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Sea snakes

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12.1 Introduction

Tropical reptiles have been less intensively studied than temperate species, and marine organisms are less accessible to observation than terrestrial species. Consequently, relatively few field studies have been performed on sea snakes, especially regarding their ecology and natural history. During the last century, pioneer researchers laid the basic foundation for current knowledge (e.g. Dunson, 1975; Heatwole, 1999), and several long-term field studies have provided additional data (Burns and Heatwole, 2000; Guinea, 2006, 2007; Lukoschek et al., 2007; Bonnet, 2012; Goiran and Shine, 2013; Sanders et al., 2013a, 2013b). Although fragmented, sufficient information is available to examine the applicability of the techniques developed for terrestrial species to sea snakes. The marine environment imposes strong constraints to observers and equipment, whereas adaptations to marine life deeply modified life-history traits of sea snakes. As a result, studying sea snakes requires specific techniques.

We first present information on how to locate and observe sea snakes and how to collect morphological data, and then progressively shift towards a description of more demanding techniques. Many sea snakes are fragile when handled, especially when they are pulled out of the water. Sea snakes are also potentially dangerous, although most species are docile unless seized. Several species are reluctant to bite, whereas some others may bite when threatened. Sea snakes are relatively slow-moving and possess short fangs, but the inherent dangers associated with working with these snakes should not be underestimated (e.g. minor incidents can be complicated during scuba diving). Dusky Sea Snakes (*Aipysurus fuscus*) retaliate vigorously during capture and can chase an observer (Arne R. Rasmussen, personal observation); *Aipysurus laevis* males become aggressive towards humans during the mating season. Many *Hydrophis* species bite defensively when handled, especially when manipulated out of water. In contrast, sea kraits (*Laticauda* spp.) are remarkably tame and reluctant to bite. Nonetheless, some individuals might bite and cause moderate symptoms of envenomation (e.g. eyelid ptosis, stiffness). Thus, caution is required for almost all species of sea snakes, turtle head sea snakes (*Emydocephalus* spp.) being the only harmless species. Simple precautions (e.g. wearing a swimming suit and thick neoprene gloves) usually are sufficient to limit the risk of envenomation. Overall, an important issue when studying sea snakes is to not harm the snakes. This chapter focuses on practical field issues; therefore, much

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essential information regarding taxonomy or general biology is omitted. Unfortunately, scientific references are often not available.

12.2 Locating, catching, and identifying sea snakes

12.2.1 Locating and catching snakes

For inventories, presence/absence information is usually sufficient. At a broad geographic scale, environmental DNA bar-coding is very efficient (Bohmann et al., 2014). However, a DNA-library and important logistics are required (Cristescu, 2014). Rapid developments considerably relax these constraints, and environmental DNA sampling may soon be the key method. Anecdotal observations are subject to errors of identification, especially when performed under water, during skin sloughing or pre-sloughing phases, or in melanistic individuals. Photographs and videos should be examined by people who are well trained in snake identification (Brischoux et al., 2013).

For population studies, capturing individuals is necessary. We first present information regarding amphibious sea snakes on land, followed by a consideration of amphibious and truly marine sea snakes at sea.

12.2.2 Amphibious sea snakes on land

Sea kraits (*Laticauda* spp.) return periodically to land, notably to lay their eggs. All species can be observed on the shore, although the most terrestrial species (*Laticauda colubrina* complex; Heatwole et al., 2005) are the easiest to detect. They rarely venture far inland, but some species are excellent climbers and can be found on the tops of cliffs. Sea kraits select the easiest way to travel between the sea and their terrestrial refuges; they prefer downwind shores, sheltered harbours, and rocky jetties (see Liu et al., 2012). These sites should be surveyed carefully. Lifting leaves (e.g. palm fronds), logs, beach rocks, or artificial refuges, and exploring cavities and crevices are often fruitful (Bonnet et al., 2009). Beach rocks must be manipulated with caution to not harm animals underneath (e.g. snakes, snails), and must be replaced carefully.

