Department of Employment, Economic Development and Innovation

Reducing the impact of Queensland's trawl fisheries on protected sea snakes

FRDC Project No. 2005/053

AJ Courtney, BL Schemel, R Wallace, MJ Campbell, DG Mayer and B Young[1]

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Toward Q2 Tomorrow's Queensland

Queensland Government

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Report to the Fisheries Research and Development Corporation
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This research report quantifies the incidental catch and fishing mortality of sea snakes in the Queensland East Coast Trawl Fishery. It also identifies bycatch reduction devices that significantly reduce snake catch rates and puts forward recommendations for mitigating the impact of trawling on snake populations. The study addressed a recommendation from the Commonwealth Department of the Environment, Water, Heritage and the Arts under the *Environment Protection and Biodiversity Conservation Act 1999* to the Queensland Government concerning the impact of trawling on sea snakes which are protected species under Australian Commonwealth and state laws.

Disclaimer

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List of acronyms

AFMA	Australian Fisheries Management Authority
BRD	Bycatch reduction device
BACI	Before-After-Control-Impact
CFISH	The Queensland commercial fishery logbook database
CI	Confidence interval
CMP	Crew-member program
CL	Carapace length
CSIRO	Commonwealth Scientific Industrial Research Organisation
CW	Carapace width
DEWHA	Department of the Environment, Water, Heritage and the Arts
DR	Deviance ratio
DERM	Department of Environment and Resource Management
DEEDI	Department of Employment, Economic Development and Innovation
EPBC Act	Environment Protection and Biodiversity Conservation Act
FRDC	Fisheries Research and Development Corporation
GBRMPA	Great Barrier Reef Marine Park Authority
GBRMP	Great Barrier Reef Marine Park
GBR	Great Barrier Reef
GOC	Gulf of Carpentaria
GLM	Generalised linear model
GPS	Global positioning system
IUCN	International Union for the Conservation of Nature
NPF	Northern Prawn Fishery
QFIRAC	Queensland Fishing Industry Research Advisory Committee
RAP	Representative Areas Program
SOCI	Species of Conservation Interest
s.e.	standard error
TED	Turtle excluder device
TrawlMAC	Trawl management advisory committee
UTAS	University of Tasmania
VR	Variance ratio

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1 Objectives

1) Collate and review existing data and literature on sea snake distribution and abundance on Queensland's east coast. This will enhance the detail and precision of the commercial fisheries (CFISH) logbook data program on species of conservation interest (SOCI).

2) Implement a crew-based data collection program to quantify information on sea snake catch rates, species composition and distribution. Where possible, consider areas that are closed and open to trawling (contingent upon Great Barrier Reef Marine Park Authority [GBRMPA] approval to sample closed areas).

3) Quantify post-trawling mortality rates of sea snakes by undertaking survival experiments at sea on commercial vessels.

4) Test effectiveness of bycatch reduction devices (BRDs), including square mesh panels, on sea snake catch rates and promote the uptake of effective devices by industry.

2 Non-technical summary

Outcomes achieved to date

- This project quantified the species composition, catch rates and mortality rates of sea snakes caught incidentally in the Queensland otter and beam trawl fishery. We estimated that 105 210 (s.e. 18 288) sea snakes, composed of 12 species, were caught in the fishery annually. Of these, 27 272 (25.9%) died as a result of capture, either immediately upon being caught or in the hours and days after being released back into the water.
- The redspot king prawn (*Melicertus longistylus*) fishery accounted for 58.9% of all sea snake catches and 84.5% of all deaths. The high catch rate of snakes in this sector was likely due to the spatial overlap of habitats between reef-associated sea snakes and redspot king prawns, which are also reef-associated. The high mortality rate was thought to be due to the bulky, venomous and spiky nature of the bycatch in this sector, which imposes relatively high levels of crushing and injury to sea snakes.
- The project tested different BRDs during a research charter and found that the fisheye BRD reduced the sea snake catch rate by 63% compared to a control net with no BRD, with no reduction in the catch rate of marketable prawns. Square mesh codends also showed potential for reducing snake catch rates, but their effectiveness is likely to be limited by the maximum size of the square meshes. We recommend that the fisheye BRD be made mandatory in the Queensland trawl fishery where the incidental catch and mortality of sea snakes is high, particularly the redspot king prawn fishery. The effectiveness of BRDs diminishes as they are installed further away from the codend drawstring, and for this reason we recommend that the fisheye BRD is installed no more than 50 meshes from the drawstring.
- The project results were disseminated to Queensland trawler operators, Fisheries Queensland (part of the Department of Employment, Economic Development and Innovation) managers and other stakeholders via presentations, publications in industry magazines, discussion, newsletters, steering committee meetings and web pages. We also worked directly with a small group of trawl fishers from Townsville to quantify their BRD effects on sea snake catches and promote uptake of the fisheye BRD. Further extension and enforcement are required to ensure that fisheye BRDs are used effectively in areas associated with high sea snake mortality, and to improve the effectiveness of BRDs in general in the fishery.
- Our results indicate that the data provided by fishers in the SOCI logbook, which is administered by Fisheries Queensland, significantly under estimates the incidental catch and mortality of sea snakes imposed by trawling in Queensland. We suggest that Fisheries Queensland review the SOCI logbook and the data, and we discuss how monitoring interactions between trawlers and protected species could be improved.

