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REVIEW

Challenges of regulating commercial use of marine elapid snakes in the Indo-Pacific

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Article impact statement: Implementation of internation trade regulations and conservation for marine elapids can positively affect small- and large-scale fisheries.

Abstract

Marine elapid snakes are a diverse, predominantly Indo-West Pacific species group. The persistent removal of some species has an unquantified but potentially dire impact on populations. We conducted the first comprehensive review of the trade in marine elapid snakes based on published literature (1974–2022) and trade data from the only species (i.e., *Hydrophis* [*Lapemis*] *curtus*) whose trade is monitored internationally. Some species and populations were subjected to targeted harvest for their meat and skins for at least the last century; fisheries are possibly the most significant threat to populations of marine elapids, with the highest numbers being exploited either accidentally, incidentally, or opportunistically in Southeast Asian fisheries targeting other seafood, including demersal trawl and squid fisheries. Southeast Asia is the core region for exploitation of marine elapids. Annual offtake is >225,000 individuals of at least 8 species in the Gulf of Thailand. Of 72 recognized marine elapids (all non-CITES [Convention on International Trade in Endangered Species of Wild Fauna and Flora] species), *Hydrophis curtus* and *Hydrophis cyanocinctus* dominate the skin trade. Skins of *H. curtus* are traded mainly in East and Southeast Asia and, to some extent, Europe. Despite some baseline information on the trade of these species, the sustainability of their harvests, particularly in the context of the burgeoning and unmanaged nature of fisheries in the region, remains the major challenge. In an era of declining fish stocks, there has been an increasing trend to commercialize the harvest and use marine elapids that were once considered accidental bycatch and discarded. This trend will continue to pose a significant risk to these snakes unless appropriate fisheries and trade regulations are enforced. Applying the precautionary principle to prevent the overexploitation of sea snakes is an indispensable measure in which trade in regional populations should be regulated through CITES. Accordingly, management plans to identify core distribution regions of exploited species would be crucial for assigning national responsibilities to sustain species and populations in the long term.

KEYWORDS

bycatch, exploitation mode, national protection, precautionary principle, sea snakes, Southeast Asia, sustainability, trade regulation

INTRODUCTION

The use of marine elapid snakes for food and their skins dates back centuries. One of the earliest accounts from Cantor (1841) reports the consumption of smoked sea snakes in Japan and sea snakes as a food source for the people of Tahiti. In a monograph on sea snakes, Smith (1926) states, "they [sea snakes] are sometimes used for human consumption. I found Sea-snakes on sale in the fish-market at Hoi-ho'w (Hainan), where they were chopped up and made into sausage meat." In the early 1920s, Japanese fishers from Riu Kiu Island harvested *Laticauda semifasciata* in Philippine waters as a food source (Herre & Rabor, 1949).

In Southeast Asia, skins of sea snakes have been traded for their leather, therein likely indicating a targeted and thus commercial international trade. In 1930, Japanese trawlers initiated the commercial trade in sea snake skins, in addition to their meat as a food source (Herre & Rabor, 1949). The commercial use of sea snakes has been documented in the Philippines since the early 1970s (Jenkins & Broad, 1994; Punay, 1975), where skins of *Hydrophis* (*Lapemis*) *curtus* (Gaulke, 1990, 1998) and of the region's 2 sea krait species (*L. semifasciata* and *Laticauda laticaudata*) were used (Warrel, 1994). The use of sea snake skins for the commercial leather industry was also reported from Thailand (Bussarawit et al., 1989) and in 1990 in Phan Thiet (Vietnam) (Warrel, 1994). In Japan, *L. semifasciata* (the most common species in Japan) were collected for consumption when they come ashore, whereas *Hydrophis ornatus*, a rarer species around the Ryukyu Islands, was harvested for its medicinal properties (Toriba, 1994). In southern Vietnam, *H.* (*L.*) *curtus* was used to treat backaches (Warrel, 1994).

Targeted harvests of sea snakes existed in the past, when their numbers were high enough to make these harvests possible in several parts of the world, particularly Asia; such harvest are currently rare; and the majority of sea snakes in trade are harvested either incidentally or opportunistically in fisheries targeting other commercial seafood, wherein they are an occasional or rare catch (Cao et al., 2014; Udyawer et al., 2018). Only Indonesia established annual harvest and trade quotas for sea snakes (for *Laticauda colubrina* from 2020 to 2023, Indonesia reported the harvest and export of 152–160 individual *L. colubrina* for the pet industry [Indonesian Ministry of Environment & Forestry, 2020, 2021, 2022, 2023]). No export quotas could be traced, for example, from Malaysia, Thailand, Vietnam, the Philippines, and Japan (https://cites.org/eng/resources/quotas/export_quotas), countries from which domestic use or international trade or both have been reported (see below; Appendix S1).

The impact of trade on sea snake populations is largely unknown, and field studies evaluating the impact of commercial trade (linked to exports in Southeast and East Asia and Europe for instance) are almost nonexistent. Thus, regulating international trade has been completely neglected, making it difficult to identify the sources of harvest (Rasmussen, Elmberg, et al., 2011). However, some relatively recent studies describe species composition and the enormous harvest quantities in South Asia (e.g., Rao et al., 2021; Tambre et al., 2020) and Southeast Asia (Cao et al., 2014) (Table 2; Tu, 1974). It has been discussed that regulating national and international trade in terrestrial elapids could have the effect that marine elapids (with trade across borders not regulated) will be included in this market (Cao et al., 2014). This strategy may give the false impression of a sustainable trade with terrestrial elapids.

None of the sea snake species are listed in the appendices of CITES (Convention on International Trade in Endangered Species of Wild Fauna and Flora [https://checklist.cites.org/#/en]); however, *H.* (*L.*) *curtus* is listed in Annex D of the EU Wildlife Trade Regulations (https://speciesplus.net/species#/taxon_concepts/7191/legal). Likewise, no elapid species is listed in CMS (Convention on the Conservation of Migratory Species of Wild Animals [https://www.cms.int]).

For example, the large-scale harvest of sea snakes from the Gulf of Thailand is opportunistic. Squid fishers recognize sea snakes as valuable bycatch that requires minimal effort to collect and sell to merchants at landing ports in Vietnam (Cao et al., 2014). Most studies that assessed sea snake species diversity and abundance used bycatch samples from trawl fisheries across the region (de Silva et al., 2011; Rasmussen, Elmberg, et al., 2011; Sarker et al., 2017; Somaweera et al., 2021; Udyawer, Read, et al., 2016). Field studies to assess region-specific species identities and abundance are relatively recent. For example, in Sri Lanka, such studies were initially conducted in 2010 and 2011 (de Silva et al., 2011).

Udyawer et al. (2018) envisaged various research priorities for sea snake conservation and management. They note that bycatch and incidental capture of sea snakes are a "recurring threat throughout their global range" despite the application of so-called bycatch reduction devices (BRDs). However, BRDs are primarily used in Australian waters and are only partially effective in excluding sea snakes (Heales et al., 2008). In the late 1990s, thousands of sea snakes were caught in the northern Australian fisheries every year (Ward, 2000). Ongoing efforts in Australia aim to develop operational practices that decrease bycatch rates and improve survival of snakes caught by trawlers (Milton et al., 2009). In regions where a commercial interest in bycatch is well established (e.g., Arabian Sea, Andaman Sea, South China Sea, and Philippine Sea), efforts to implement bycatch-reducing technologies will not succeed (Udyawer et al., 2018). Consequently, other management options may be more effective, for example, spatial closures in addition to enforcement of catch limits for designated coastal regions (Udyawer, Read, et al., 2016). Although incidental captures of sea snakes are widespread throughout their range (e.g., "in Australian waters thousands of true sea snakes are captured in tropical trawl fisheries each year"), the opportunistic harvest of sea snakes is negligible for Australian populations (Udyawer et al., 2018). Interestingly, Wassenberg et al. (1994) note that sea snake skins have been industrially processed in northern Queensland since at least 1977. These authors call this business a cottage industry based on the supply of snakes from the incidental catch by prawn trawlers and add that 3 licenses for a total of 30,000 snakes were issued for the Gulf of Carpentaria in 1986 and 1990.