During hot weather, sea kraits remain sheltered. Detectability increases in winter or under cool conditions when snakes bask in the sun. Rainfall after drought allows finding many individuals and offers an opportunity to assess population structure; natural and artificial sources of freshwater are attractive (Lillywhite et al., 2008). Males are more visible during the mating season (late spring, early summer). Sea kraits travel between land and ocean from early dusk to the first hours of full night; dawn is also favourable. To a lesser extent, the tide can be important because snakes tend to avoid crossing large open areas on land; thus, fewer sea kraits are visible during low tides. Sand tracks can remain visible for prolonged periods, are easily identified, and represent an excellent clue as to the presence of snakes. Sloughed skins can be found under beach rocks, in logs and crevices, and within thick herbaceous layers of vegetation. Capturing sea kraits by hand is generally easy, both on land and at sea. It is recommended to gently grab individuals around mid-body and to maintain them horizontally; indeed, strong escape attempts are triggered when the snakes are sized and lifted by the tip of the tail. Using two hands provides a better support of the snake, and thus permits a smoother capture.

12.2.3 Sea snakes at sea

Snakes regularly surface to breathe and can be observed from a boat. In coral reefs and lagoons, snakes can be located by navigating slowly (~4 knots) along transects using small boats, preferably avoiding windy conditions. Most species can be identified at depths up to 3 m in clear water. At low tide, surveys can be performed by walking on the reef flats along transects, notably to search for individuals resting under coral or rocky structures (e.g. *Aipysurus* spp., *Hydrophis (Astrotia) stokesii*). It is important to not disturb fragile ecosystems and to not destroy living corals; inspection of reef flats is thus not always possible.

Manta board surveys, a standard tool of the Australian Institute of Marine Science, are often used to assess snake abundance (Michael Guinea, Arne R. Rasmussen, personal observations). The board is attached with a 25–30 m rope to the stern of a boat, and the observer is dragged at 2–3 knots to look for sea snakes through a mask, usually during 15–30 minute sessions. The trip is recorded with a GPS, and the perpendicular distance of the animal from the transect line is estimated to calculate densities. The observer's identity, time, sea snake species, and other information (e.g. age, condition) should be noted. Video recordings can be used to improve a record's accuracy. For security, one assistant must continuously monitor the observer(s), and hand signals should be used in accordance with international diving rules. Two parallel manta boards can be used to improve survey efficiency and to estimate the heterogeneity of the data associated with each observer. Manta board surveys are very efficient in shallow waters (~10 m depth) during the day and at low tide. This technique also permits collecting sea snakes; the observer indicates to the assistant when to release the board in order to capture the snakes with a net.

Hydrophis (Pelamis) platurus is an exception among sea snakes, insofar as it is the only pelagic species. It ranges from the coastal waters of eastern Africa along the southern Asian coasts to Japan, southward and eastward to Australia and islands of the western Pacific, and eastward to the Americas. This species is found in tight association with oceanic slicks (Dunson and Ehlert, 1971), which are smooth glassy streaks forming drift lines in the ocean while accumulating foam, floating parts of plants, and other debris. Slicks are typically small, ephemeral, mobile oceanic structures resulting from Langmuir circulations, internal waves or convergent currents. Locating slicks and snakes requires experienced skippers. Slicks containing a high density of debris, high solar irradiance, and searched in the early morning (06:00–11:00 h) offer better conditions (Brischoux and Lillywhite, 2011). Captures are relatively easy with a scooping net, but great care is required; the circulatory system of sea snakes is not adapted to handle gradients of gravitational (or hydrostatic) pressure when held vertically outside of water (Lillywhite, 2014). In addition, *H. platurus* can readily bite.

Some species can be easily located during snorkelling, for example, *Emydocephalus* snakes foraging intensively in the shallow reefs near the shore in search of fish eggs deposited on rocky substrates. Other species tend to dive at greater depths (Cook and Brischoux, 2014; Cook et al., 2015). *Hydrophis (Acalyptophis) peronii*, for example, often forages on soft bottoms between 10 and 20 m depth, and surveys for them generally require scuba diving. Sea snakes are more easily located when they forage during the day. In general, most species can be approached by divers without exhibiting signs of disturbance. Some individuals are curious and approach divers, whereas others slowly move away, yet rapidly escape during capture attempts. Sea snakes have been regularly pictured or filmed when hunting. Continuous records during several hours suggest that sea kraits tend to ignore the observer (Xavier Bonnet, personal observation). This tolerance during long sessions of close observation is far greater compared to most terrestrial species, facilitating behavioural projects under natural conditions. Monitoring, photographing, and videotaping sea snakes are relatively simple in shallow waters (5–20 m). Unfortunately, observations become far more complicated in deep waters (40–100 m) and as a consequence records by divers can be anecdotal. On average, sea snakes are not easy to spot under water at night, even using powerful lights and selecting appropriate timing.