Sea snakes are protected species under Australian Commonwealth and state laws. They are ‘listed marine species’ under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) and protected under the *Great Barrier Reef Marine Park Act 1975* and the Queensland *Nature Conservation Act*

1992. At the time of writing, the status of sea snakes was also being reviewed under the International Union for the Conservation of Nature (IUCN) Red List.

Despite their protected status, observations by researchers and fishery observers in Queensland, and peer-reviewed research on Australia's Northern Prawn Fishery (NPF), strongly suggest that several thousand sea snakes are likely to be caught and killed incidentally in Queensland's East Coast Trawl Fishery each year.

Fisheries Queensland monitors interactions between commercial fishers and protected species through the mandatory Species of Conservation Interest (SOCI) logbook, introduced in 2003, but analysis of these data indicate that fishers under report the catch and mortality of sea snakes by a factor of 30-40 times. If interactions between commercial fishers and sea snakes are to be effectively monitored and assessed, additional measures are required.

This research project established a voluntary crew member program (CMP) to provide detailed information on the sea snake species catch composition, catch rates and estimates of the within-trawl mortality rate of snakes. Sixty-seven crews participated in the program between July 2005 and October 2007. Data were collected from all of the major east coast trawl fishing sectors; the shallow and deepwater eastern king prawn, scallop, banana prawn, redspot king prawn, North Queensland tiger/endeavour prawn, Moreton Bay, black tiger prawn broodstock collection, beam trawl and stout whiting finfish trawl fisheries. Additional data were obtained from research charters, research surveys and the fishery observer program. Detailed information was collected from a total of 8289 trawls that reported catching 3910 sea snakes.

Participating crews were provided with digital cameras and asked to photograph every snake they encountered. Twelve sea snake species were identified from the images. The most commonly encountered was the spine-bellied sea snake *Lapemis curtus*, followed by the olive sea snake *Aipysurus laevis* and the reef shallows sea snake *Aipysurus duboisii*, which collectively made up about 60% of all snakes caught. The remaining species, in decreasing abundance, were the horned sea snake *Acalyptophis peronii*, the elegant sea snake *Hydrophis elegans*, the small-headed sea snake *Hydrophis mcdowelli*, the stagger-banded sea snake *Aipysurus eydouxii*, the ornate sea snake *Hydrophis ornatus*, the beaked sea snake *Enhydrina schistosa*, the olive-headed snake *Disteira major*, the spectacled sea snake *Disteira kingii* and Stoke's sea snake *Astrotia stokesii*.

Project staff also participated in trawl fishing trips with five commercial fishers and one research charter to observe snakes in water-filled containers after they were trawl-caught in order to quantify their post-trawl mortality rates. A total of 206 snakes were held in the containers for a minimum of 96 hours (four days).

The sampled means were then used to extrapolate total annual catches and mortalities of sea snakes for each sector, based on average annual fishing effort obtained from compulsory fisher logbook data. The project concluded that a mean of 105 210 s.e. 18 828 sea snakes were caught annually in the fishery, with 25.9% dying while still in the nets (i.e. within trawl mortality of 8.5%) or in the hours and days immediately after trawling (i.e. post-trawl mortality rate of 17.4%). Most of the post-trawl mortalities occurred in the first 24 hours after trawling and mortality increased with snake size.

In general, trawl fishing sectors south of about 20°S (i.e. the eastern king prawn, stout whiting, beam trawl, Moreton Bay, banana prawn and scallop fisheries) imposed relatively little incidental mortality on sea snake populations, mainly because catch rates were low or survival rates were high. The redspot king prawn fishery accounted for 58.9% of all sea snake catches and 84.5% of all mortalities. The reason for this is due to the relatively high catch rate (i.e. adjusted mean of 10.23 snakes caught boat-day^{-1}) combined with a high mortality rate of 37.2% and moderately high fishing effort.

Redspot king prawns are a reef-associated species. The post-larval and juvenile prawns use reef-lagoons as nursery areas and sub-adults and adults migrate off the lagoons into deeper trawled grounds adjacent to the reef. Most of the sea snakes caught in this sector, particularly the olive sea snake (*A. laevis*) and the reef shallows sea snake (*A. duboisii*), are reef-associated species. The high snake catch rates appear to be due to overlapping habitats of the prawns and snakes. The high mortality rate of snakes in this sector may be attributed to the bulky, spiky and sometimes venomous character of the bycatch, which crushes, injures and envenomates the snakes.