REVIEW RATIONALE

The regional and international use of sea snakes has been known for decades. Over the last decade, a few regional studies have shed light on the species and quantities utilized, highlighting the potential for detrimental impact of trade on natural populations (e.g., Cao et al., 2014; Elfes et al., 2013). To date, however, no comprehensive study has directly examined the use and trade as a potential threat to populations and species of true sea snakes and sea kraits.

The CITES document, "Snake Trade and Conservation Management," compiles findings and recommendations of the CITES Asian snake trade workshop in Guangzhou (China) (April 2011 [https://cites.org/sites/default/files/eng/com/sc/61/E61-46-01.pdf]). At the 61st meeting of the

CITES Standing Committee, it was agreed that "there is a need for an improved knowledge base of the extent and nature of trade in a range of parts, products and derivatives of Asian snakes, including sea-snakes." Specific recommendations included the development of manuals (identification guides) to improve management and regulate international trade for Asian snakes, including sea snakes, and funds were allocated to conduct training workshops for use by CITES and "other relevant Authorities of range States of Asian snake species, including sea-snakes, subject to international trade." It was recommended for parties to the convention to "communicate Appendix-II export quotas to the Secretariat, and … export quotas for non-CITES snake species, including sea-snakes, to the general public."

Twelve years later, none of these recommendations have been implemented. We examined the challenges around the domestic and regional use and trade of marine elapids to provide a basis for regulation of cross-border trade activities of selected marine elapid species as a precautionary measure.

DATA SOURCES

The backbone of this review is open-access databases, which are essential as a basis for making recommendations. Taxonomic status of species was determined from the website http://www.reptile-database.org and relevant publications listed therein. Current conservation status came from the IUCN Red List (https://www.iucnredlist.org; assessments published in 2009–2021) (Appendix S1 contains date of assessments). Using these data, we developed a new database of all sea snake species currently recognized by science that contains information on, for example, taxonomy, distribution, national protection status, and interaction with fisheries (incidental and opportunistic bycatches, domestic and/or international use and trade) (Appendix S1).

Documentation of international trade is challenging, particularly because not one species of sea snake (true sea snakes and sea kraits) is listed in the appendices of CITES. However, the Council Regulation (EC) No 338/97 of 9 December 1996 (https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:01997R0338-20230520), implementing CITES and species listed on its appendices, has an Annex D that lists species "not listed in Annexes A to C (equivalent to Appendix I-III of CITES, incl. few additional species not listed in CITES) which are imported into the Community in such numbers as to warrant monitoring." Therein, *H.* (*L.*) *curtus* is listed as "*Lapemis curtus* (includes *Lapemis hardwickii*)" as being related to the trade of "§1 Any whole, or substantially whole, skins, raw or tanned" since 1 June 1997 (https://speciesplus.net/species#/taxon_concepts/7191/legal). Trade data on Annex D species are also compiled in the CITES Trade Database (https://trade.cites.org). Our query was made according to the following filter: year range, 2000–2021; exporting countries, all countries; importing countries, all countries; source, all sources; purpose, all purposes; trade terms, all terms; species, *Lapemis curtus* (*Hydrophis curtus*). Even though little data for 2022 may have been recorded, the deadline for submission of 2022 annual reports is not until 31 October 2023; hence, trade data reported for 2022 are incomplete.

Data retrieved from these outputs were aggregated for all records for which information on taxon, term, importer, exporter, country of origin, purpose of transaction, source of specimen, and year in which the trade occurred was identical (as reported by the exporter or importer). Identical reporting of all this information by both the exporter and re-exporter and importer means that shipments appear on the same line of tabulations and quantities are accordingly summed. Hence, each row of a comparative tabulation reported could include any number of actual shipments (see https://trade.cites.org/cites_trade_guidelines/en-CITES_Trade_Database_Guide.pdf).

The search yielded trade reported in 6 trade terms, from which we excluded the terms "*derivatives*," "*leather products* (*small*)," "*skin pieces*," and "*live*." We retained data reported with the terms "*plates*" and "*skins*" for our analyses. Plates and skins were predominantly reported by number. Parties also reported trade in square meters (plates and skins) and kilograms (skins only). We assumed that trade reported indicating plates also referred to square meters. Plates, according to the CITES guidelines, are "plates of multiple skins—includes rugs if made of several skins." These are expected to include a unit of measure (square meters) to indicate size (https://cites.org/sites/default/files/notifications/E-Notif-2021-044-A1.pdf) (Malsch, personal communication 29.06.2023). This means that skins from several individual snakes might be attached to each other. In West Malaysia, we observed plates composed of skins of up to 12 *H.* (*L.*) *curtus* individuals (Appendix S2).

Information on trade suspensions was retrieved from the website Species+ (https://speciesplus.net) and was developed by UNEP-WCMC and the CITES Secretariat. Species+ provides access to important information on species of global concern and contains information on CITES and CMS species and on species listed in the Annexes of the EU Wildlife Trade Regulation (EU-WTR). The EU-WTR basically implements CITES in the European Union; however, it includes an additional annex and lists species not listed in the appendices of CITES (see https://environment.ec.europa.eu/topics/nature-and-biodiversity/wildlife-trade_en#:~:text=The%20). Searches on the TRAFFIC Wildlife Trade Portal (https://www.wildlifetradeportal.org/) for either "*sea snakes*," "*Laticauda*," "*Lapemis*," "*Hydrophis*," "*Elapidae*," or "*Hydrophiinae*" resulted in zero entries in any of the incident categories provided (e.g., seizures indicating trade of marine elapid snakes). Finally, publications relevant to this review were retrieved from our databases and filtered as were websites (Appendix S3) documenting the use and trade of marine elapids.

TAXONOMY, DIVERSITY, AND DISTRIBUTION

Currently, 71 species of marine elapids are known to science (Uetz et al., 2023). Sea snakes include 2 groups that evolved

TABLE 1 Number of recognized species of viviparous and oviparous sea snakes.