Snakes swimming at the surface can be captured using a dip net (Lillywhite et al., 2015). This technique is particularly successful at night when snakes remain relatively motionless (Arne R. Rasmussen, personal observation). Swimming snakes can be captured using a cylindrical net 300–400 mm diameter, 1 m long, with 10 mm mesh. If researchers wear neoprene gloves and a swimming suit, snakes can be gently grasped behind the head and the mid-body simultaneously. After capture, snakes are stressed; they try to escape and they require frequent breaths. During prolonged dives (>15 minutes), calico bags can be partly filled with air bubbles (e.g. blowing air into the bag), thus avoiding the risk of drowning snakes (Xavier Bonnet, personal observation); nets should not be used in such cases. After capture, snakes must be kept in appropriate conditions on board or in captivity. During transport or short-term captivity, sea kraits can be kept in calico bags or nets placed in shaded, moist, and ventilated places. Water can be poured on the snakes. Out of water, net-bags or dry calico bags must be employed because snakes can suffocate in wet bags (high moisture makes the fabrics airproof). Truly marine snakes must be kept in sea water but they must not be crowded inside plastic holding barrels. The snakes tend to wrap around each other, and this creates pressure on the snakes' bodies and prevents voluntary surfacing for air breathing. Plastic holding barrels can be provided with pieces of dead coral or other objects on which snakes can anchor themselves (Harvey Lillywhite, personal communication). Temperature must be maintained below 30°C, preferably around 20–25°C.

Dead snakes should be collected, frozen, or photographed. At some localities, very large numbers of snakes are accidentally or voluntarily collected. Agreements with fishermen enable researchers to gather important information, yet it is important to not support snake harvesting that can be highly destructive (Van Cao et al., 2014).

12.3 Identifying sea snakes

Several genera and species are relatively easy to identify using appropriate guides. Note that many snakes pictured on the internet are not correctly identified, and reference books should be preferably used. We point out several additional difficulties in Section 12.4. Identifying sea snakes to species is not always an easy task (Shine et al., 2002); the genus *Hydrophis* shows particularly great interspecific and intraspecific variation (Sanders et al., 2013b). External characters are crucial, although internal characters are sometimes important. Many species can be identified using a combination of head shields, counts of scale rows around the neck and the body, and the number of ventral scales (multiple counts are required to obtain mean, minimum, and maximum values; Smith, 1926). The shape and size of the head, position of the maxillary bone, number of maxillary teeth, and the colour pattern are useful, but not easy to collect in living specimens. To examine maxillary teeth, a small rod is used to open the mouth of the snake and to gently push impression material (e.g. clay) upwards to a level above the maxillary bone. Two rods can be used to keep the impression material in the desired position against the roof of the mouth. Imprinted marks of the dentition can then be examined. In the genus *Hydrophis,* it is sometime necessary to use additional characters: e.g. vertebral counts (using radiography) of the body and of the tail (from the first pair of forked ribs in the cloacal region). In general, the colour pattern should be recorded, including the number of bands on the body and on the tail.

12.4 Measuring and describing sea snakes

Body size and sex represent important information to collect; other morphological traits are usually less important. Body size is difficult to measure in snakes. Snout–vent length (SVL) and total length (TL) are generally recorded by a single person by gently stretching the snake on a flexible ruler (Figure 12.1). This measurement requires training to avoid overstretching (revealed by vertebrae creaking), to limit the influence of contraction, and thus to get the measurement exactly when the snake relaxes between contractions. Long individuals (>1 m) can be measured in two steps (e.g. anterior and posterior parts). Repeated measurements are required to determine imprecision and observer variation. Photographing a snake while it rests on a substrate next to a metric ruler is a simple and safe alternative method (Harvey Lillywhite, personal communication). Subsequently, precise measurements of length can be obtained using computer programs that scale the length of the snake with the ruler for calibration (e.g. ImageJ; http://imagej.nih.gov/ij/features.html). Measurements of body mass simply require an appropriate device (e.g. ±1.0 g or ±0.1 g electronic spring). However, palpation is important to take into account clutch or litter mass and food items in addition to the actual body mass of the snake. Palpation often permits estimating clutch or litter mass and allows determination of whether prey were ingested head or tail first. Palpation must be quick and gentle and thus requires some training.