The project undertook a dedicated research charter to evaluate the effects of different BRDs on sea snake, prawn and bycatch rates. The fisheye and square mesh codend BRDs reduced the catch rate of sea snakes by 63% and 60%, respectively—compared to the standard net that had no BRD—with no significant reduction in the catch rate of marketable prawns (i.e. ≥ 20 mm carapace length [CL]). These two devices also significantly lowered the catch rates of the remaining bycatch by 33% and 31%, respectively. Although there was no significant difference between them, the fisheye is likely to be more effective at excluding sea snakes because the limited size of the square meshes will almost certainly prevent large sea snakes from escaping.

Management options for reducing the impacts of fishing on sea snakes could include identifying areas associated with high incidental mortalities and closing them to trawl fishing effort. Given that a significant additional proportion of the Great Barrier Reef Marine Park (GBRMP) was closed to trawling in 2004 under the Representative Areas Program (RAP) and that this initiative resulted in a large compensation to those affected by the closures—at the time of writing the structural adjustment package approximated $216 million (Steve Jackson, Acting Director, GBRMP Structural Adjustment Package, pers. comm. Department of the Environment, Water, Heritage and the Arts, DEWHA 2010)—it seems unlikely that additional closures would be the preferred management option for sea snake bycatch mitigation by either the Commonwealth or Queensland Governments.

Regulatory measures requiring the use of highly effective BRDs appear to be one of the few practical measures for mitigation. As a comparatively low-cost but effective mitigation measure, we recommend that the use of the fisheye BRD be made mandatory in those sectors associated with high sea snake mortalities, particularly, the redspot king prawn fishery. Increasingly, research on BRDs is showing that the effectiveness of the devices diminishes with increasing distance from the codend drawstring. Frequently, in the Queensland trawl fishery and other prawn trawl fisheries, fishers install their BRDs as far forward from the drawstring as legally possible because they are concerned about adverse effects on their prawn catch rates.

The research charter was undertaken with the BRDs installed 50 meshes from the drawstring. Because it was highly effective at reducing sea snake catches—with no adverse effect on prawn catch rates—we recommend that the fisheye be installed at a distance of no more than 50 meshes from the drawstring.

Finally, observations of the BRDs (other than TEDs) used by Queensland trawler operators, the position of the devices in codends, modifications to the devices, and the way in which they are installed, suggest that a high proportion of the devices used by the fleet are largely ineffective. Further initiatives are therefore required to ensure that only highly effective BRDs are deployed and that they are installed effectively. Such initiatives might include, but are not necessarily limited to, additional support and training for the Queensland Boating and Fisheries Patrol so that officers can more-confidently identify ineffective or poorly installed devices and successfully prosecute such infringements (as a means of dissuading such practices). At present, the lack of successful prosecutions for ineffective, modified or poorly installed BRDs suggest that the Patrol have difficulty pursuing such matters through the legal system. This may be partly attributed to the technical and descriptive definitions used for BRDs.

KEYWORDS: sea snakes, *Acalyptophis peronii*, *Aipysurus duboisii*, *Aipysurus eydouxii*, *Aipysurus laevis*, *Astrotia stokesii*, *Disteira kingii*, *Disteira major*, *Enhydrina schistosa*, *Hydrophis elegans*, *Hydrophis mcdowelli*, *Hydrophis ornatus, Lapemis curtus,* trawl bycatch, prawns, redspot king prawn *Melicertus longistylus,* eastern king prawn, *Melicertus plebejus*, tiger prawns, *Penaeus esculentus*, *Metapenaeus ensis, Metapenaeus endeavouri,* saucer scallops, *Amusium balloti*, BRD, square mesh codends, fisheye BRD.

3 Background

The meshes used in the construction of prawn trawl nets are relatively small (e.g. generally smaller than 50 mm). As a result, the nets have poor selectivity—that is, many other non-targeted species, collectively referred to as bycatch, are caught and retained with the prawns. Most of these bycatch species have no commercial value and although they are returned to the water, most individuals die as a result of the experience.

In Queensland, the weight of bycatch from the trawl fishery greatly exceeds that of the targeted catch (Robins & Courtney 1998). The bycatch can include endangered or protected species (such sea turtles and sea snakes) and vulnerable species (including some shark and ray species). In Australia, sea snakes are protected under Commonwealth and state laws. The mandatory adoption of both turtle excluder devices (TEDs) and other BRDs in all otter trawl nets in Queensland since 2000 has reduced the catch rates of some species, particularly the larger fauna (such as turtles, sponges, sharks and rays).

In Queensland coastal waters, the impact of prawn trawling on sea snakes and their populations is unknown. Because the Queensland trawl fishery is large (i.e. approximately 470 licensed otter trawlers and an additional 138 licensed beam trawlers in 2007) the impacts are potentially significant. Preliminary estimates, based on bycatch observations, suggest that tens of thousands of snakes are caught by the Queensland fleet annually. Very little is known about the number of snakes that die as a result. Sea snakes are also caught incidentally in the Commonwealth NPF, particularly in the Gulf of Carpentaria (GOC)—where most of the fishing effort is distributed. Research undertaken in the NPF in the 1990s suggested that 48.5% of snakes caught in trawls died (Wassenberg et al. 2001), but the more recent work of Milton et al. (2008) indicates that survival rates have improved.