Genera	No. species	Geographic core range	Reference
Aipysurus	9	Australia	Sanders, Lee, et al., 2013
Emydocephalus	3	Australia	Nankivell et al., 2020
Ephalophis	1	Australia	Sanders, Lee, et al., 2013
Hydrelaps	1	Indo-Australia	Kharin, 2008; Smith, 1974; Sweet, 1989
Hydrophis	47	Indo-Pacific	Rasmussen et al., 2014; Rasmussen, Hay-Schmidt, et al., 2021; Uetz et al., 2023; Ukuwela et al., 2012
Laticauda	8	Indo-Pacific	Heatwole et al., 2017; Kishida et al., 2021
Microcephalophis	2	Indo-Pacific	Lee et al., 2016; Rezaie-Atagholipour et al., 2016
Parahydrophis	1	Indo-Australia	Burger & Natsuno, 1974; Sanders, Rasmussen, et al., 2013

independently from terrestrial elapids. Eight recognized species of oviparous sea kraits belong to the genus *Laticauda* and must go on land to lay eggs (Cogger & Heatwole, 2006; Gherghel et al., 2016; Heatwole et al., 2005, 2017; Kishida et al., 2021), and 64 species of viviparous sea snakes (also called true sea snakes) belong to 7 genera that give birth in the water. The taxonomy of the viviparous sea snakes has changed significantly since the thorough treatment by Smith (1926); however, in the last 10 years, there has been an increasing consensus on the taxonomy in this group (Bessesen et al., 2022; Ganesh et al., 2019; Lee et al., 2016; Sanders, Lee, et al., 2013; Uetz et al., 2023; Ukuwela et al., 2022; Voris, 2017). Species richness of the 8 recognized genera of sea snakes are in Table 1. The formerly recognized genera *Acalyptophis*, *Astrotia*, *Disteira*, *Enhydrina*, *Kerilia*, *Lapemis*, *Kolpophis*, and *Thalassophina* are all now nested within *Hydrophis* (Lee et al., 2016; Sanders, Lee, et al., 2013).

Stable taxonomy allows for long-term monitoring without the worry that the taxonomy will undergo a drastic rearrangement that could hinder future comparative analyses. Relevant here is *Lapemis hardwickii*, which is, according to Gritis and Voris (1990), considered a synonym of *L. curtus* and is now included in the genus *Hydrophis*. For this review, we maintained the former reference to the genus *Lapemis* for the readership and refer to *H.* (*L.*) *curtus*.

Oviparous and viviparous sea snakes are found in the tropical and subtropical waters of the Indian Ocean and the Pacific Ocean, from the east coast of Africa to the Gulf of Panama (David & Ineich, 1999; Nankivell et al., 2020; Rasmussen, Hay-Schmidt, et al., 2021). Two areas have high concentrations of sea snakes—the South China Sea, with more than 26 species (Kharin & Czeblukov, 2006, 2009; Rasmussen, Elmberg, et al., 2011), and the Australian region, with more than 30 species of sea snakes (Elfes et al., 2013; Nankivell et al., 2020; Rasmussen et al., 2014).

Hydrophis platurus, a typically pelagic sea snake, is the most widely distributed species and occurs in the Pacific and Indian Oceans; a few have been recorded in the Atlantic Ocean (Bessesen & Galbreath, 2017; Branch, 1998). Some species, such as *Hydrophis caerulescens*, *Hydrophis cyanocinctus*, *H. curtus*, *Hydrophis ornatus*, *Hydrophis peronii*, *Hydrophis spiralis*, *Hydrophis stokesii*, *L. colubrina*, and *L. laticaudata*, have an extensive distribution in Asia and in the Australian region (Buzas et al., 2019; Ganesh et al., 2019; Ineich & Rasmussen, 1997; Rasmussen et al., 2014; Rezaie-Atagholipour et al., 2016). Sea snake species broad distributions could be used in monitoring programs across these regions (Rasmussen, Hay-Schmidt, et al., 2021). Other species are known only from very limited areas. For example, *Hydrophis laboutei* is only known from the Chesterfield Reef, New Caledonia, *Hydrophis parviceps* is only known from a single locality in the South China Sea (Vietnam), *Hydrophis semperi* has only been collected in Taal Lake in the Philippines, and *Hydrophis sibauensis* is only known from a limited area, more than 1000 km upriver from the coast in the Sibau River in Borneo (Garcia et al., 2014; Rasmussen & Ineich, 2000; Rasmussen et al., 2001).

Marine elapids are found in shallow waters in and around coral reefs, mangroves, rivers, and river mouths, and some species are recorded most often in deeper water on gravel and sand bottom (Buzas et al., 2019; Cao et al., 2014; Lukoschek & Shine, 2012; Smith, 1974; Voris, 2015). Water depths observed for sea snakes are usually <100 m (Greer, 1997); however, 2 observations have recorded sea snakes foraging as deep as 245 m (Crowe-Riddell et al., 2019).

LIFE-HISTORY CHARACTERISTICS

Some life-history traits of marine elapids are unfavorable for high-level offtakes. Specific biological and ecological traits of some species rather reflect stenoecious species (e.g., several *Emydocephalus* spp. [Nankivell et al., 2020]), and this knowledge is relevant if effective management plans are to be established for threatened marine elapid species.

In general, information on the biology of sea snakes increased significantly in the last 40 years, giving a much better point of departure for establishing management plans and monitoring sea snakes (Brischoux et al., 2009; Rasmussen, Hay-Schmidt, et al., 2021; Udyawer et al., 2018). However, the ecology of many species remains unknown, including the extent of site fidelity and whether long-range movement occurs (Lynch et al., 2023). A recent study showed that species, such as

Hydrophis coggeri and *Hydrophis major*, move long distances (over 12 km) and thus may be less affected by highly localized threats (Udyawer et al., 2023).

Focusing on the reproductive status of harvested species provides invaluable information that can inform assessments of endangerment and harvest and trade management schemes.

Habitat preferences of sea kraits

The oviparous sea snakes (*Laticauda*) forage at sea but lay eggs on land (Bonnet et al., 2014). In New Caledonia, mark–recapture studies show that female *Laticauda saintgironsi* seasonally migrate from home areas (more than 50 km) to coastal nurseries to lay eggs (Bonnet et al., 2014). Whether other species in *Laticauda* do the same has not been investigated. Eggs from *Laticauda* species have been found in seabird burrows and tree cavities, on grasslands, in crevices of the walls of caves and large stone blocks and old corals, and on small rocky islands (Bacolod, 1983; Brischoux & Bonnet, 2009; Ineich & Laboute, 2002). Such areas are also used as resting habitat for *Laticauda* spp. (Bonnet et al., 2009; Brischoux & Bonnet, 2009; Lading et al., 1991; Liu et al., 2012; Saint Girons, 1964).

Reproductive season/biology

The scattered information available on the breeding season of *Laticauda* shows that it follows the warm season in northern and southern populations but is more diffuse closer to the equator (Bacolod, 1983; Bonnet, 2012; Bonnet et al., 2014; Brischoux & Bonnet, 2009; Brischoux et al., 2011; Pernetta, 1977; Saint Girons, 1990; Shetty & Shine, 2002; Shine et al., 2002; Toriba & Nakamoto, 1987; Tu et al., 1990).

Viviparous marine elapids give birth in water and rarely or never come on land. In some species, there is anecdotal evidence of nursery areas, where many females congregate to give birth (Porter et al., 1997; Udyawer, Read, et al., 2016; Voris, 2015).

Data on litter size and seasonal reproduction patterns in viviparous sea snakes are available for many Australian species but are still missing in many Asian species, despite some published data (e.g., (Bacolod, 1990; Bergman, 1943; Burns, 1984a; de Silva et al., 2011; Deraniyagala, 1955; Fry et al., 2001; Fujishima et al., 2021; Greer, 1997; Hin et al., 1991; Lemen & Voris, 1981; Marcos & Lanyon, 2004; Masunaga & Ota, 2003; Mirtschin et al., 2017; Rasmussen, 1989, 1993; Rasmussen, Murphy, et al., 2011; Sarker et al., 2017; Voris & Jayne, 1979; Wall, 1921; Ward, 2001). However, for *H.* (*L.*) *curtus*, litter size has been reported as 1–6 neonates (Deraniyagala, 1955; Fry et al., 2001; Hin et al., 1991).

