020).

The locations marked as suitable habitats for *A. fuscus* demonstrate the sparse and patchy distribution of this species (**Figure 4**; Udyawer *et al.*, 2020). There is likely little to no movement between subpopulations because *A. fuscus* is not found in deep waters (Lukoschek *et al.*, 2010). This is supported by the genetic distinction between populations of different regions (Lukoschek, 2018a).

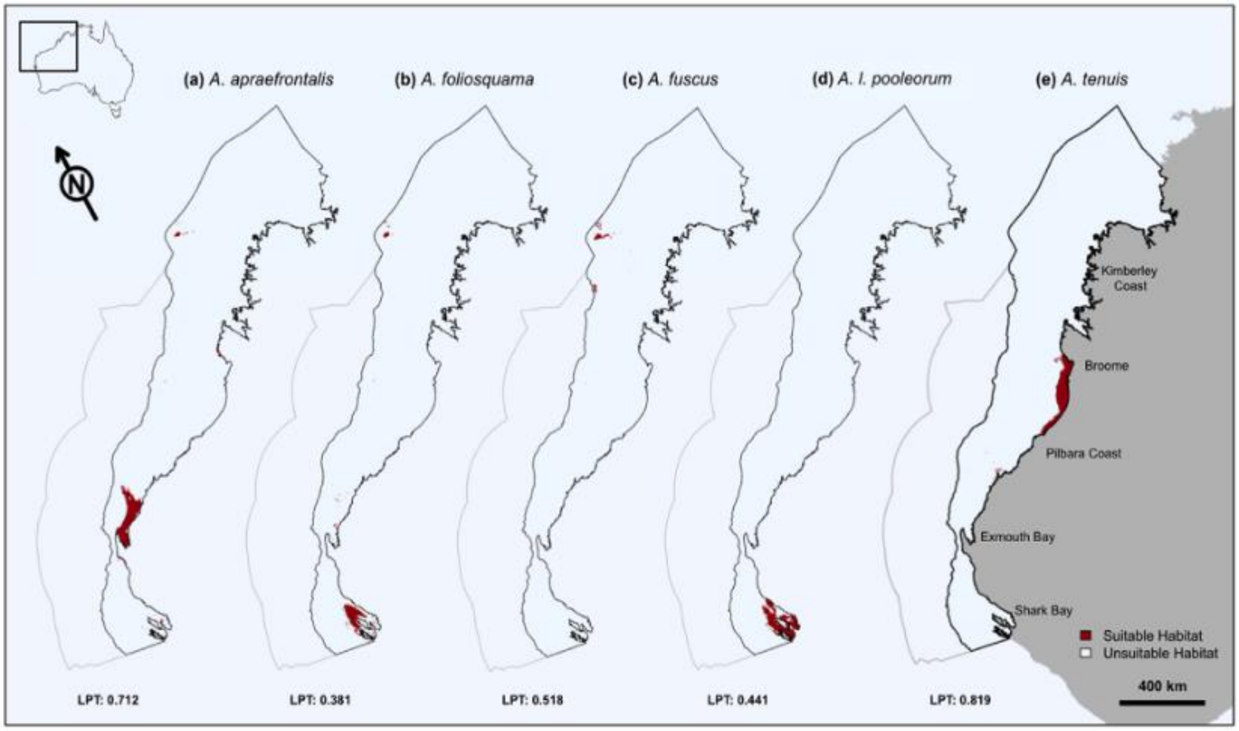

Figure 4. Locations which are suitable habitats for *A. fuscus*. The possible range is very limited and patchy (Udyawer et al., 2020).

Most of the suitable habitat predicted by models for *A. fuscus* is around Ashmore and Scott Reefs (Udyawer and Heupel, 2017). Models have also extended the possible range of *A. fuscus* to Rowley Shoals, however it is not certain that the species occupies these areas because simple modelling cannot take into consideration factors such as predators, competition, and habitat cover (Udyawer *et al.*, 2020). For example, although there are protections in place in the Ashmore Reef Marine Park, there have been no sightings of any *A. fuscus* in the past decade at this location (Udyawer *et al.*, 2020). The lack of data from Ashmore Reef implies that the species is locally extinct at Ashmore Reef. If *A. fuscus* is no longer able to reside on Ashmore Reef, then the area of suitable habitat for this species decreases from 618.63 km^2 to 11.44 km^2 (Udyawer *et al.*, 2020). The vast majority of this 11.44 km^2 is located outside of any marine protected area (**Figure 5**). There are likely no adequate conservation methods in place for the active range of *A. fuscus*.

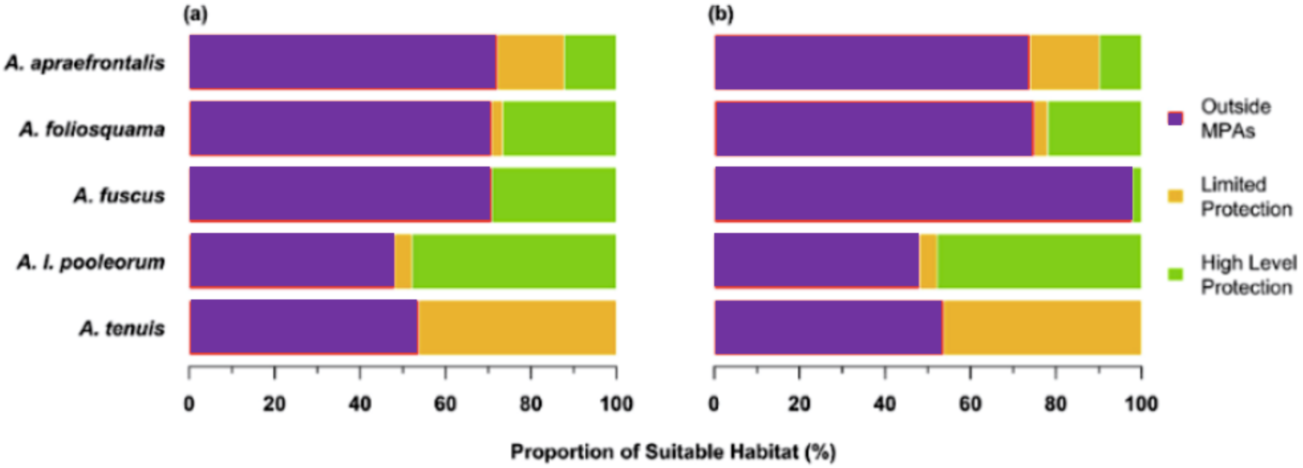

Figure 5. The percentage of suitable habitat per species that a) takes into consideration the area of Ashmore Reef and b) excludes Ashmore Reef. Assuming Ashmore Reef is no longer suitable for *A. fuscus*, there is only a very small proportion of habitat that has any level of protection (Udyawer et al., 2020).