Hemipenes are well developed in male sea snakes. Examining the shape of the tail is often sufficient to determine the sex of individuals, although a close comparison of the tail of a female and a male is necessary to appreciate sexual dimorphism. Males have longer and wider tails, and, ventrally, the medium part of the tail is markedly wider in males. In juveniles or in problematic cases, the hemipenes can be everted through a quick manual squeezing of the back portion of the tail, thereby pushing out the hemipenes towards the cloaca (Figure 12.1). The use of probes to determine sex is possible but delicate in sea snakes because openings (cloaca, nostrils, hemipenis orifices) are partly obstructed by twisted valves.

Figure 12.1 Illustration of several field techniques used in sea kraits: (a) measuring snout–vent length (SVL); (b) taking marginal parts of scales; (c) hemipenis eversion; (d) measuring jaw length.

Head dimensions are important traits. Jaw length, from the quadrato-articular joint to the tip of the snout, can be measured with a calliper. The flat part of the external jaws of the calliper preferably is used. It is important to take measurements when the jaws of the calliper touch the joint and the tip of the snout (Figure 12.1).

Many sea snakes exhibit banded patterns with dark bands or rings, i.e. dorsal bands or complete rings depending upon the species or individual (Shine et al., 2010). The number of rings on the body (head included) and on the tail can be counted. These counts can help to determine the sex of individuals (females tend to have more rings on the body and fewer on the tail). Colour background, unusual patterns (e.g. divided rings), injuries, and scars (shape, colour, location) are important traits (e.g. skin rugosity that often varies with sex and with season; Avolio et al., 2006) that enhance the description of individuals and are useful for recognizing recaptures.

As with many living and inert objects, sea snakes are subjected to epibiosis. The description and quantification of external epibionts and parasites (e.g. ticks in sea kraits) can provide useful information (Pfaller et al., 2012).

12.5 Photographing sea snakes

Technical aspects of photographing marine animals are available in specialized books and magazines. This section focuses on subjects. Both terrestrial and marine habitats where the snakes are observed are important to photograph. A comprehensive description of the habitats and microhabitats used by the different snake species, different age classes, and seasonal variation is lacking for almost all species. Photographs help to fill in this lack of information. Additional measurements should be recorded where possible—notably air, substrate, or water temperature and body temperatures as well as oxygen levels, and other parameters such as salinity and pH—that are of potentially high in value to investigate climate change scenarios.

Photographs are useful to minimize identification errors, particularly to avoid confusion between species because of colour changes under water or attributable to skin sloughing. In addition to classical photographs of the head and of the entire individual, injuries, scars, unusual patterns, and external parasites can be photographed. Regurgitated prey can often be identified with photos; however ingested items must be first cleaned with water to remove the coating resulting from ingestion. Macrophotography of the dentition of the prey (also cleaned with water) can be very useful.

12.6 Recapture studies

Gathering accurate ecological information is essential to address questions that are fundamental to ecology and conservation. Under natural conditions, there is no surrogate to mark–recapture studies. Although demanding, this is the best approach to monitor fluctuations and trends in populations, assess inter-individual variability, and to reveal unexpected and important patterns of population functioning (e.g. Voris, 1985; Bonnet et al., 2015).

12.6.1 Marking snakes

A modified version of the classical scale-clipping method works well in sea kraits. Light iron burning of the targeted scale rows (to code units, tens, hundreds) entails a permanent colour change (Bonnet, 2012; see Chapter 4). Electric or gas tools can be employed, although medical cauterizers powered by batteries must be used on small individuals (Winne et al., 2006). The tip of the iron must be hot enough to induce a fast superficial burn. When paired with a comprehensive description of individuals (sex, ring numbers, scars), this technique is very efficient. In our sea-krait studies, failure to recognize an individual at recapture remained below 0.5% on more than 15,000 individuals marked over 10 years (Bonnet, 2012). Cauterizing is cheaper and more reliable than passive integrated transponder (PIT) tags (i.e. radiofrequency identification) because this method is not subjected to tag loss and does not necessitate an electronic reader. In addition, very small snakes, including neonates, can be marked whereas pit tags are too large. However, cauterizing requires training to ensure that the snakes are not injured during marking. Further, setting up specific codes to circumvent the blurring effect of abnormal scales or injuries on those scales that must be counted represent a complication. It also takes a certain amount of time to mark each snake.