A more detailed picture of the reproductive strategy in viviparous marine elapids is needed, such as whether most species use nursery sites sensitive to anthropogenic threats (e.g., fisheries, port development, and pollution) (Udyawer et al., 2018). The negative effects of opportunistic and targeted harvest of species that mature late and have small litters (i.e., *Aipysurus laevis* attains sexual maturity only at the age of 4−5 years, and only reproduces 2–8 neonates biennially or annually [Burns, 1984b; Fry et al., 2001]) may be more severe than that of species attaining sexual maturity at an earlier age and characterized by a higher reproductive output (e.g., *Hydrophis* [*Enhydrina*] *schistosa*; de Silva et al., 2011; Voris & Jayne, 1979). Therefore, a solid foundation of relevant biological and ecological knowledge of species is vital.

Feeding biology

The distribution of species with specific environmental requirements (habitat, prey) is more narrow than the distribution of opportunistic feeders that are not associated with specific ecosystems.

The oviparous sea snakes are specialized for feeding on eels. More than 45 species of eels were found in stomach contents in New Caledonian populations (Brischoux & Bonnet, 2009). Tabata et al. (2017) investigated 3 species of *Laticauda* in Japan and confirmed that *L. colubrina* and *L. laticaudata* primarily feed on eels. However, according to studies in Taiwan, *L. semifasciata* also feeds on other fish families (Mao & Chen, 1980).

Viviparous marine elapids feed on a variety of fish families; some are specialized feeders—for example, *Aipysurus eydouxii* feeds exclusively on fish eggs (McCarthy, 1987) and *Hydrophis* [*Enhydrina*] *schistosus* and *H. major* preferably prey on catfishes (Letourneur & Briand, 2012; Tambre et al., 2020). Other species are more generalists, eating fish from more than 10 fish families (Voris & Voris, 1983). *Hydrophis* (*Lapemis*) *curtus* has a wide distribution and is a generalist predator, feeding on a wide range of fish species, in addition to cephalopods and invertebrates (Glodek & Voris, 1982).

Despite there being some literature available on viviparous sea snake diets, this information is still lacking for more than half of all species (Buzas et al., 2019; Fujishima et al., 2021; Glodek & Voris, 1982; Greer, 1997; Letourneur & Briand, 2012; Marcos & Lanyon, 2004; McCosker, 1975; Rasmussen, 2001; Rezaie-Atagholipour et al., 2013; Sanders, Rasmussen, et al., 2013; Tambre et al., 2020; Voris & Voris, 1983; Voris et al., 1978).

IUCN RED LIST ANALYSES

Among the currently recognized 72 species of marine elapid snakes, 2 species remain unassessed in the IUCN Red List: *Emydocephalus orarius* and *Hydrophis hendersoni*. The status of 62 species was last assessed in 2009, one species in 2013, and 6 species in 2018 (Appendix S1).

Aipysurus fuscus is endangered (EN); *Laticauda schistorhyncha*, *H. semperi*, and *Laticauda crockeri* are vulnerable (VU) (these species are associated with freshwater land-locked lakes); *Hydrophis pacificus*, *L. semifasciata*, *Laticauda frontalis*, and *Laticauda guineai* are near threatened (NT). It is clear that threats to species that inhabit or depend on terrestrial ecosystems are more likely to be evaluated. Of the remaining species, 26 are data deficient (DD), and 34 are least concern (LC). In all 3 assessment periods (2009, 2013, 2018), the population trend in 55 species

(77% of all sea snake species) were evaluated as unknown, 8 as stable, and 5 as decreasing. In species assessed LC, the population trend in 22 species is unknown. This high degree of uncertainty is explained on the one hand by the fact that evaluating the conservation status of these marine reptiles remains a major challenge. On the other hand, despite the extensive distribution of many species, it cannot be ruled out that populations have been regionally depleted by combined effects of many threats.

The intensity and impact of fishing practices and land-use activities influencing coastal waters (pollution, trophic cycles) in the Indo-West Pacific are factors that have a lasting impact on these marine ecosystems. Numerous threats, other than the bycatch of trawlers or targeted use of few species for either domestic use or exports for the leather trade, are known to affect marine elapid species, with some populations being more affected than others.

The difficulty of identifying the key threats that adversely affect species and populations is illustrated by the example of sea snakes in Ashmore Reef (Timor Sea) between the Australian shelf and Roti Island (Indonesia). Three potential threats include vulnerability to pathogens due to specific environmental factors, regional change in the weighting of certain trophic levels (e.g., an increase of sea snake predators and competitors), and significant increases in local boat traffic (Somaweera et al., 2021). The absence of commercial fishing in the regions, however, allows incidental bycatch to be ruled out as a threat in and around the Ashmore Reef.

THREATS AFFECTING MARINE ELAPIDS

Marine fisheries

Interactions with fisheries are perhaps the most significant threat affecting marine elapid snakes throughout their range, particularly in the South and Southeast Asian region, where fisheries management is a recent development. That said, industrial fisheries, particularly bottom trawlers using unselective nets targeting demersal species, such as shrimp, pose a disproportionately large threat to their populations.

Marine elapid snakes are air breathers and need to surface at regular intervals. When caught in fishing gear, they are kept submerged for extended periods; this and probably the stress they undergo when caught cause them to drown. Mortality and injury rates of these snakes exploited by fisheries can be particularly high, and some species are more affected than others (Milton, 2001; Rao et al., 2021; Wassenberg et al., 1994). This varies based on their relative vulnerability to capture in fisheries and the relative capacity of their populations to sustain increased mortality due to fishing (Milton, 2001). For example, in Australia's Gulf of Carpentaria, it was estimated that prawn trawlers caught approximately 119,571 snakes, for which the estimated survival rate was 60% (Wassenberg et al., 1994). Similarly, in Sabah (Malaysia), prawn trawlers were estimated to have killed approximately 1.3 million marine snakes (Wong, 2006). In at least 45 species (63% of all species), bycatch from trawling is a potential or serious threat to population persistence of, for example, *Hydrophis annandalei*, *Hydrophis elegans*, *Hydrophis mamillaris*, *H. pacificus*, and *H.* [*E.*] *schistosus* (IUCN Red List assessments) (Appendix S1). Published studies allow identification of those species most affected quantitatively by bycatch or targeted and intentional captures (Table 2).

Although the threat from industrial fisheries, such as trawling, on marine elapid snakes is established, what is largely undocumented is the impact that small-scale and artisanal fisheries have on these reptiles. Marine elapid snakes have been reported from these fisheries and have been caught in relatively passive gear (in contrast to mobile gear, such as trawl nets), such as shore seines and stake nets (Voris, 1985). One report from Goa, India, highlights the large numbers of *H. schistosus* "accidentally exploited" as bycatch in shore seine operations in Goa (Tambre et al., 2020). Although the small-scale fisheries sector in Asia is a major contributor to livelihood and food security in the region, they are largely unmonitored and unmanaged (FAO et al., 2023). This poses an additional and a largely unknown threat to various threatened marine taxa accidentally exploited in these fisheries.

Of serious concern is that some of the regions with the highest diversity of marine elapid snakes are also areas that have been reported to have high levels of IUU (illegal unregulated and unreported) fisheries, particularly in South and Southeast Asia (Fujii et al., 2021; Williams & Staples, 2010).