This project proposal was initially developed in collaboration with the NPF and CSIRO, as the problem of sea snake bycatch is common to both fisheries. However, after consideration, it was concluded that the needs of the NPF and Queensland east coast fisheries, and their respective management agencies, were sufficiently different to justify two separate research projects (one for the NPF and one for Queensland).

Under the Queensland *Fisheries Act 1994* trawler operators are obligated to reduce their incidental capture and mortality of sea snakes. In addition, the Commonwealth Department of the Environment, Water, Heritage and the Arts (DEWHA) has recommended to the Queensland Government that research into the impact of trawling on sea snakes be promoted, and that all reasonable steps should be undertaken to reduce interactions between protected species and the Queensland trawl fishery.

The project was developed in consultation with the Fisheries Queensland trawl manager and the Queensland Trawl Management Advisory Committee (TrawlMAC). It was also discussed with members of GBRMPA and researchers at the Reef Cooperative Research Centre, as much of the trawl fishery is located within the GBRMP. The proposal was also reviewed by members of the Queensland Fishing Industry Research Advisory Committee (QFIRAC). Fisheries Queensland was highly supportive of the proposal and provided a substantial funding contribution to the project.

4 Need

Legal obligation

In Australia, sea snakes were protected under Schedule 1 of the National Parks and Wildlife Regulation 1994 and are now listed marine species under the EPBC Act; however, despite their protected status, large numbers of snakes (i.e. probably tens of thousands) are caught incidentally in the Queensland and other northern Australian trawl fisheries each year. In the NPF it was estimated that between 81 000 and 120 000 were caught annually in the early 1990s (Ward 1996b; Wassenberg et al. 1994). Wassenberg et al. (2001) reported that 48.5% of sea snakes caught from research and commercial prawn trawling die as a result of being trawled. The Queensland Government and Queensland's commercial trawl fishers are obliged to address the problem and minimise sea snake–trawl interactions.

Recommendations by the Commonwealth Department of the Environment, Water, Heritage and the Arts (DEWHA)

The impact of prawn trawling on the sustainability of sea snake populations on the Queensland east coast is a major concern to DEWHA. In their review of the 2002 ecological assessment of the Queensland East Coast Trawl Fishery, DEWHA recommended to the Queensland Government that research into the impact of trawling on sea snakes be promoted, and that all reasonable steps should be undertaken to reduce interactions between protected species and the Queensland trawl fishery.

In summary, there is a strong need to undertake research that provides a better understanding of the impacts of trawling on sea snake populations on the Queensland east coast and investigates mitigation measures. In addition, addressing DEWHA’s recommendations will help ensure that that the Queensland East Coast Trawl Fishery remains on the list of fisheries that are accredited for export, thus ensuring the continued export of seafood caught by the fishery.

5 Objective 1. Review of the literature and data on sea snakes from the Queensland east coast

5.1 INTRODUCTION

In his foreword to *The venomous sea snakes: a comprehensive bibliography* (Culotta & Pickwell 1993), Heatwole described the task of assembling the world's literature on sea snakes as formidable and daunting to even the bravest of herpetologists. In this 503-page 1993 bibliography, about 30% of all research on sea snakes pertains to venom toxicity, biochemistry and pharmacology, while another 30% refers to distributions, collections and sightings from early voyages, taxonomy and systematics. The remaining sections cover general behaviour, ecology and adaptations, feeding, predators, parasites, reproduction and growth, and anatomy and physiology.

The main literature on sea snakes is scattered through an amazing number of journal titles and the 'grey' (i.e. not independently reviewed) literature is even more widely dispersed. In this section we review the relevant biological literature to gain a better understanding of sea snake behaviour and the likely impacts of incidental trawl capture on their population dynamics. We also collate and review the available data on sea snakes from the Queensland east coast.

5.1.1 Taxonomy and genetics

The taxonomy of sea snakes and sea kraits is still being debated. Many herpetologists believe sea snakes and sea kraits represent separate families, while others suggest they are either separate subfamilies within the closely related terrestrial Elapidae family, or grouped as a single family but in different genera (Cogger 1994; Heatwole et al. 2005; Kharin 2006; Lading et al. 1991; Masunaga & Ota 2003; Murphy et al. 1999; Scanlon & Lee 2004). It is generally considered that the sea snakes and sea kraits are members of two separate families, Hydrophiidae and Laticaudidae, respectively; however, both groups are referred to as 'marine snakes'.

Marine snakes only occur in tropical and subtropical parts of the Indian and Pacific Oceans and do not occur in the Atlantic Ocean (Dunson 1975a). They are probably the most numerous group of reptiles (Karthikeyan et al. 2008) and comprise almost 90% of extant marine reptiles. Recent reports suggest there are 53–60 species within the family Hydrophiidae and approximately five in the family Laticaudidae (Karthikeyan & Balasubramanian 2007; Karthikeyan et al. 2008; Ward 2001).