In truly marine sea snakes, scale-clipping does not work sufficiently well; the marks tend to disappear over time, and sea snakes do not tolerate prolonged handling. Therefore, PIT tags are preferred (Voris, 1985; Goiran and Shine, 2013). This method is accurate, very fast and it does not require much specialized training. In certain species, numbers can be directly 'painted' on the side of the snakes using liquid nitrogen (Heatwole, 1999). Snakes must be rapidly released at the place of capture, i.e. a few hours after capture for most species and preferably within 24 hours for sea kraits.

Capture sessions are usually organized annually. A typical annual field session should last two weeks, although one month (or more) is preferable. When several sites are surveyed, alternating between them in order to survey each site two times (or more) is profitable, especially in sea kraits. Indeed, foraging bouts, skin sloughing, or digestion that often requires more than one week may influence individual catchability and can heavily bias estimates during short field sessions. Intensive recapture studies on individuals and on populations were shown to have no noticeable impact on survival in sea kraits (Fauvel et al., 2012).

12.6.2 Organizing data

Because disturbance associated with transect surveys and recapture studies is limited and because different observers can be involved simultaneously, these approaches are compatible with repeated/multiple surveys. Repeated surveys allow researchers to take into account important sources of heterogeneity in their analyses. Matrices can be built with time sessions in columns and species or individuals in rows, thus filling cells with observation codes (e.g. 0: absence, 1: male, 2: female) and co-variables (e.g. water temperature). They open avenues for robust analyses, notably to examine important effects of time, season, year, and observer ability to spot and accurately identify species (providing that observers do not influence each other during observations). Implementing repeated surveys (e.g. weeks) within broader sessions (e.g. years) enables researchers to use robust designs to calculate various demographic parameters and abundance or richness estimates, or to perform site occupancy analyses (MacKenzie et al., 2003; Chapter 26). Species richness, abundance, survival, and population trends, for example, can be estimated accurately (Chapters 21 and 27). Overall, mark recapture studies should be encouraged in sea snakes.

12.7 Blood and other tissue sampling

Blood is one of the main connective tissues of an animal and is conveniently studied. Many assays can be performed to address various biological and conservation questions, notably following centrifugation to separate plasma from cell platelets. Withdrawing blood from the heart (cardiocentesis) of snakes is an acceptable and usually satisfactory method of collecting blood, but cardiac blood withdrawal can be more delicate to perform in sea snakes compared to terrestrial species. The laterally flattened body shape of truly marine snakes poses difficulties, and thus training is required. The heart is often easily located via gentle palpation. The difficulty is to target the tip of the cardiac ventricle without harming delicate tissues situated just anterior. Using very small needles is important (27 G–30 G), connected to a 1 ml syringe. Very small amounts of heparin are required and the tip of the needle must remain sharp (e.g. not passed through the rubber lid of a vial). In adults (body mass >150 g), 200 μl to 1 ml of blood can be taken. This quantity must be adjusted in smaller individuals (~100 μl/100 g of body mass when body mass <150 g). We never attempted to take blood from neonates or very small individuals (<50 g). Sinuses and lymphatic vessels (e.g. sometimes impaled during tail puncture) should be avoided as they deliver unknown proportions of blood mixed with lymph that can influence assays.

For eco-physiological investigations, centrifuging the blood immediately in the field is preferable (using a battery powered centrifuge). The plasma can be stored in liquid nitrogen (cryotubes are required) or frozen at –25°C, especially to assay hormones, metabolites, and organic contaminants. Cell platelets can be frozen and/or preserved in alcohol for genetic analyses or to assay stable isotopes and trace metals. A blood volume of 100 µl is sufficient for many analyses (e.g. several steroids, genetic material, and stable isotopes) and 1 ml is sufficient for almost all routine analyses (e.g. including trace metals, various metabolites, and organic contaminants). For RNA preservation, as for other elements that degrade rapidly (e.g. enzymes), immediate preservation of tissues in liquid nitrogen or RNAlater can be critical.

For DNA, isotope, and several trace metal analyses, the tip of scales can be collected (notably when marking snakes; Figure 12.1) and stored in alcohol within screw-cap vials. Sloughed skins that offer larger amounts of material should be collected opportunistically.