TYPES OF EXPLOITATION

The exploitation of marine elapid snakes can be categorized into 4 modes (based on Branch et al. [2013]): targeted exploitation, accidental exploitation, incidental exploitation, and opportunistic exploitation.

In targeted exploitation, marine snakes are targeted exclusively for their skin and meat because they have a high economic value of their own. For example, in the Ryukyu islands of Japan, *L. semifasciata* was harvested for a thriving sea snake leather industry located there, and the meat was also consumed (Heatwole, 1997). Similarly, the Philippines had targeted marine snake harvests since the 1930s, and commercial exports of these skins to Japan began since 1934. The targeted exploitation of these marine elapid snakes seems to have declined drastically, possibly because of local and regional overharvest of snakes, which has made it economically infeasible (costs of searching and capturing snakes outweigh the economic benefits) to continue targeted exploitation (Bacolod, 1984).

In accidental exploitation, marine elapid snakes are accidentally caught while fishing for other species (typically fisheries) and thus have no economic value. Marine elapids encountered as bycatch in fisheries in the Middle East, parts of South Asia, and in Australia typically belong to this category of exploitation.

In incidental exploitation, marine elapid snakes are not the main target and possess an economic value that is lower than the targeted species. Snakes caught in trawl fisheries in many parts of South and Southeast Asia could constitute an incidental catch. In Mangalore, along the West coast of India, marine

TABLE 2 The 10 most dominant marine elapid species documented as catches in trawlers from studies reporting at least 50 individuals per species regardless of the duration of the study.

Species	No. individuals	Region	Date of study	Reference
Aipysurus eydouxii	243	Gulf of Thailand	1969	Tu, 1974
Aipysurus eydouxii	213	Gulf of Thailand	1972	Tu, 1974
Aipysurus eydouxii	76	Australia	1976–1979	Wassenberg et al., 1994
Aipysurus eydouxii	138	Sabah (Malaysia)	1987–1988	Stuebing & Voris, 1990
Hydrophis (*Lapemis*) *curtus*	68	Gulf of Thailand	1967	Tu, 1974
H. curtus	4305	Gulf of Thailand	1969	Tu, 1974
H. curtus	914	Peninsular Malaysia	1971, 1974–1975	Voris, 2017
H. curtus	6970	Gulf of Thailand	1972	Tu, 1974
H. curtus	681	Australia	1974–1979	Wassenberg et al., 1994
H. curtus	754	Sabah (Malaysia)	1987	Hin et al., 1991
H. curtus	1676	Sabah (Malaysia)	1987–1988	Stuebing & Voris, 1990
H. curtus	121	Sabah (Malaysia)	1998–1999	Wong, 2006
H. curtus	165	Goa, India	2002–2003	Lobo et al., 2005
H. curtus	>50	Vietnam	2010	Rasmussen, Elmberg, et al., 2011
H. curtus	236	Konkan Coast, India	2016–2018	Rao et al., 2021
Hydrophis cyanocinctus	92	Gulf of Thailand	1969	Tu, 1974
H. cyanocinctus	271	Gulf of Thailand	1972	Tu, 1974
H. cyanocinctus	101	Sabah (Malaysia)	1987–1988	Stuebing & Voris, 1990
H. cyanocinctus	>50	Vietnam	2010	Rasmussen, Elmberg, et al., 2011
Hydrophis elegans	207	Australia	1976–1979	Wassenberg et al., 1994
Hydrophis jerdonii siamensis	55	Gulf of Thailand	1969	Tu, 1974
Hydrophis ornatus	73	Gulf of Thailand	1969	Tu, 1974
H. ornatus	>50	Vietnam	2010	Rasmussen, Elmberg, et al., 2011
Hydrophis peronii	>50	Vietnam	2010	Rasmussen, Elmberg, et al., 2011
Hydrophis schistosus	73	Gulf of Thailand	1969	Tu, 1974
H. schistosus	54	Gulf of Thailand	1972	Tu, 1974
H. schistosus	104	Australia	1976–1979	Wassenberg et al., 1994
H. schistosus	53	Sabah (Malaysia)	1987–1988	Stuebing & Voris, 1990
H. schistosus	914	Konkan coast, India	2016–2018	Rao et al., 2021
H. schistosus	1448	Goa, India	2017–2018	Tambre et al., 2020
Hydrophis stokesii	60	Australia	1976–1979	Wassenberg et al., 1994
Hydrophis torquatus diadema	250	Gulf of Thailand	1972	Tu, 1974
Hydrophis viperinus	99	Gulf of Thailand	1969	Tu, 1974
H. viperinus	357	Gulf of Thailand	1972	Tu, 1974
H. viperinus	>50	Vietnam	2010	Rasmussen, Elmberg, et al., 2011
Microcephalophis gracilis	101	Gulf of Thailand	1972	Tu, 1974

snakes are among the species harvested by trawl fisheries that constitute "low-value bycatch" (Dineshbabu et al., 2014).

Opportunistic exploitation is similar to incidental exploitation. Marine elapid snakes are not the main target, but they constitute a highly desirable catch and are more valuable than the target species in terms of economic value per unit weight. Opportunistic exploitation can be seen in the case of marine elapid snake harvest in the squid fisheries from the Gulf of Thailand (Cao et al., 2014). Opportunistic exploitation poses a particular risk and can drive the extinction and extirpation of species because it allows for the continued exploitation of species when densities are below the bioeconomic equilibrium and can also drive the presence of a more abundant species (in this case, squid) (Branch et al., 2013). Although it does make economic sense for fishers to target marine elapid snakes alone, exploiting them opportunistically in a fishery targeting relatively abundant squid resources makes this sort of exploitation viable.

Although marine elapid snakes encountered in fisheries were traditionally considered accidental bycatch and discarded, they seem to have gained an economic value over time, particularly in South and Southeast Asia. Besides international markets for their skins and meat, a bigger plausible driver for their commercialization and growing value is the declining fisheries in the South and Southeast Asian region. With declining, due to overexploitation and lack of proper management, the commercialization of once accidental bycatch is very common throughout most of South and Southeast Asia. This phenomenon is in part also driven by the animal feed industry, which relies on low-value bycatch (fishmeal), mainly for the poultry and aquaculture industries (Lobo et al., 2010).

Given their life histories (late maturation, low fecundity, air breathing), sea snake populations may not be able to withstand high levels of sustained fishing pressure. Some populations are declining drastically, and certain species are more vulnerable to fisheries-driven exploitation than others (Rao et al., 2021). There are undoubtedly species-specific criteria that are unfavorable for the regular capture of certain species, such as when endemic species are involved (e.g., *H. parviceps* that is endemic to Vietnam waters [Rasmussen, Elmberg, et al., 2011]).

TRADE

From the above discussion on fisheries impacts on marine elapid snakes, it is clear that fisheries exploitation (predominantly incidental and opportunistic exploitation) in South and Southeast Asia is also the main source of these species in trade for their meat and skin for domestic and international markets. The mode of exploitation of marine elapids varies among regions and depends on the extent and diversity of domestic use and national and international demand. The status of marine elapid snake populations is unknown, but regional declines have been reported (Cao et al., 2014). We could not determine the main driver of these declines; a combination of threats is possible, with overharvest and habitat deterioration being the most likely.

One species undoubtedly being targeted for harvest, for which international trade data are available, is *H.* (*L.*) *curtus*, an Annex D-listed species. Trade data on targeted species are compiled in the CITES trade database (Figures 1 & 2; Appendix S4), and we examined these for *H.* (*L.*) *curtus*.