There is no new information regarding whether *A. fuscus* seeks other habitats for refuge or mating. Gravid females and young sea snakes of other species have been known to reside in coastal bays or shallow waters as this may be a suitable refuge from trawling activity (Udyawer *et al.*, 2016b). Many *Aipysurus* sea snakes, including *A. fuscus*, demonstrate habitat specialism (Udyawer *et al.*, 2020). This puts *A. fuscus* at risk if extreme weather events or anthropogenic activities were to damage the few reefs upon which it resides.

2.3.1.6. Habitat or ecosystem conditions (e.g., amount, distribution, and suitability of the habitat or ecosystem):

Because *A. fuscus* is only endemic to a small number of reefs, reef ecosystem health is important. In comparison to other reefs in and around the Timor Sea, Ashmore Reef Marine Reserve has a smaller percent of live hard coral cover (Edgar *et al.*, 2017). It was hit by the 2003 bleaching event, with the final sighting of *A. fuscus* on this reef occurring in 2005 (**Figure 6**). Lukoschek *et al.* (2013) mentions that the majority of sea snake species declined on Ashmore Reef before this bleaching event, so coral condition may not have played a role in this decline. However, when evaluating the timeline specifically for *A. fuscus,* there appears to be a strong correlation between mass bleaching and loss of abundance for this species (**Figure 6**). If bleaching has played a role in the decline of *A. fuscus* in this location, there is cause for concern for the population on Scott Reef, which is also suffering from coral bleaching and mortality. Degree heating weeks (DHW) is a measure of the heat stress over a 12 week period. In the summer of 2015-2016, Scott Reef saw a maximum DHW of 16.5ºC, higher than many other reefs in the region (**Figure 7**; Gilmour *et al.*, 2019). This heat stress event decreased coral cover on Scott Reef from 48% in January 2016 to 13% in October 2016 (Gilmour *et al.*, 2019).

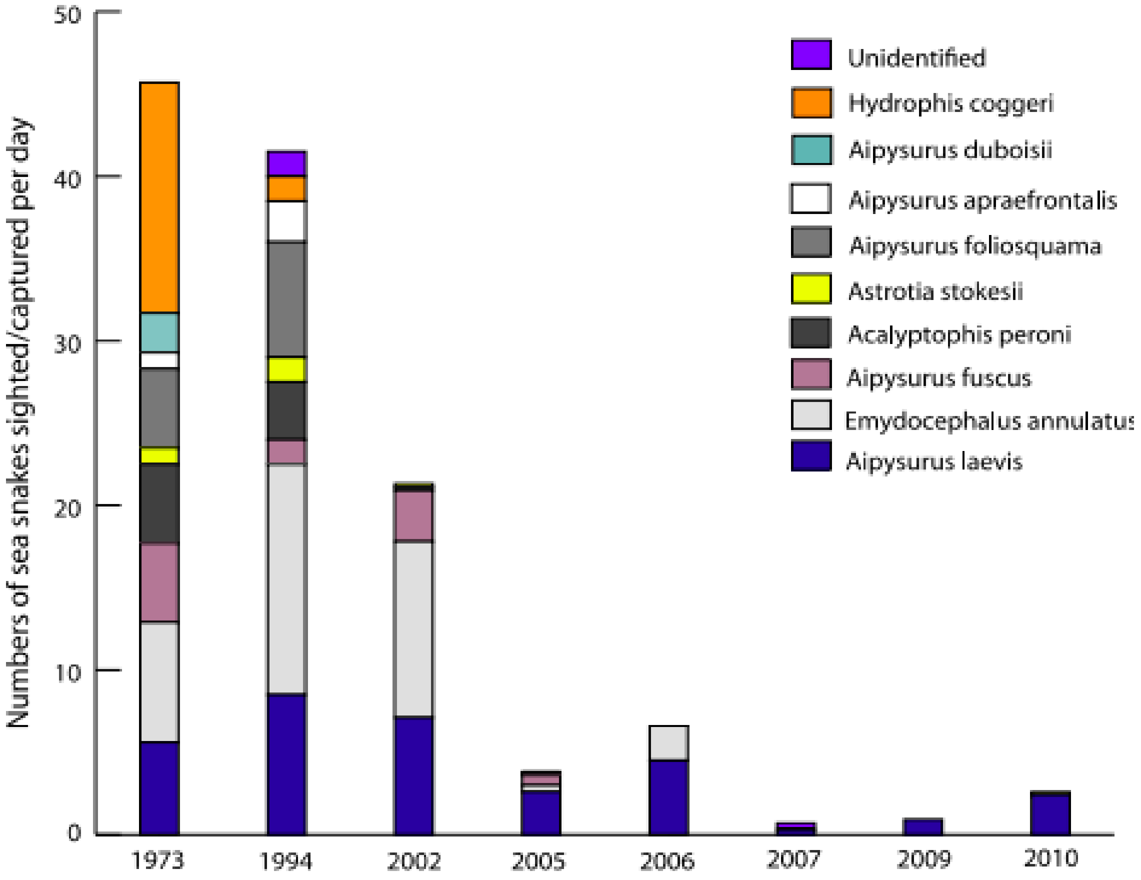

Figure 6. Plot of number of sea snakes seen per day at Ashmore Reef. *A. fuscus* was not seen after 2005 at this location. This came two years after the 2003 mass bleaching event (Lukoschek et al., 2013).