All but one hydrophiid species (the freshwater *Hydrophis semperi*) are marine. Hydrophiids spend their entire lives at sea and have evolved many characteristics for life in the ocean, while laticaudids often return to land. Laticaudids represent a classic intermediate state of evolutionary adaption to a new environment, with a combination of traits for life in water and on land (Shetty & Shine 2002b).

Both families have paddle-shaped tails, valvular nostrils—located dorsally—and lack the broad ventral scales of their terrestrial cousins (Cogger 1994; Heatwole 1999). They also differ in lung morphology from terrestrial snakes and have a specialised gland under the tongue for eliminating excess salt (Avolio et al. 2006). An interesting attribute specific to hydrophiids is rugose scales, which are exhibited by over half of the species. The function of the rugosity is unclear but Avolio et al. (2006) found that it varied between sexes and throughout the year, peaking during breeding, leading the authors to theorise it may be controlled hormonally.

Both hydrophiids and laticaudids are venomous and several species are lethal to humans. Some marine snake species are highly regarded for their venom in the creation of antivenin and use in medical research (Chetty et al. 2004). Due to this, venom toxicology is by far the most extensively studied area of sea snake biology. In contrast, the population dynamics of sea snakes and sea kraits are not as well documented.

Evolutionary relationships within and between the marine hydrophiine sea snake groups were investigated by Lukoschek and Keogh (2006) based on a mitochondrial DNA dataset. This analysis confirmed that the hyrophiine sea snakes comprise at least three lineages. The two main groups are the genus *Aipysurus* and the genus *Hydrophis*, while *Hydrelaps darwiniensis* and *Parahydrophis mertoni* comprise a third group. Genetic divergence relative to morphological diversity suggests that the genus *Hydrophis* represents rapidly diverged adaptive radiation, possibly due to sea level fluctuations isolating populations and promoting speciation. Lukoschek et al. (2007b) examined the phylogeography of the olive sea snake (*Aipysurus laevis*) in northern Australia and found that genetic diversity was low in the Great Barrier Reef (GBR) and the GOC compared to most Western Australian (WA) reefs. Phylogenetic analyses indicated that the GBR and GOC haplotypes were derived from WA haplotypes. Recent range expansion in the GBR and the GOC probably occurred from east coast populations, possibly from the Coral Sea.

5.1.2 Anthropogenic impacts

The two most significant anthropogenic impacts on marine snake populations are attributed to capture for food, venom and leather (Karthikeyan et al. 2008; Ward 1996b) and incidental fishing mortality (Fry et al. 2001; Heales et al. 2008; Milton 2001; Redfield et al. 1978; Ward 1996a; Ward 2000; Ward 2001; Wassenberg et al. 2001; Wassenberg et al. 1994).

Sea snakes are vulnerable to trawl capture as they regularly inhabit trawl grounds. Ward (1996b) estimated that 81 080 (±13 670) sea snakes were caught by trawlers between Koolan Island and Cape York (northern Australia) during 1990, while Wassenberg et al. (1994) estimated between 73 583 and 165 559 were caught by trawlers in the GOC in 1991. Wassenberg et al. (2001) estimated that overall mortality of trawl caught snakes was 48.5%, due to drowning or injuries sustained during trawl capture. Milton (2001) identified *Aipysurus laevis* and *Astrotia stokesii* as having life history traits indicative of limited capacity to sustain additional mortality in northern Australia, but a more recent, semi-quantitative assessment has shown there is a low risk of sea snake populations in the NPF falling below levels required to maintain populations (Milton et al. 2008).

The IUCN Red List currently lists one sea snake species as vulnerable—*Laticauda cocker*. Throughout the Australasian region sea snakes are afforded varying levels of protection. Taiwan and Hong Kong do not list any species as protected or threatened, while all species are protected within Indian and Australian waters (Karthikeyan &

Balasubramanian 2007; Karthikeyan et al. 2008). At the time of writing, the IUCN were reviewing the status of sea snakes and much of the data collected from Queensland as part of the current FRDC 2005/053 Project were presented at an IUCN Red List Assessment Workshop in Brisbane from 11–14 February 2009. As a result of this workshop, the IUCN intends to release a revised Red List of sea snake species vulnerability in the near future. Sea snakes are not listed by the Convention on International Trade on Endangered Species of Fauna and Flora (Wassenberg et al. 2001) because they are not in demand in global markets.

In the early 1980s, the Queensland Government issued two permits each for the collection of 20 000 sea snake skins in support of a growing Cairns-based cottage industry for sea snake leather goods. The details of, and conditions for, the permits are now scant but several Queensland commercial trawler operators participated in the collecting, which was based on trawl bycatch.