CHALLENGES TO INTERPRETING TRADE STATISTICS

For 2000–2021, we calculated and analyzed export and import of skins and plates. The aggregated, comparative tabulations showed that skins composed the majority of exports. Exporting countries reported 19 skins, whereas importing countries reported 175,524 skins (Appendix S4). Major exporting countries were Thailand and Malaysia. From 2000 to 2009, most exports were shipped from Thailand, whereas from 2009 to 2021, they were shipped from Malaysia (Figure 1). What made the leading exporters change? Did all skins exported from Thailand or Malaysia originate from the territorial waters of those countries? An answer to the latter question was provided in 2008 by a Malaysian reptile dealer in Perak State who stated that 20,000 raw skins were usually sent to Thailand (no time frame was specified) (Auliya, 2011). Interestingly, in none of the 105 transactions documented in the CITES trade database was Thailand reported as an exporting country, where Malaysia was indicated as the country of origin; skins were reported as originating from Malaysia (Appendix S4). So, from which territorial waters did the exports originate? Control of territorial marine waters is challenging, so it cannot be denied that individual shipments of hundreds or thousands are composed of skins from different populations, which in turn are from territorial waters of different countries. Complexity increases if stockpiling is involved, as more skins from more range states may accumulate. Based on what the dealer in Malaysia said, suspicion is inevitably aroused that claimed "bycatches" are actually intentional catches used as commercial resources. Here, the line between unintentional and intentional catch appears very blurry.

Plates of *H.* (*L.*) *curtus* were also traded from 2000 to 2021. A minimum of 20,190 m^2 of plates were reported by the importing countries (no quantities were reported by exporting countries). An aggregated comparative tabulation indicated 60.833 plates (i.e., "…the result of the comparative tabulation report aggregating 2 records of 60 and 0.833 plates") (J. Vitale, personal communication 07.07.2023). We added the 60 plates but omitted the 0.833 plates to simplify the total calculation. If one plate is made of 12 individual skins, then 20,190 plates refer to 242,280 individual skins of *H.* (*L.*) *curtus*. Adding this value to the number of skins, in the period 2000–2021, 417,804 skins of individual *H.* (*L.*) *curtus* were shipped internationally (the condition being that one plate consists of 12 skins) for the leather fashion industry.

These trade data document international commercial trade, primarily to Europe, and thus the incorporation of skins for the leather fashion industry (Appendix S2). Italy was by far the largest importer (also reported by a reptile dealer in Perak State, West Malaysia [Auliya, 2011]). Germany and Spain appeared only marginally as importing countries (Figure 2). It was challenging to analyze trends, and the data prompt several significant questions, for example, why did imports peak in 2007 and 2008, what has caused distinct drops in 2012 and 2018, and why were no imports documented in 2017? Trade suspensions of *H.* (*L.*) *curtus* have been documented since 1999 on 3 occasions up to 2018, and these suspensions referred to 2 countries (Table 3).

Trade in non-CITES-listed species that reflect stricter domestic measures as reported by EU Member States in their annual reports is denoted as Appendix N in the CITES trade database. It cannot be ruled out that trade data were reported by other CITES Parties, but this is usually very limited, and trade data for non-CITES-listed species cannot be considered comprehensive or representative of overall trade in that species (J. Vitale, personal communication 07.09.2023). Trade data can affect patterns and trends, for example, through the submission of annual reports, trade suspensions, or export quotas. Analysis

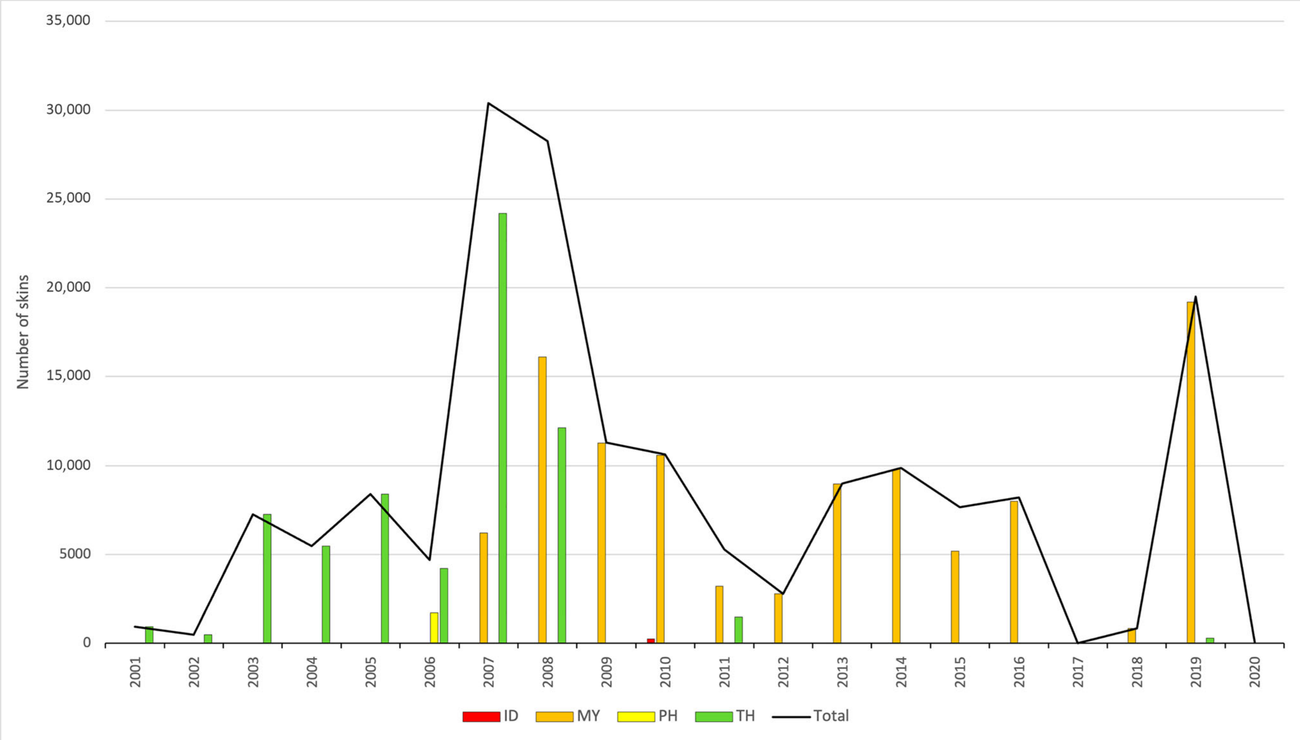

FIGURE 1 Exports of *Hydrophis* (*Lapemis*) *curtus* skins from 2000 to 2021 (ID, Indonesia; MY, Malaysia; PH, Philippines; TH, Thailand; source, CITES Trade Database [https://trade.cites.org]).

TABLE 3 Trade suspensions for *Hydrophis* (*Lapemis*) *curtus*.

Date	Country	Remarks	Reference
31 May 1999	IN	Refers to "exports of wild-taken specimens for commercial purposes…"	https://cites.org/sites/default/files/eng/notif/2010/E038.pdf
29 Nov. 2010	PH	Refers to "export of wild-caught specimens of terrestrial fauna for commercial purposes …"	https://cites.org/sites/default/files/eng/notif/2010/E038.pdf
26 March 2018	IN	Ban of exports "for commercial purposes of all wild-taken specimens of species included in Appendices I, II, and III, …"	https://cites.org/sites/default/files/notif/E-Notif-2018-031.pdf

Abbreviations: IN, India; PH, Philippines.
Source: https://speciesplus.net/species#/taxon_concepts/7191/legal.

of CITES trade data and trends derived from it should therefore be discussed with caution (Challender et al., 2022).