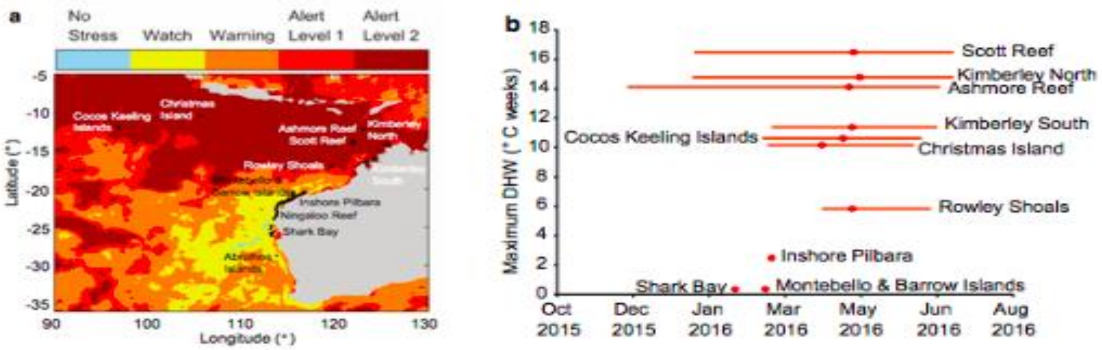

Figure 7. A depiction of the heat stress event from October 2015 to August 2016. (a) Shows the maximum bleaching alerts with the range of *A. fuscus* in the most-affected areas. (b) Red dots show the magnitude of DHW, while lines show the length of heat stress on certain reefs (Gilmour et al., 2019).

Increased water temperature, intense storms, and ocean acidification that accompany climate change can be major threats to *A. fuscus* and its habitat. Temperature plays a large role in the health of a reef. The heatwave that hit northwest Australia in the summer of 2015-2016 caused the waters of Scott Reef to see a 2°C increase in temperature during this time, with 92% of sampled sites along this reef system being at least 60% bleached (Green *et al.*, 2019). Additionally, after this heat stress event, coral mortality from sampled sites on Scott Reef ranged from 54% to 91% (Gilmour *et al.*, 2019). This level of mortality could have a significant impact on *A. fuscus* since it is only known to reside on and around hard coral reef ecosystems.

The increased intensity of storms resulting from climate change can also impact sea snakes. Increased rainfall and high wind speed have both shown positive correlations with sea snake strandings in northeast Australia (Gillett, 2017). There is no information regarding whether *A. fuscus* individuals tend to be displaced by storms. Storms can also affect the coral reef ecosystems on which *A. fuscus* resides. A single cyclone does not usually cause a mean loss in coral cover, but it can cause slow recovery from bleaching and cause damage if multiple storms come in succession (Gilmour *et al.*, 2019). Scott Reef is generally more impacted by cyclones than other reefs in the area due to its exposed corals in the direction of the waves (Gilmour *et al.*, 2019).

Ocean acidification poses another potential threat to sea snakes. Changes in water chemistry can impact suitable habitat and availability of prey species. The coral mortality brought about by a decrease in pH can cause problems for *A. fuscus*, which resides and scavenges along hard coral habitats. As the health of the coral ecosystem deteriorates, *A. fuscus* might be severely affected because of its specialist tendencies.

2.3.1.7. Other:

In 2010 and 2012, specimens from two other species of sea snakes that were believed to be found only in Timor Sea reefs and were presumed extinct since 2001 were found in other locations, proving to be members of separate populations instead of vagrants (Sanders *et al.*, 2015). This may provide some hope for other species such as *A. fuscus* that they might be residing in locations previously undocumented. Perhaps more importantly, however, it highlights the lack of abundance data for Australian sea snakes in general and does not necessarily imply that the populations will be more successful.

To slow the decline of sea snake populations, the best course of action may be to reduce impacts of climate change and environmental degradation (Lukoschek, 2018a). There is little research on the biology, threats, and effective management options for sea snakes (Lukoschek *et al.*, 2013). This knowledge would be very important for a declining species with a limited range such as *A. fuscus*. More research should be conducted on abundance, population connectivity, disease susceptibility, pollution, and the effects of coral bleaching on sea snakes, and a virtual data bank for sample analysis would be helpful for future work (Udyawer *et al.*, 2018).

Two approaches to increasing abundance of *A. fuscus* on certain reefs in the Timor Sea could include translocating individuals and the captive breeding and release of individuals. Translocating individual sea snakes to areas where numbers have declined would most likely not be successful due to the specific adaptations and genetic signatures of snakes in any given area (Lukoschek, 2018a). Additionally, it would fail to address the reason for the decline, making a reduction in numbers likely to reoccur. The other method, captive breeding, would take time and would be more costly than translocating individuals (Lukoschek, 2018a). Despite these drawbacks, captive breeding is currently being considered due to the very low numbers of *A. fuscus* (B. D'Anastasi, Personal communication, June 2, 2020).

2.3.2. Five-Factor Analysis (threats, conservation measures, and regulatory mechanisms)

Section 4 of the Endangered Species Act designates the Secretary of Commerce or the Secretary of the Interior the role of determining a species' status as threatened or endangered based on existing data in these five threat categories: destruction of habitat, overutilization, disease or predation, inadequacy of existing conservation mechanisms, and other natural or anthropogenic factors (Manning, 2014). Although information on *A. fuscus* is sparse, the following section analyzes the most recent information available in regard to the five threats. The cause of decline in abundance of *A. fuscus* is unknown, but the following section provides historical and current evidence on how each of the threats are impacting the species.

2.3.2.1. Present or threatened destruction, modification or curtailment of its habitat or range:

A. fuscus is only known to reside on hard coral reef habitats. Loss of these ecosystems would impact its ability to find shelter and prey. Global warming, intense storms, and other factors worsened by anthropogenic presence are threatening coral reefs globally. Coral reef ecosystems along northwest Australia are being impacted by weather events. El Niño conditions are related to marine heatwaves in northwest Australia, while La Niña conditions are associated with marine heatwaves in Western Australia (Green *et al.*, 2019). El Niño events led to bleaching of Sahul Shelf reefs in 1998 and 2003 (Manning, 2014). Heat stress can contribute to severe loss in coral cover. Heat stress has been increasing in severity in recent decades; since 1990, almost all of Western Australia's reef systems have experienced coral bleaching from increased temperatures (Gilmour *et al.*, 2019). From the 2016 heat stress event, all of Australia's northwestern reefs experienced increased sea temperatures

(**Figure 7**; Gilmour *et al*., 2019). This event caused a 70% reduction in coral cover on Scott Reef.