In the period 1984–87, Heatwole and Burns (1987) undertook a study for the Australian National Parks and Wildlife Service to assess the impact of the leather fishery on sea snake populations. Their study included the collection and analysis of sea snake bycatch in the Commonwealth NPF in the GOC and Torres Strait, as well as the Queensland east coast from Cairns to Cape York. They described the catch rates, growth rates and reproductive biology of several sea snake species which formed the basis of Burn's PhD thesis (Burns 1984) and subsequent journal articles (Burns & Heatwole 1998, 2000). In their report and papers, Burns and Heatwole also quantified the population size for the olive sea snake (*Aipysurus laevis*) at Mystery Reef in the Swain Reefs complex off the Central Queensland coast, and derived a second preliminary estimate for Little Warrior Reef in Torres Strait. Importantly, they also quantified sea snake bycatch rates from commercial trawlers, in number per km^2 (square kilometres), which can be compared with catch rates derived from the current project to comment on possible long-term changes in population size.

Lukoschek et al. (2007a) examined presence/absence survey data for two sea snake species (*Aipysurus laevis* and *Emydocephalus annulatus*) from the Pompey Reefs – Swain Reefs complex in the southern GBR that were collected over 35 years. The design of the surveys and the subsequent quality of data and conclusions drawn from their analysis are questionable because the surveys were not standardised, used different methods between years (i.e. scuba and manta tows) and, in most cases, were not designed for sea snake population estimates. Ninety reefs were surveyed, of which 52 were surveyed once, 21 surveyed twice, seven surveyed three times, three surveyed four times, two surveyed five times and five surveyed more than five times. Lukoschek et al. (2007a) found the distribution of *Aipysurus laevis* to be affected by longitude, reef exposure and reef area, while no factors were found to affect the distribution of *E. annulatus*. Although the authors concluded that there were no temporal patterns in the change of occurrence of *A. laevis* in the region, they also concluded this species had experienced recent local extinctions.

5.1.3 Diet

Many marine and terrestrial snakes feed infrequently and typically prey on a single, large prey item (Marcos & Lanyon 2004; Shine et al. 2004). This can result in dietary studies finding few prey items as empty stomachs often exceed 70% (Ineich et al. 2007; Su et al. 2005).

Hydrophiids and laticaudids fall roughly into one of two feeding categories: the specialist or the generalist (Heatwole 1999). Foraging mode, habitat and prey biology and behaviour are all important factors affecting which category a marine snake species belongs (Glodek & Voris 1982; Ineich et al. 2007; Voris & Voris 1983). The majority of marine snakes are specialists that prey on a small number of fish species and show low dietary overlap between species (Fry et al. 2001; Glodek & Voris 1982; Heatwole 1999; Marcos & Lanyon 2004; Voris 1972; Voris & Voris 1983). Furthermore, when a variety of prey items are consumed, the prey usually have similar morphologies (Glodek & Voris 1982).

Reed et al. (2002) showed at least three laticaudid species displayed high diet specialisation towards eel species, with some cases showing a preference for one particular eel species. Similarly, Brischoux et al. (2007) indicated that over half the diet of *Laticauda laticaudata* consisted of three different eel species and 46% of *L. saintgironsi's* diet consisted of one eel species (*Gymnothorax chilospilus*).

The most highly specialised feeders among sea snakes are those that feed almost exclusively on fish eggs (Heatwole 1999). This adaption is a significant change from typical snake behaviour, and only three species are known to use this strategy—*Aipysurus edouxii, Emydocephalus annulatus* and *E. ijimae* (Heatwole 1999; Li et al. 2005; Shine et al. 2004; Voris & Voris 1983). These species feed frequently as they encounter eggs. As a result, their feeding mode is more similar to that of grazing or browsing species than it is to the predatory modes of most sea snakes (Shine et al. 2004).

In contrast to this highly specialised diet, the highly abundant *Lapemis curtus* (previously known as *L. hardwickii*) is one of the few generalist feeders; its diet includes squid, crustaceans and fish (Fry et al. 2001; Glodek & Voris 1982; Lobo et al. 2005; Marcos & Lanyon 2004; Redfield et al. 1978; Voris 1972; Voris & Voris 1983; Wassenberg et al. 1994). Lobo (2005) found 90% of *L. curtus'* stomachs examined contained prey, suggesting that they feed more frequently than most other snakes.

Predator–prey interactions play an influential role in marine snake behaviour and habitat association. Unlike terrestrial snakes, the prey of marine snakes is strongly associated with a particular environment. As such, specialised adaptations have evolved within snake species. For example, *Hydrophis mcdowelli* has a thin, elongated body (anteriorly) and a very small head for extracting eels from their hiding places.

5.1.4 Reproduction

Hydrophiids are viviparous, giving birth at sea, while laticaudids are oviparous, returning to land to lay their eggs (Girons 1990; Shetty & Shine 2002a).

An important component of sea snakes' reproductive ecology involves the relationships among female weight, clutch size, birth weight, and reproductive effort (Lemen & Voris 1981). The clutch size of viviparous sea snakes increases with female size (Fry et al. 2001; Hin et al. 1991; Lemen & Voris 1981; Voris & Jayne 1979; Ward 2001). Many viviparous terrestrial snakes also display this trait, suggesting that increased clutch size is an evolutionary advantage regardless of environment inhabited (Pleguezuelos et al. 2007; Seigel et al. 1986; Shine 1977).