Other exporting countries and those that may potentially export sea snake skins and derivatives are the Philippines, Indonesia, Vietnam, and Japan. According to the CITES trade database, the Philippines and Indonesia are indicated as exporters. In 2006, the Philippines exported 1723 skins to Italy, whereas Indonesian exported 250 skins to Italy in 2010. In 2015 and 2018, plates were in Indonesian exports shipped to Italy. Italy reported import of 2 plates in 2018 (Appendix S4). The commercial harvest of *H.* (*L.*) *curtus* in Indonesia took place only before the 1980s (G. Saputra, personal communication in Rasmussen, Crowe-Riddell, et al. [2021]). This report, however, did not match the trade documenting Indonesian exports. Interestingly, Indonesia is the only country that has allocated an annual harvest quota of one sea snake species, *L. colubrina* (pet trade), but no other sea snake species even though annual harvest and export quotas were established for several CITES and non-CITES elapids in 2023 (Indonesian Ministry of Environment & Forestry, 2023).

In Vietnam, sea snake harvest for local consumption has been established for decades, whereas international trade commenced around 2000–2001. *Hydrophis* (*Lapemis*) *curtus* represents one of the major species harvested in Vietnam and exported to China (Cao et al., 2014). Such exports, because they are non-European, are not documented in the CITES trade database.

Other species for which international trade has been reported for skins and meat are *Hydrophis lamberti* and *L. colubrina*. Species for which international trade activities cannot be reliably

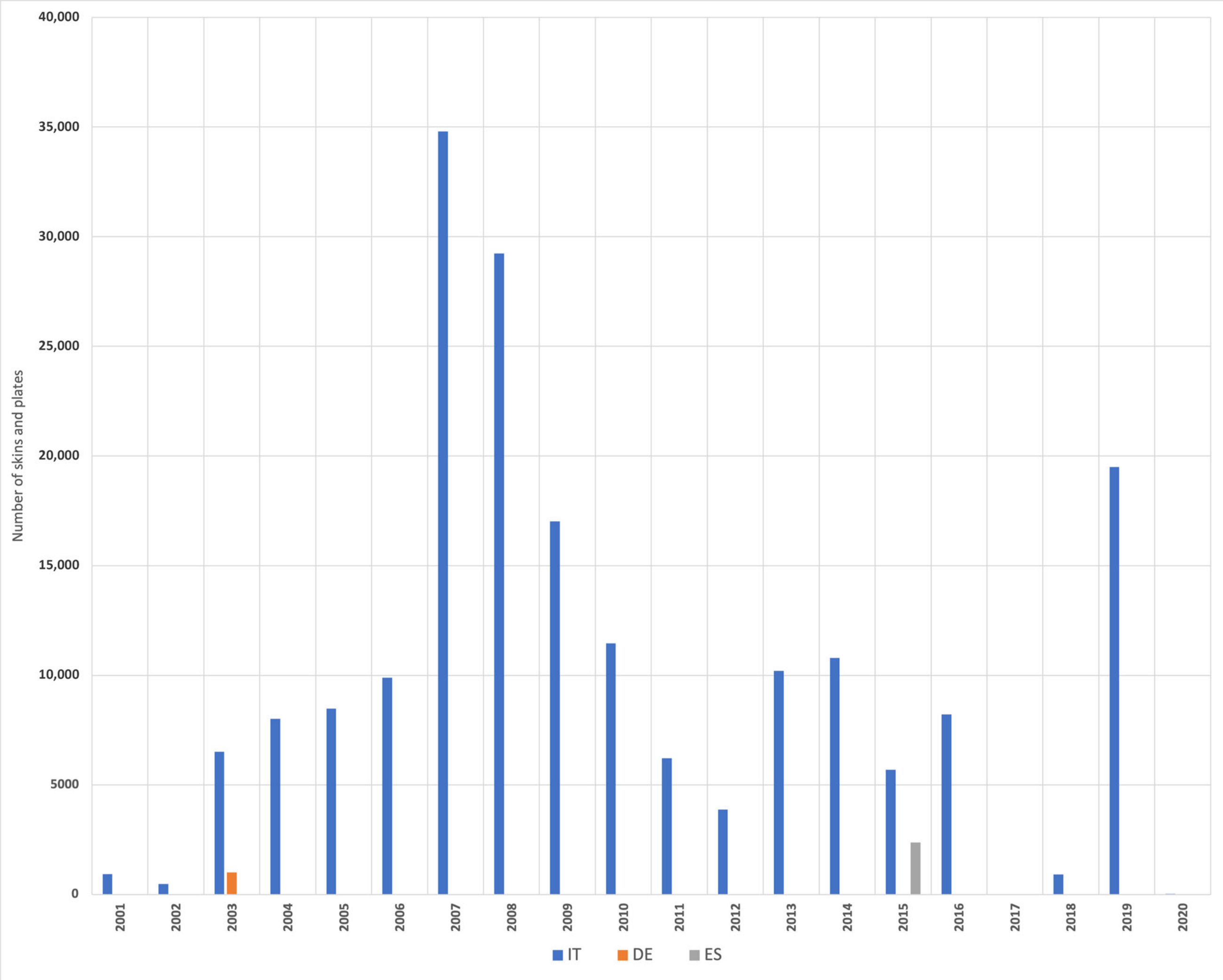

FIGURE 2 Number of *Hydrophis* (*Lapemis*) *curtus* skins and plates imported by the 3 primary importing countries (IT, Italy; DE, Germany; ES, Spain) from 2000 to 2021 (source, CITES Trade Database [https://trade.cites.org]).

ascertained are *Hydrophis belcheri*, *Hydrophis pachycercos*, *H. spiralis*, *Hydrophis viperinus*, and *L. semifasciata*. Until the 1980s, the latter species was heavily exploited for its meat and skin in the Philippines, and its meat is consumed smoked in Japan (Appendix S1).

Climate change

As ectotherms sea snakes cannot regulate their body temperature internally. Water temperatures between 37 and 39°C are lethal to sea snakes, and all species have short survival times at temperatures above 34°C (Heatwole et al., 2012). Marine elapids may not be able to adapt physiologically to short-term temperature changes and would therefore have to change their diving behavior due to increased metabolic demands in warmer waters, which would benefit trawling catches (Udyawer, Simpfendorfer, et al., 2016). Sea snakes are thus critically vulnerable to rising sea temperatures. In general, IUCN Red List assessments evaluating the conservation status of marine elapids indicate that "all sea snakes are vulnerable to indirect threats from habitat loss and climate change throughout their range" (Rasmussen, Crowe-Riddell, et al., 2021). Several species are associated with coral reef ecosystems, and sea-level changes together with mass coral bleaching events are direct drivers that particularly affect amphibious sea krait species that display unique reproductive traits and thus depend on specific intertidal habitats (Francis, 2006; Lane & Guinea, 2010a). In IUCN assessments of at least 19 species of sea snakes (including all *Laticauda* spp.), climate change is indicated as a potential threat. Rising water temperatures appear very likely to explain the decline of *A. fuscus*, for example (Lukoschek, Guinea, & Rasmussen, 2010), and extinction risk of this species was evaluated by Manning (2014).