Temperature stress is exacerbated by damaging storms. High energy waves caused by cyclones can cause damage to exposed sites on a reef and can slow recovery time from bleaching events. All of the reef systems in northwest Australia have suffered from the damaging waves of cyclones or tropical lows since 1990 (Gilmour *et al*., 2019). Cyclone Lua in 2012 resulted in an 8% decrease in mean coral cover on Scott Reef (Gilmour *et al*., 2019). Cyclones in 2016 and 2017 coincided with a bleaching event on Ashmore Reef to cause a decrease in coral cover from 36% to 24% on this reef (Gilmour *et al*., 2019). It is uncertain how *A. fuscus* responds to mass bleaching events, but loss of coral reefs is becoming a greater threat as climate change intensifies.

Other anthropogenic impacts may be affecting the habitat of *A. fuscus*. For example, an increase in fishing activity in northern Australia since 2000 has corresponded with an increase in derelict fishing nets and debris (Edyvane and Penny, 2016). In particular, although Ashmore Reef Marine Park is a protected area, recreational and illegal fishing has occurred on Ashmore Reef (Edgar *et al*., 2017) which can leave behind fishing materials in the Timor Sea. This can physically damage the reef ecosystem and contribute to ghost fishing.

While the 2003 loss of coral cover on Ashmore Reef comes just two years prior to the final sighting of *A. fuscus* in this location, there is no direct evidence to conclude that bleaching directly caused the decline of this species. There is no clear correlation at this time between coral condition and *A. fuscus* abundance. However, the fact that *A. fuscus* has a very limited range and is a habitat specialist makes it more vulnerable to changes in habitat, which are becoming more prevalent due to global warming and anthropogenic impacts.

2.3.2.2. Overutilization for commercial, recreational, scientific, or educational purposes:

Trawling poses a general threat to sea snakes, perhaps more so than it does to many fishes, because of low reproductive rates and the inability to breathe underwater (Milton *et al.*, 2008). Thousands of sea snakes are captured in trawls off Australia annually (Udyawer *et al.*, 2018). Bycatch reduction devices (BRD) have been shown to decrease sea snake bycatch if placed within 70 meshes from the codend (Milton *et al.*, 2008). However, although BRDs have been imposed on the vessels of the Northern Prawn Fishery (NPF), they do not result in a significant difference of sea snake bycatch when set at the maximum legal distance along the mesh, about 120 meshes from codend (Milton *et al.*, 2008). Sea snake bycatch showed 11 species of sea snake are regularly caught by the NPF (Milton *et al.*, 2008), but bycatch appears to pose little threat to *A. fuscus*. The sharp incline of the Timor Sea means that trawling is not a threat to benthic communities in this region (D'Anastasi *et al*., 2016a).

There is only one trawl fishery, the North West Slope Trawl Fishery, known to operate within the range of *A. fuscus*, and this is considered a deep-water fishery (Manning, 2014). Due to the small area in which trawling occurs in the Timor Sea, fisheries at this location generally do not have issues with overexploitation (Edyvane and Penny, 2016). The fishing portion of Ashmore Reef that is open to the public is for finfish that will be eaten within a day of catch (Manning, 2014). Additionally, *A. fuscus* is not commonly caught by fisheries in this region because there is a heavier focus on pelagic species. There is no evidence that bycatch from Australian trawl fisheries or Indonesian fisheries has played a role in the disappearance of *A. fuscus* on Ashmore Reef (Lukoschek *et al.*, 2013). This limits the threat of fishing for *A. fuscus*, but it also means that abundance and distribution are less documented than in other species.

Illegal harvesting for trade is also a threat to marine snakes, yet no sea snakes are listed under the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES; Lukoschek, 2010). Southeast Asia is seeing an increase in fisheries selling marine snake bycatch instead of releasing back into the water (Suntrarachun *et al.*, 2018). Sea snakes can be used in the aquarium trade, eaten as meat, used for elixirs, or claimed as having medicinal properties (Suntrarachun *et al.*, 2018). Illegal fishing was observed on Ashmore Reef before the conservation policies became strictly enforced at this location (Speed *et al.*, 2019). Fewer protections remain in place on Scott Reef (Speed *et al.*, 2019). However, there is no evidence that sea snakes are being targeted on Timor Sea reefs, and there is currently no information to suggest that illegal harvesting is a concern for *A. fuscus* (Lukoschek *et al.*, 2013). Therefore, at this time there is no information to suggest that overutilization has caused the decline in *A. fuscus*.

2.3.2.3. Disease or predation:

There is little information about disease in *A. fuscus* specifically. A study that examined stranded sea snakes in northeast Australia, outside of the range of *A. fuscus*, revealed from necropsies that 90% of these snakes had endoparasites in the lungs and/or gastric mucosa and about 43% had inflammatory conditions, such as ulcerative stomatitis, pericarditis, pancreatitis, encephalitis, and bronchopneumonia (Gillett, 2017). These illnesses may cause sea snakes to be more vulnerable to changes in habitat conditions, strandings, and predation. Although sea snakes surveyed at Ashmore Reef in 2002 showed no external signs of disease or parasite, this does not mean disease has played no definitive role in the decline of *A. fuscus* (Lukoschek *et al.*, 2013). Due to the limited amount of research, it is unclear whether endoparasites or illnesses with no external symptoms could have affected *A. fuscus*. Pathogens and other exotic species that are carried by foreign vessels are known to affect other marine animals. There has been a doubling in foreign fishing vessels along northern Australia since 2010, corroborated by Australian customs data (Edyvane and Penny, 2016). The Arafura and Timor Sea region has 15 different fisheries that are permitted to operate, but it also sees an underreported number of illegal vessels from Taiwan and other nations (Edyvane and Penny, 2016). Greater numbers of vessels coming from areas outside of the Arafura and Timor Sea region, combined with warming temperatures, increases the probability of carrying pathogens into the coral reef area that *A. fuscus* resides.

Being predatory reptiles, sea snakes are susceptible to bioaccumulation. While there are no reports for *A. fuscus* in particular, other species have been found with high concentrations of hydrocarbons and heavy metals in their liver and kidneys (Gillett, 2017). External injuries also pose a threat to sea snakes, which can be injured by sea birds, large fish, and boat propellers. Injuries such as fractures and lacerations (**Figure 8**) were seen in about 37% of stranded sea snakes surveyed in northeast Australia (Gillett, 2017). However, there are no new reports of predation on *A. fuscus* or evidence to suggest that predators are responsible for the decline of the species. Additionally, although there is increased vessel activity in northern Australia, there is no data on propeller strikes as a threat to *A. fuscus*.