Sexual maturation is the most significant stage of a snake's life. Biological and behavioural changes occur as energy is diverted from somatic growth to reproductive development. Female and male *L. curtus* reach sexual maturity at 23 and 20 months, respectively (Hin et al. 1991; Ward 2001). Female *Hydrophis elegans* also mature at approximately 24 months (Ward 2001). Voris & Jayne (1979) were able to determine that *Enhydrina schistosa* reach maturity at 18 months. In contrast, *A. laevis* reach maturity at a much later age, usually three years for males and 4–5 years for females (Burns & Heatwole 2000; Heatwole 1999). These ages are slightly older than most terrestrial snakes (family Elapidae), which reach maturity at either 12 or 24 months (Seigel et al. 1987; Shine 1977; Shine 1978).

Once hydrophiids, laticaudids and elapids are mature, the majority reproduce annually (Fry et al. 2001; Lemen & Voris 1981; Shine 1977; Voris & Jayne 1979; Ward 2001). Notable exceptions are *A. laevis, E. ijimae* and *H. elegans*, which reproduce every 2–3 years (Masunaga & Ota 2003; Ward 2001).

Lemen and Voris (1981) identified two reproductive strategies in relation to clutch size, with snakes either producing a small number of large young or numerous smaller young. Both strategies result in approximately equal amounts of reproductive effort in relation to the total clutch weight-to-female weight ratio. All marine snakes, with the exception of *Enhydrina schistosa*, adhere to the first strategy (Lemen & Voris 1981).

Conversely, terrestrial snakes tend to use the second strategy. Hydrophiids give birth from February to April to 3–9 young, which vary from 200–570 mm in length, depending on species (Fry et al. 2001; Lemen & Voris 1981; Voris & Jayne 1979; Ward 2001). An exception is *H. elegans*, which produces both larger (440–660 mm in length) and more young (~13 clutch^{-1}), possibly to compensate for a lower reproductive frequency (Fry et al. 2001; Ward 2001). Gestation lasts 6–9 months for most hydrophiids, depending on species. The diverse range of reproductive traits in the family Hydrophiidae possibly reflects the relatively recent evolution of this family, as suggested by Lukoschek and Keogh (2006).

5.1.5 Growth and mortality rates

The growth rate of most reptiles declines with the onset of sexual maturity, mainly due to the increased energy demands for gonad maturation and reproductive behaviour (Burns & Heatwole 2000). For example, Masunaga and Ota (2003) found that *E. ijimae* of lengths <500 mm, 500–700 mm and >700 mm grew at 0.30±0.05 mm day^{-1}, 0.15±0.08 mm day^{-1} and 0.05±0.03 mm day^{-1}, respectively. In their first year *E. schistosa* grew at 1 mm day^{-1}, more than doubling in size after one year, but growth was found to slow significantly at 18 months when sexual maturity was reached (Voris & Jayne 1979). Similarly, *A. laevis* grows at 0.07–0.32 mm day^{-1}, with the rate decreasing by 50% once maturity is reached (Burns & Heatwole 2000).

These rates were determined using mark and recapture experiments, which are the most common methods for measuring growth. Ward (2001) undertook a skeletochronological analysis to determine the age of *L. curtus* and *H. elegans*. Length-at-age data were then used to create von Bertalanffy growth curves for both species. Rates of growth were found to decrease as length increased. Ward (2001) is the only study, of those reviewed, to apply growth models to sea snake populations, possibly suggesting that further research is required.

Little quantitative information is available on the mortality rates (i.e. both natural mortality and fishing mortality) of sea snakes. Milton et al. (2008) derived estimates of the instantaneous rate of natural mortality (*M*) for snakes caught in the NPF and used them in a risk assessment of populations falling below specified reference points, due to incidental fishing. They used Pauly's (1980) estimate based on the formula:

$$\log(M) = -0.0066 - 0.279\log(L_\infty) + 0.6543\log(K) + 0.4634\log(T)$$

where L_∞ and K are the von Bertalanffy growth parameters and T is the mean annual water surface temperature in ^{o}C. A re-investigation of this work by Lijam (1990), using a larger data set and correcting some of Pauly's original data, gives similar values. Using Pauly's formula and estimates of von Bertalanffy growth parameters, Milton et al. (2008) estimated M for 16 sea snake species, ranging from 0.193 year^{-1} for *A. laevis* to 0.517 year^{-1} for *A. eydouxii*.

Estimates of the incidental fishing mortality rate experienced by sea snakes in the NPF have been estimated to vary between 42.0% (Heatwole & Burns 1987) and 48.5% (Wassenberg et al. 1994).

5.1.6 Reviewing the Queensland data

There are relatively few data available on sea snakes from the Queensland east coast and most of what is available has come from trawl fishery surveys and research projects. Following is a chronology, brief description and summary of each known and available source of data.

1984–87: Heatwole and Burns (1987) investigated the sustainability of a trawler-based sea snake leather fishery in northern Australia, including the Queensland east coast from 1984–87. They reported that a 'cottage industry' leather fishery had been operational for at least 10 years and that the Queensland Government had issued two permits, each for an annual take of 20 000 sea snake skins.