Stomach contents obtained from spontaneous or forced regurgitation must be weighed, identified (photographed) and stored in alcohol for DNA, trace metal and stable isotope analyses, or preferably frozen. Similarly, ticks and other parasites can be collected and preserved in alcohol.

Snakes found freshly dead offer excellent opportunities to obtain different tissues in relatively large quantities and for donations to local museums. Individuals can be dissected, and all the organs and gut contents can be carefully measured, weighed, and examined. If only a few tissues can be obtained, fat bodies and liver should be collected and frozen in priority because these organs accumulate contaminants and provide important ecological indexes (e.g. fat content and/or liver mass correlate with body condition). Muscles, skin, and gonads also are important to collect and freeze. Drying whole specimens or tissues represents an alternative that should be preferred over formalin. Formalin hampers eco-toxicological and genetic investigations, is carcinogenic, and is difficult to transport. For museum collections, formalin offers important benefits, such as better long-term storage, more natural looking specimens, ability to study gut contents, and morphometrics. A simple solution is to take tissue samples of the specimen for eco-toxicological and genetic studies and then fix the specimen in formalin.

12.8 Bio-logging

Current knowledge about diving, displacement, or home range is extremely meagre in sea snakes (e.g. Burns and Heatwole, 1998). Bio-logging is appropriate to monitor free-ranging individuals (Cook et al., 2015). However, the flexible morphology and small body size of sea snakes usually preclude using external devices (but see Rubinoff et al., 1986, 1988). Nonetheless, externally attached loggers can be used in controlled conditions (Brischoux et al., 2010). Sea snakes display remarkable capacities to recover from wounds (e.g. caused by aggressive prey) and from surgery; therefore, implantation of internal devices is possible. Anaesthesia and tolerance to implanted devices must be carefully considered, and our field experience has revealed unexplained differences (i.e. recovery from anaesthesia) between closely related species (e.g. *L. colubrina* vs. *L. saintgironsi*). Despite similar dosages, intra-peritoneal injections (e.g. ketamine) or inhalation (e.g. isoflurane) were either successful (i.e. rapid anaesthesia and rapid recovery) or posed major complications (prolonged recovery requiring breathing assistance, or sometimes death). We also observed that combining local analgesics (e.g. lidocaine) and anaesthesia delayed recovery. Truly marine sea snakes are generally more fragile than sea kraits, but information regarding anaesthesia, surgery, and bio-logging is fragmentary. Overall, bio-logging methodology for sea snakes is in its very early stages of development. Consequently, we strongly suggest adopting a practical step-by-step approach to select the best method, e.g. by gradually increasing minimal dosage of a drug. Miniaturization now makes bio-logging investigation possible with limited perturbation, although sea snakes appear to be more sensitive to the presence of internal devices compared to their terrestrial relatives. We further suggest using the smallest devices available, to avoid attachment to the ribs, and not to combine devices. For instance, implanting depth time recorders but not transmitters is recommended, even in individuals weighing more than 300 g when the total load of both devices may remain below 15 g. Indeed, transmitters have a long and problematic antenna that must be inserted below the fragile skin of sea snakes (since skin contributes to respiration). Selecting a study system where recapture probabilities are elevated to offset the lack of transmitters is important. Further technical improvements (e.g. shape of devices, coating material) would be welcome for sea snakes.

12.9 Captivity

Sea kraits are relatively robust compared to other sea snakes. They accept various prey (e.g. freshwater eels) and they can be maintained in both marine and fresh water tanks. Emergent shelters and freshwater bowls must be provided. Other species are less tolerant to captivity; *Emydocephalus* are particularly fragile and unexplained mortality has been observed during brief captivity episodes (only a few hours). Captivity should be limited to short-term experiments (hours, days) to record locomotor, physiological, and behavioural traits, for example, and should be performed with great care in the most sensitive species. Our limited experience suggests that few aquariums display sea snakes, individuals are not often fed, and they are regularly replaced. However, encouraging exceptions exist. For example, olive sea snakes have been maintained and fed in the Reef HQ Aquarium of Townsville (Australia). It is noteworthy that both sea kraits and sea snakes require regular access to freshwater to survive (Lillywhite et al., 2008, 2015). In general, improvements are required to study and breed sea snakes in captivity, particularly for threatened species, and not simply to maintain individuals alive.