Figure 8. Two stranded sea snakes that showed signs of injury: (a) A puncture wound on a *Hydrophis platurus* from a sea eagle (b) A laceration on a *Hydrophis elegans* from a boat strike (Gillett, 2017).

2.3.2.4. Inadequacy of existing regulatory mechanisms:

A. fuscus is listed under Australia's Environment Protection and Biodiversity Conservation Act of 1999. This Act considers killing, injuring, or capturing sea snakes to be an offense (DSEWPaC, 2012), however there is no conservation plan for *A. fuscus* because there are few opportunities to reduce threats due to its very low numbers and limited range (DAWE, 2019). Suitability of habitat for *A. fuscus* has been modeled based on several factors such as distance to freshwater, distance to reef, distance to land, and percentage gravel (**Figure 9**;

Udyawer *et al.*, 2020). Based on the models, less than half of the total area determined to be suitable for *A. fuscus* is a Marine Protected Area (Udyawer *et al.*, 2020).

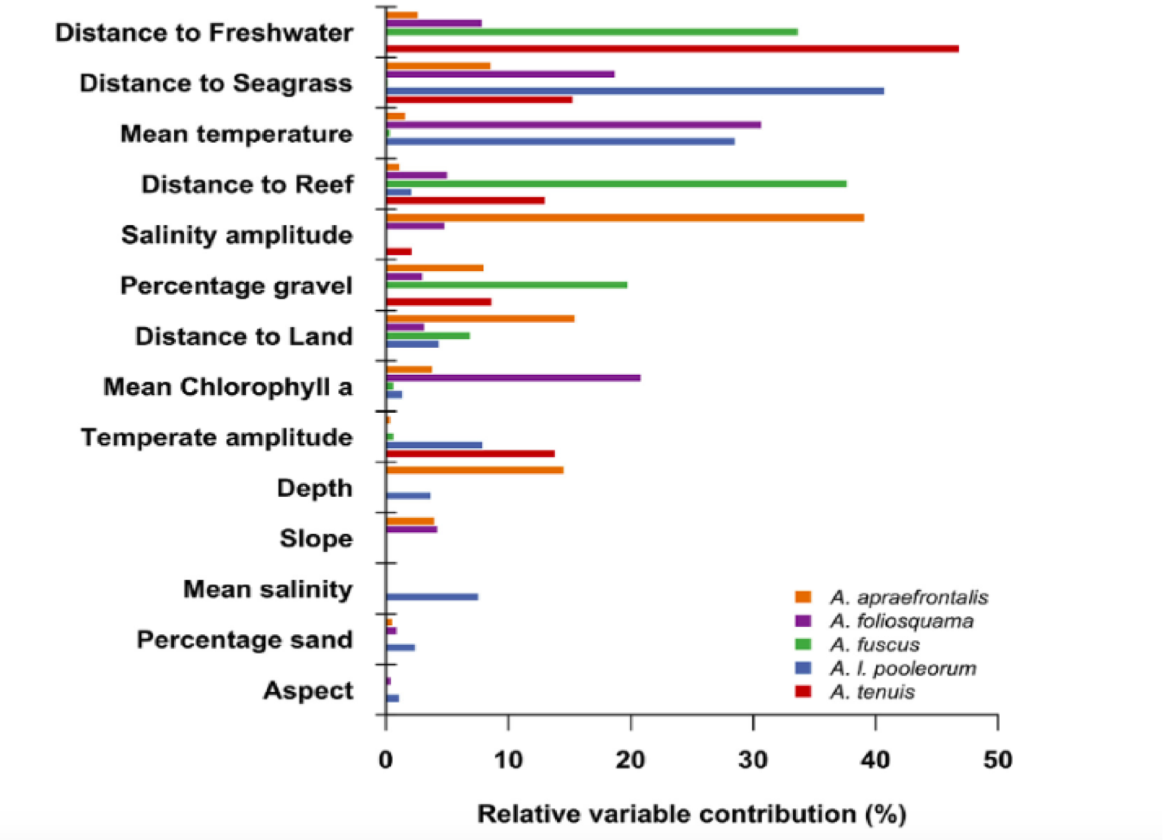

Figure 9. Contribution of each environmental factor in calculating habitat suitability for models. Gravel substrate and proximity to reef and freshwater are shown to be important for *A. fuscus* (Udyawer et al., 2020).

The Ashmore Reef National Nature Reserve was created in 1983 with a no-take policy being established in 1988 (Speed *et al*., 2019). However, it was not considered fully protected until 2008 when a patrol vessel occupied the reef full-time (Speed *et al.*, 2019). The protections put in place at Ashmore Reef brought about a shift in ecosystem, with larger mesopredatory fishes and sharks recovering in numbers, while smaller mesopredatory fishes declined in numbers (Speed *et al*., 2019). Total sea snake abundance has been declining at Ashmore Reef over the last two decades, with a 2008 survey averaging 1 sea snake per 10 hectares, a much lower population density than was seen in the 1990s (Guinea, 2013). Although much of the protected part of Ashmore Reef Marine Park is considered a suitable environment for *A. fuscus,* no sightings of this species have been recorded at Ashmore Reef over the last decade (Udyawer *et al.*, 2020). This implies that the protections in place at this site are not effective in conserving or protecting the species. The vast majority of the Ashmore Reef

Commonwealth Marine Reserve is considered an IUCN Sanctuary Zone, with the rest being a Recreational Use Zone (Edgar *et al.*, 2017). Despite this, reef fish biomass has been found to be lower in this reserve than at other sampled reefs in northwest Australia, including Hibernia, Scott, Imperieuse, Mermaid, and Clerke Reefs (Edgar *et al.*, 2017). Whatever the reason for abundance and diversity loss might be, sea snakes may be hit especially hard because they are predominantly habitat and dietary specialists and often have fragmented populations. In fact, the only likely species to remain on Ashmore Reef is *A. laevis* (Lukoschek *et al.*, 2013), which is a feeding generalist (Voris and Voris, 1983).

One other reef, Cartier Island, within the possible range of *A. fuscus* receives protection. It was labelled as a Marine Reserve in 2000 (Manning, 2014). This reef was once a bombing range for the British Air Force and is now considered a strict nature reserve of category 1a according to the IUCN, meaning human access is highly controlled (Manning, 2014). This reef is a biologically important area due to its high density of sea snakes (DSEWPac, 2012), but has historically produced few recorded sightings of *A. fuscus*.