Coastal development

Species that predominantly depend on coastal waters (e.g., estuarine and mangrove ecosystems) next to shallow-water coral reefs are potentially exposed to anthropogenic alterations and degradation and destruction of coastal ecosystems through, for example, the development of infrastructure and mining activities and extraction of salt (e.g., *Ephalophis greyae*) (Lukoschek, Guinea, & Milton, 2010). Several studies describe the sensitivity of marine elapids to habitat changes (e.g., Rasmussen, Hay-Schmidt, et al., 2021). Hence, the destruction, degradation, and alteration of, for example, coral reefs and shorelines (estuaries, mangroves) will threaten species dependent on such coastal systems (e.g., Bonnet et al., 2009; Lukoschek & Sanders, 2010c; Polidoro et al., 2011). Despite all marine elapids being nationally protected in Australia, this taxon is rarely considered in environmental impact assessments for industry (Sanders et al., 2015); thus, change in coastal developments may threaten *Aipysurus* spp. (Sanders et al., 2015).

Pollution

The frequent occurrence of species in shallow coastal waters makes sea snakes particularly susceptible to pollution flushed into estuaries and lagoons via rivers and to wastewater from coastal industries. Water pollution also affects the freshwater lake species, for example, *L. crockeri* (Lane & Guinea, 2010b) and *H. semperi* (Gatus, 2010), whereas the pelagic *H. platurus* may be threatened by, for example, oil spills and industrial and military effluents (Guinea et al., 2017; Yaghmour et al., 2022). Another not insignificant aspect of marine pollution is plastic waste from abandoned and torn fishing nets, which also affects other marine organisms. Entanglement in fishing nets and plastic net waste of marine snakes has been reported in India (Patel et al., 2022).

CONCLUSIONS AND RECOMMENDATIONS

Scientific knowledge of marine elapids is still limited. For many species, there is a lack of data on abundance, global and regional distribution patterns, and population ecology. The use and trade as a potentially linked threat to marine elapids have received little attention so far. Therefore, various scientific and economic uncertainties persist—for example, what species are used and traded for their skins, meat, venom, and medicines. How many more species are involved in opportunistic and targeted exploitation (several marine elapids are assigned an economic value), and what are the socioeconomic drivers of this trade? Generation of scientific knowledge, such as estimates of densities and abundance, of marine elapids is challenging. However, population sizes have been estimated for *Aipysurus laevis* (0.70–0.86 individuals/m along a reef [Burns & Heatwole, 2000]) and the endemic Costa Rican *Hydrophis platurus xanthos* (76 individuals/km^2). For the latter species, the question remains whether such estimates reflect viable populations because historical data are unavailable (Bessesen et al., 2022). Nonetheless, it is a measure, and such studies must necessarily be carried out continuously in addition to adjusting existing protective measures. Such estimates will not only indicate the frequency of occurrence of certain species in time and space, but also the disturbances of specific ecosystems and climate change events.

We devised 7 recommendations for the conservation of sea snakes that are domestically utilized and involved in regional and international trade activities.

First, range states of sea snakes should consider the designation of those species and populations occurring in their territorial coastal waters as nationally protected wildlife according to current conservation status evaluations or, if exploitation is to take place nationally, authorize adapted management plans. Two species of marine elapids are protected in India (Appendix S1). All species are protected in Australia, and New Zealand lists 4 species as protected for which available data are poor. However, populations of these species (*L. colubrina*, *L. laticaudata*, *L. saintgironsi*, and *H. platurus*) are considered secure elsewhere (Hitchmough et al., 2016). Heatwole (1997) advocates a management policy for sea snakes that is highly tailored to the species and level of threat (e.g., different, set closed periods for pregnant females throughout the year in which the species-specific reproductive periods are considered or establishment of quotas that are species specific in different seasons) and that recommends complete protection for some species.

Second, we recommend identification of exploited species. With established management of potentially nationally protected species or species regulated for international trade, such identification is crucial, especially if the corpses of species consumed and thus species-specific morphological characteristics (color pattern and scalation data) are absent. A DNA forensics approach can be used to assess legal harvest and inform improvement of trade management schemes (Suntrarachun et al., 2018). Protecting national wildlife in particular should include species and populations that represent monophyletic groups geographically confined to specific regions (i.e., *H. cyanocinctus*), which would help protect evolutionarily significant units (Ukuwela et al., 2022).

Third, we recommend regular updates of IUCN Red List assessments of marine elapids. For several marine elapids that have been evaluated by IUCN, it is noted that some species "may occur in marine protected areas." However, key knowledge gaps need to be filled before one can be reassured by this (e.g., the connectivity of populations across protected areas is unknown, as are fishing grounds and threatened habitats). Asian countries are particularly prone to high levels of IUU fishing, which makes the exact harvest of sea snakes difficult to quantify (Fujii et al., 2021). There is the need to strengthen monitoring, control, and surveillance (MCS) efforts at national and regional levels to promote sustainable fisheries, and monitoring of threatened marine taxa, including sea snakes, should be taken up to better understand the sustainability of these harvests.

Fourth, in the short term, we recommend listing of species in CITES Appendix II to generate transparency in offtakes, countries involved, and so forth, as well as analyses of the impact their use and trade may have (e.g., for *H.* [*L.*] *curtus*). Indispensable for a CITES listing would be nondetriment findings (conducted by varying stakeholders) that include information on population trends, which establish a useful framework for research and management.

Fifth, analyses of CITES trade data should be taken up by the CITES Standing Committee. Such analyses remain problematic unless documentation is improved and standardized. For example, the transmission of the number of individuals of a species, be it as a weight measure or square meter of skin, should be standardized. Data that reflect the number of individuals are elemental to proper management, not only internationally, but also at local and regional levels.

Sixth, we recommend that responsible authorities monitor and manage regional populations. In line with such established management schemes, the identification of core distribution regions of species utilized is crucial to allocate national responsibilities to sustainably protect marine elapid populations (Kukkula et al., 2019). Additional management strategies proposed to sustain populations of marine elapids affected by the fisheries industry imply the evaluation of specific harvest methods (e.g., mesh size of nets) to prevent demographic changes and reduce mortality rates (Tambre et al., 2020).

Seventh, aside from the development of regional environmental awareness campaigns at selected coastal fisheries locations, the compilation of a sea snake color identification guide (see "REVIEW RATIONALE"), a recommendation of 61st meeting of the CITES Standing Committee (15–19 August 2011), is recommended for predominantly authorities to be able to identify and distinguish between look-alike species and to analyze and regulate the exploitation. In 2001, a key was designed on for the UN Food and Agriculture Organization for, at that time, currently known genera (Rasmussen, 2001). This key version could be updated and incorporated as an appendix to the guide.

The variety of threats affecting marine elapids cannot be halted, or even suspended, soon, and it remains a political exercise and challenge to impose constraints on regional fishing industries to minimize the current bycatch of marine elapids. Despite the knowledge of the many uncertainties, the recommendation alone to initially fill research gaps and only then successively implement conservation measures based on the newly gained knowledge is time consuming and will not stop the perceived decline of some populations. We therefore propose that the precautionary principle be applied to regulate the use and trade of selected species to generate transparency of the species and quantities utilized and traded. In parallel, interdisciplinary field research should be aligned with research priorities, for example, to fill knowledge gaps, in close cooperation with regional scientific institutions, regarding the morphology and reproductive status of exploited species and their harvest regions, annual harvest rates, trade patterns, and dynamics.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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