12.10 Conclusions

The ecology and general biology of sea snakes are insufficiently documented, although appropriate study techniques are now available for most species. Because scientific curiosity and knowledge represent the foundation for education and conservation, investigations are urgently needed to improve our information about their distribution and population status, to address fundamental scientific questions, and eventually to implement conservation and management programmes. In the following paragraphs, we list several suggestions to focus practical action.

In addition to the widespread pelagic *Hydrophis (Pelamis) platurus*, several sea snake species have a broad distribution in both the Indian and Pacific Oceans and were/are locally abundant, e.g. *Hydrophis (Lapemis) curtus, H. cyanocinctus, H. ornatus, H. (Acalyptophis) peronii, H. (Astrotia) stokesii, Laticauda colubrina* complex, and *L. laticaudata*. Investigations concerning geographic variation and connectivity across populations would likely be profitable. Other species have been collected in restricted areas and might well be vulnerable. Only five *Hydrophis parviceps* have been observed in a small area in the southern part of Vietnamese waters of the South China Sea (Rasmussen et al., 2012). The recently described species *Hydrophis sibauensis* is known only from three individuals collected more than 1000 km upstream in rivers of Borneo. Two individuals of *Hydrophis laboutei* were collected in the Chesterfield Reefs in New Caledonia. Other examples of species with a limited distribution are *Aipysurus apraefrontalis, A. foliosquama*, and *A. fuscus* from Western Australia. *Hydrophis semperi* occurs only in Lake Taal in the Philippines, and *Laticauda crockeri* occurs only in Lake Te-Nggano, Rennell Island. In these species, both field population studies and captive breeding programmes are needed.

For almost a century, intensive commercial exploitation of skin, various organs, blood, and meat severely impacted sea snakes in the Philippines, Indonesia, Japan, Taiwan, Thailand, and Vietnam, as well as in Australia, New Caledonia, and China. This includes unjustified massive killing for venom research, where thousands of individuals were decapitated, although alternatives already existed (e.g. Tu, 1976). Several species (e.g. *Laticauda* spp. and some *Hydrophis* spp.) have been exploited to the point of pushing populations to extinction. Vietnamese squid fishers currently take more than 220,000 sea snakes annually from the Gulf of Thailand (Van Cao et al., 2014). Large numbers of other species are likely taken by fisheries. Unfortunately, sea snakes are not protected by CITES and only rarely by national law or regulation. For example, in New Caledonia none of the 14–15 sea snake species is protected. In a few instances, local protection of sea snakes has avoided extinction, e.g. in the Philippines where a catastrophic decline of *Laticauda* species occurred in the 1970s. Populations never recovered, however, likely because a minimum population threshold was exceeded from which the population cannot recover. Over large geographic areas, dramatic declines over the last 10–15 years remain unexplained (e.g. Ashmore Reef; data collected by Mick Guinea; Lukoschek et al., 2013), although habitat destruction (e.g. coral bleaching) may be the main cause. Changing rainfall patterns associated with global climate change may also be an important factor (Brischoux et al., 2012; Lillywhite et al., 2014). Overall, many species previously abundant and/or with previously dense populations are now relictual (e.g. *Hydrophis torquatus* and *H. klossi*) or locally extinct (e.g. *Aipysurus apraefrontalis* and *A. foliosquama* in Ashmore Reef). Fishermen mention that the mean size of harvested sea snakes has decreased over time (Van Cao et al., 2014). Specific effort is thus needed to improve the worldwide protection of all sea snakes.

To protect sea snakes and to determine sustainable harvest levels, scientific information is required. Foraging and breeding areas for most species of sea snakes are unknown; thus, the impact of habitat destruction (e.g. mangrove clearings) or oil exploration (e.g. sonar blasting) has not been evaluated yet. Future studies should focus on breeding cycles, mortality associated with fisheries, population abundance, sexual maturity, taxonomy, and diet, especially in Asia (Voris, 2015).

Finally, sea snakes are useful bio-indicators to monitor the health status of coral reefs (Reed et al., 2002; Brischoux et al., 2009). Catching and measuring approximately 30 individuals per year in a given site is sufficient for a broad monitoring programme over time and for site comparisons (e.g. polluted versus non-polluted areas). In addition, prey, blood, sloughed skin, and dead individuals offer excellent opportunities for contaminant investigation (Bonnet et al., 2014).

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