The main cause of disappearance of *A. fuscus* from Ashmore Reef is still undetermined. Relocating *A. fuscus* individuals from other reefs would likely be unsuccessful because it would fail to address the initial cause of decline on Ashmore Reef (Lukoschek *et al.*, 2013). Therefore, unless the reason for decline is discovered and addressed, Ashmore Reef Marine Park will likely not provide suitable habitat for *A. fuscus*. Scott Reef, which most likely holds the largest population of this species, is under Western Australia State Government management and has no management plans under the Environment Protection and Biodiversity Conservation Act (Anon, 2015). It will be difficult to create an effective conservation plan for *A. fuscus* until this knowledge gap is filled.

2.3.2.5. Other natural or man-made factors affecting its continued existence:

Climate change is negatively effecting *A. fuscus* and its habitat. Scott Reef took more than a decade to recover from its 1998 mass bleaching event (Gilmour *et al.*, 2019). It suffered moderate bleaching in 2010, 2011, and 2013 and then a disastrous bleaching event in 2016 (Gilmour *et al.*, 2019). This ecosystem holds the largest population of *A. fuscus*, and it is suffering from warming temperatures. The gradual increase in water temperature could also have impacts on sea snakes' health and fitness in northwest Australia, who favor 18-22^{o}C water (Udyawer *et al.*, 2020). Temperature is known to affect sea snake distribution (Udyawer *et al.*, 2016a). In fact, sea snake abundance at Shark Bay decreased after a 2011 heatwave, perhaps due to physiological stress, predation from shelter loss, or emigration to cooler water (D'Anastasi *et al.*, 2016b). Being ectotherms, sea snakes' metabolic rate is known to be affected by water temperature (Udyawer *et al.*, 2016c). As water temperature increases, sea snakes tend to demonstrate shorter dive lengths and increased surfacing frequency (Udyawer *et al.*, 2016c). In fact, as temperature increases from 21^{o}C to 30^{o}C, maximum dive length of some sea snake species is almost halved (Udyawer *et al.*, 2016c). This implies that heatwaves and seasonal changes might decrease scavenging time and increase risk of surface predation.

Little was documented about the recruitment conditions for sea snakes at Ashmore Reef in the years in which *A. fuscus* was still declining there (Lukoschek *et al*., 2013). Sex ratios of sea snakes at Ashmore Reef were not dramatically affected during the decline, and sea snakes were observed mating at this reef during periods of decline (Lukoschek *et al*., 2013). It is possible that environmental conditions may have impacted gamete or gestation quality, contributing to the decline in abundance of sea snakes (Lukoschek *et al*., 2013). There is a lack of research on how temperature and pH affect fecundity in sea snakes.

Another anthropogenic factor that may be impacting *A. fuscus* is drilling. Oil and gas accounts for 36% of the gross domestic product for the country of Timor-Leste (EITI, 2020). All of its exploration and production for these resources takes place in the Timor Sea (EITI, 2020). Seismic surveys for the fossil fuel industry started in the Timor Sea in 1990, which is around the start of recorded decline of sea snakes on Ashmore Reef (Anon, 2015). While there is no reason to conclude sound pollution from seismic arrays has affected *A. fuscus* abundance, it does provide a stressor for sea snakes due to their long lung and inward-opening nostril valves (Udyawer *et al.*, 2018). Additionally, due to the large amount of natural gas and oil in the Timor Sea and Timor-Leste’s reliance on these resources, drilling in this region is likely to continue into the future (Manning, 2014).

Oil spills may also occur when there is drilling, and one was observed in August of 2009 in the Montara oil field in the Timor Sea. This leak occurred 80 nautical miles from Ashmore Reef National Nature Reserve (Watson *et al*., 2009). After the leak, sheens were reported at Ashmore Reef, Cartier Island, and Hibernia Reef (Guinea, 2013). However, this event did not appear to have a significant effect on the sea snake population sizes at these three reefs (Guinea, 2013). A brief survey conducted just after the start of this spill revealed one dead sea snake and multiple lethargic individuals lying within a thick oil layer (Watson *et al.*, 2009). No members of *A. fuscus* were identified in this survey. The tendency of *Aipysurus* snakes to spend more time away from the surface may have helped prevent a significant impact on these populations during the spill. Of the surveyed sea snakes, more were found within the oil slick region compared to nearby cleaner locations, suggesting they might be drawn to the oil spill (Watson *et al.*, 2009). While the impacts of petroleum drilling are concerning for sea snakes, there remains no evidence that this is leading to the decline in abundance of *A. fuscus*.

2.4. Synthesis

Since the initial status review, few studies have been published that evaluate the abundance of *A. fuscus*. No sightings of this species have been recorded at Ashmore Reef for the past fifteen years, implying it is locally extinct at this location. In addition, there have been difficulties finding this species at other reefs within the Timor Sea. Although there is no current estimate on population size, *A. fuscus* abundance appears to have declined dramatically in the last two decades.

The large decline of sea snakes and other marine life from Ashmore Reef Marine Park reveals the inadequacy of the conservation policies in this location. Excluding this area, the total range of suitable habitat for *A. fuscus* falls almost entirely outside of protected areas.

While overutilization poses little threat to *A. fuscus*, other anthropogenic factors are affecting its health. Increases in vessel presence and intense storms that accompany climate change are causing sea snakes to be more susceptible to being caught or stranded. Rising water temperatures are associated with shorter sea snake dive lengths and more frequent surfacing, which increases chances of predation by sea birds. *A. fuscus* may be suffering from damages to its ecosystem. A mass coral bleaching event occurred on Scott Reef in 2016, yet it is unclear how this has affected the species.

In summary, *A. fuscus*' limited range within the Timor Sea has continued to contract due to its local extinction at Ashmore Reef. A knowledge gap remains on its current abundance, reproduction, and disease susceptibility. However, it is known that climate change is contributing to coral bleaching and mortality in its largest habitat, Scott Reef. Based on these factors, *A. fuscus* continues to be at risk of extinction over all or most of its range. Consequently, reclassification should not occur, and the status of this species should remain as 'endangered.'

3. RESULTS

3.1. Recommended Classification

_____**Downlist to Threatened**
_____**Uplist to Endangered**
_____**Delist** *(Indicate reason for delisting per 50 CFR 424.11):*
_____*Extinction*
_____*Recovery*
_____*Original data for classification in error*
__X__**No change is needed**

3.2. New Recovery Priority Number

Not Applicable

3.3. Listing and Reclassification Priority Number

Not Applicable

4. RECOMMENDATIONS FOR FUTURE ACTIONS

Existing knowledge and data gaps for *A. fuscus* make it difficult to properly assess the status of the populations and to implement effective conservation measures for this species. A survey should be conducted to more accurately estimate the current abundance of this species, especially on Scott Reef. The exact cause of decline on Ashmore Reef remains undetermined. If the cause of this decline was better understood, that knowledge could potentially be used to prevent similar declines on Scott Reef. No research specifically examines the effect that the 2016 Scott Reef coral bleaching event has had on *A. fuscus*. This would be an important area of study to better understand current population numbers and responses to heatwaves. Research into reproduction and connectivity between populations are also important next steps in filling critical knowledge gaps on *A. fuscus*.

Perhaps the most important work would be to devise conservation methods that are more effective than the ones currently in place. If the captive breeding that is being considered results in an increase in numbers of animals, these individuals will need a habitat that can support them. The changes in habitat conditions that accompany warming temperatures, pollution, increased fishing, and other anthropogenic issues will make it challenging for this species to find a healthy ecosystem suitable for increasing abundance.

5. REFERENCES

Anon. (2015). Threatened Species Nomination Form 2014/2015 Assessment Period *Aipysurusfuscus*. Retrieved from https://www.environment.gov.au/system/files/pages/a7465fc2-2fa1-4de4-b562-4eb56012296d/files/nomination-aipysurus-fuscus-2014.pdf.

D'Anastasi, B., van Herwerden, L., Hobbs, J.P.A., Simpfendorfer, C.A. (2016a). New range and habitat records for threatened Australian sea snakes raise challenges for conservation. *Biological Conservation*, 194, 66-70. doi: 10.1016/j.biocon.2015.11.032. Personal communication with author D'Anastasi via email, 2 June 2020.

D'Anastasi, B.R., van Herwerden, L., Hobbs, J.A., Simpfendorfer, C.A., Lukoschek, V. (2016b). Habitat and behavioural associations of Aipysurus group sea snakes in Western Australia. Interim report to Marine Species Conservation, Department of the Environment, Australian Government.

Department of Agriculture, Water and the Environment (DAWE). (2019). Species nominations not prioritized for assessment. Australian Government. Retrieved from https://www.environment.gov.au/biodiversity/threatened/nominations/species-not-prioritised-assessment.

Department of Sustainability, Environment, Water, Population and Communities (DSEWPaC). (2012). Species group report card – marine reptiles. Prepared under the *EnvironmentProtection and Biodiversity Conservation Act 1999*. Retrieved from http://www.environment.gov.au/system/files/pages/1670366b-988b-4201-94a1-1f29175a4d65/files/north-west-report-card-reptiles.pdf.

Edgar, G.J., Ceccarelli, D., Stuart-Smith, R.D., Cooper, A.T. (2017). Reef Life Survey Assessment of Coral Reef Biodiversity in the North-West Commonwealth Marine Reserves Network. Reef Life Survey Foundation Incorporated.

Edyvane, K.S. and Penny, S.S. (2016). Trends in derelict fishing nets and fishing activity in northern Australia: Implications for trans-boundary fisheries management in the shared Arafura and Timor Seas. *Fisheries Research* 188, 23-37.

EITI (Extractive Industries Transparency Initiative). (2020). Timor-Leste. EITI. Retrieved from https://eiti.org/fr/implementing_country/40.

Gillett AK. 2017. An investigation into the stranding of Australian sea snakes. Ph.D. thesis, The University of Queensland, St Lucia, QLD.

Gilmour, J.P., Cook, K.L., Ryan, N.M., Puotinen, M.L., Green, R.H., Shedraw, G., Hobbs, J.P.A., Thomsom, D.P., Babcock, R.C., Buckee, J., Foster, T., Richards, Z.T., Wilson, S.K., Barnes, P.B., Coutts, T.B., Radford, B.T., Piggott, C.H., Depczynski, M., Evans, S.N., Schoepf, V., Evans, R.D., Halford, A.R., Nutt, C.D., Bancroft, K.P., Heyward, A.J., and Oades, D. (2019). The state of Western Australia's coral reefs. *Coral Reefs* 38, 651-667. https://doi.org/10.1007/s00338-019-01795-8.

Green, R.H., Lowe, R.J., Buckley, M.L., Foster, T., Gilmour, J.P. (2019). Physical mechanisms influencing localized patterns of temperature variability and coral bleaching within a system of reef atolls. *Coral Reefs* 38, 759-771. https://doi.org/10.1007/s00338-019-01771-2.

Guinea, M.L. (2013). Surveys of the Sea Snakes and Sea Turtles on Reefs of the Sahul Shelf. Monitoring Program for the Montara Well Release Timor Sea. Draft Final Report 2012-2013. Charles Darwin Univerisity.

Lukoschek, V. (2018a). Congruent phylogeographic patterns in a young radiation of live-bearing marine snakes: Pleistocene vicariance and the conservation implications of cryptic genetic diversity. *Diversity and Distributions* 24, 325-340. doi: 10.1111/ddi.12687.

Lukoschek, V. (2018b). Population declines, genetic bottlenecks and potential hybridization in sea snakes on Australia's Timor Sea reefs. *Biological Conservation* 225, 66-79. https://doi.org/10.1016/j.biocon.2018.06.018.

Lukoschek, V., Beger, M., Ceccarelli, D., Richards, Z., and Pratchett, M. (2013). Enigmatic declines of Australia's sea snakes from a biodiversity hotspot. *Biological Conservation* 166, 191-202. http://dx.doi.org/10.1016/j.biocon.2013.07.004.

Lukoschek, V., Guinea, M., and Rasmussen, A. (2010). *Aipysurus fuscus*. The IUCN Red List of Threatened Species 2010: e.T176763A7299535. https://dx.doi.org/10.2305/IUCN.UK.2010-4.RLTS.T176763A7299535.en.

Manning, L.M. (2014). Endangered Species Act Status Review Report for the Dusky Sea Snake, *Aipysurus fuscus*. Report to the National Marine Fisheries Service, Office of Protected Resources. 46 pp.

Milton, D., Zhou, S., Fry, G., and Dell, Q. (2008). Risk assessment and mitigation for sea snakes caught in the Northern Prawn Fishery. Final report on FRDC Project 2005/051. CSIRO Cleveland, pp. 123.

Murphy, J.C. (2012). Marine Invasions by Non-Sea Snakes, with Thoughts on Terrestrial-Aquatic-Marine Transitions. *Integrative and Comparative Biology* 52(2), 217-226. doi:10.1093/icb/ics060.

Rasmussen, A.R., Sanders, K.L., Guinea, M.L., Amey, A.P. (2014). Sea snakes in Australian waters (Serpentes: subfamilies Hydrophiinae and Laticaudinae) - a review with an updated identification key. *Zootaxa* 3869(4), 351-371. http://dx.doi.org/10.11646/zootaxa.3869.4.1.

Rose, J.P., Wademan, C., Weir, S., Wood, J.S., Todd, B.D. Traditional trapping methods outperform eDNA sampling for introduced semi-aquatic snakes. *PLoS ONE* 14(7). https://doi.org/10.1371/journal.pone.0219244.

Sanders, K.L., Rasmussen, A.R., and Guinea, M.L. (2014). High rates of hybridisation reveal fragile reproductive barriers between endangered Australian sea snakes. *Biological Conservation* 171, 200-208. http://dx.doi.org/10.1016/j.biocon.2014.01.013.

Sanders, K.L., Schroeder, T., Guinea, M.L., Rasmussen, A.R. (2015). Molecules and Morphology Reveal Overlooked Populations of Two Presumed Extinct Australian Sea Snakes (Aipysurus: Hydrophiinae). *PLoS ONE* 10(2). doi:10.1371/journal.pone.0115679.

Speed, C.W., Rees, M.J., Cure, K., Vaughan, B., Meekan, M.G. (2019). Protection from illegal fishing and shark recovery restructures mesopredatory fish communities on a coral reef. *Ecology and Evolution* 9, 10553-10566. https://doi.org/10.1002/ece3.5575.

Suntrarachun, S., Chanhome, L., Sumontha, M. (2018). Identification of sea snake meat adulteration in meat products using PCR-RFLP of mitochondrial DNA. *Food Science and Human Wellness* 7, 170-174. https://doi.org/10.1016/j.fshw.2018.04.002.

Udyawer, V., Barnes, P., Bonnet, X., Brischoux, F., Crowe-Riddell, J.M., D'Anastasi, B., Fry, B.G., Gillett, A., Goiran, C., Guinea, M.L., Heatwole, H., Heupel, M.R., Hourston, M., Kangas, M., Kendrick, A., Koefoed, I., Lillywhite, H.B., Lobo, A.S., Lukoschek, V., McAuley, R., Nitschke, C., Rasmussen, A.R., Sanders, K.L., Sheehy, C. III, Shine, R., Somaweera, R., Sweet, S.S., Voris, H.K. (2018). Future Directions in the Research and

Management of Marine Snakes. *Frontiers in Marine Science* 5, 399. https://doi.org/10.3389/fmars.2018.00399.

Udyawer, V., D'Anastasi, B., McAuley, R., and Heupel, M. (2016a). Exploring the status of Western Australia's sea snakes. National Environmental Science Programme.

Udyawer, V. and Heupel, M.R. (2017). Spatial and temporal patterns in sea snake populations on the North West Shelf. Report to the National Environmental Science Programme, Marine Biodiversity Hub. Australian Institute of Marine Science.

Udyawer, V., Read, M., Hamann, M., Heupel, M.R., and Simpfendorfer, C.A. (2016b). Importance of Shallow TIdal Habitats as Refugia from Trawl Fishing for Sea Snakes. *Journal of Herpetology* 50(4), 527-533. doi: 10.1670/15-026.

Udyawer, V., Simpfendorfer, C.A., Heupel, M.R., Clark, T.D. (2016c). Coming up for air: thermal dependence of dive behaviours and metabolism in sea snakes. *Journal of Experimental Biology* 219: 3447-3454. doi:10.1242/jeb.146571.

Udyawer, V., Somaweera, R., Nitschke, C., D'Anastasi, B., Sanders, K., Webber, B.L., Hourston, M., and Heupel, M.R. (2020). Prioritizing search effort to locate previously unknown populations of endangered marine reptiles. *Global Ecology and Conservation* 22. https://doi.org/10.1016/j.gecco.2020.e01013.

Ukuwela, K.D.B. (2013). Systemics, Evolution, and Biogeography of Viviparous Sea snakes of the Indo-Pacific. Ph.D. thesis, University of Adelaide.

Voris, H.K. and Voris, H.H. (1983). Feeding Strategies in Marine Snakes: An Analysis of Evolutionary, Morphological, Behavioral and Ecological Relationships. *American Zoologist* 23(2), 411-425. https://doi.org/10.1093/icb/23.2.411.

Watson, J.E.M., Joseph, L.N., Watson, A.W.T. (2009). A rapid assessment of the impacts of the Montara oil leak on birds, cetaceans and marine reptiles. Prepared on behalf of the Department of the Environment, Water, Heritage and the Arts by the Spatial Ecology Laboratory, University of Queensland, Brisbane.

NATIONAL MARINE FISHERIES SERVICE
5-YEAR REVIEW
Dusky Sea Snake

Current Classification: Endangered

Recommendation resulting from the 5-Year Review

____ Downlist to Threatened
____ Uplist to Endangered
____ Delist
__X_ No change is needed

Review Conducted By:
Grace Carter, Office of Protected Resources, Hollings Scholar
Heather Austin, Office of Protected Resources

LEAD OFFICE APPROVAL:

WIETING.DONNA.S.1365710607 Digitally signed by WIETING.DONNA.S.1365710607 Date: 2020.09.10 15:14:12 -04'00'

Approve: ______________________________________ Date: ________________

HEADQUARTERS APPROVAL:

Assistant Administrator, NOAA Fisheries

OLIVER.CHRISTOPHER.WAYNE.1408430670 Digitally signed by OLIVER.CHRISTOPHER.WAYNE.1408430670 Date: 2020.09.16 23:10:27 -04'00'

_____Concur _____ Do Not Concur

Signature:_____________________________________ Date:____________________