Heatwole and Burns (1987) quantified catch rates, mortality rates, distribution and aspects of the reproductive biology of snakes in northern Australia. They expressed concern about the potential of the fishery to expand and recommended that the harvest be restricted to the two most numerically abundant sea snake species, *Hydrophis elegans* and *Lapemis hardwickii* (now generally known as *L. curtus*) and that no more than 5000 skins be harvested from each species. Importantly, Heatwole and Burns quantified mean catch rate rates of sea snakes per swept area by the trawls, and mortality rates, which can be compared against current and future estimates.

1991–96: The far northern section of the GBRMP 'green zone' and Before-After-Control-Impact (BACI) research project. Details of this project can be found in Poiner et al. (1998). A total of 69 snakes were caught during the project surveys, experimental impact trawling and sampling of this section of the GBR.

1996–98: These sea snake bycatch data were collected by Mr Keith Chilcott (from the former Queensland Department of Primary Industries and Fisheries) as part of a project designed to describe and quantify bycatch in the Queensland banana prawn trawl fishery.

The data were collected on 10 sampling trips aboard commercial trawlers operating in the fishery from 25 November 1996 to 24 March 1998. Details of the sampling trips, location of the trawls and analysis of the bycatch data are provided in Chapter 6 of Stobutzki et al. (2000). A total of 154 sea snakes were caught during the bycatch sampling; 141 *Lapemis hardwickii* (i.e. *L. curtus*), 43 *Hydrophis elegans*, 6 *Disteira major* and 4 *D. kingii*. The observed catch rate in the banana prawn fishery, based on these data, was 1.05 snakes net^{-1} trawl^{-1}. Of the 154 snakes caught, 87 carcasses were forwarded to the CSIRO, where they were examined together with other sea snake samples that had been collected from northern Australia. Aspects of the reproductive biology and diet of these snakes were subsequently published by Fry et al. (2001).

2003–06: The GBR seabed mapping project. Details of this project can be found in Pitcher et al. (2007). A total of 332 sites in the GBRMP were trawl-sampled using research trawls from the Queensland Government *RV Gwendoline May*. From these sites a total of 25 sea snakes were caught—8 x *Aipysurus duboisii*, 5 x *A. eydouxii*, 4 x *A. leavis*, 4 x *Acalyptophis peronii*, and 1 x each of *Astrotia stokesi*, *H. elegans*, *Hydrophis ornatus* and *L. hardwickii* (i.e. *L. curtus*).

2003–present: The Queensland SOCI database. This database was an initiative of the Queensland Government (former Department of Primary Industries and Fisheries) designed with the purpose of recording interactions between commercial fishing gear and species of high conservation status, including sea turtles, whales, dolphins, dugongs and sea snakes. In addition to other catch and effort information, fishers are required to record their interactions with these species, including their catches, in compulsory daily logbooks. While it is difficult and impractical (and possibly unsafe) for fishers to record their sea snake catches to species level, they are requested to record the number of snakes caught and the number that are alive or dead.

Analysis of the SOCI sea snake data indicate that Queensland trawler operators reported catching an annual maximum of 4840 sea snakes in 2003 and an annual minimum of 1640 in 2006 (Figure 5.1.1), with an annual mean of 2940. Over the six year period 2003–08, of the total 17 640 snakes reported caught, 884 (5%) were reported as dead and 352 (2%) were reported as injured. Spatial analysis of the data (Figure 5.1.2) suggest that the average annual catch of sea snakes is relatively high in the north Queensland region around Townsville (19^{o}S), and in far north Queensland in Princess Charlotte Bay (14^{o}S), while reported landings in the southern half of the state (south of 20^{o}S) are low.

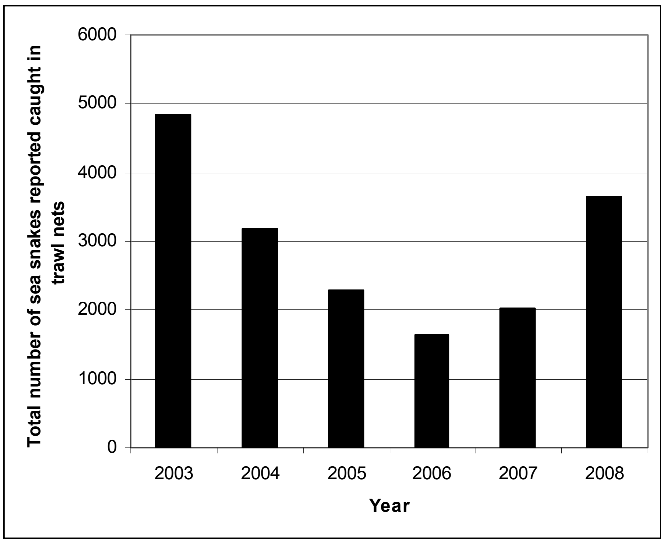


Figure 5.1.1. The reported number of sea snake captures by Queensland trawler operators from 2003–08, based on the SOCI logbook database.

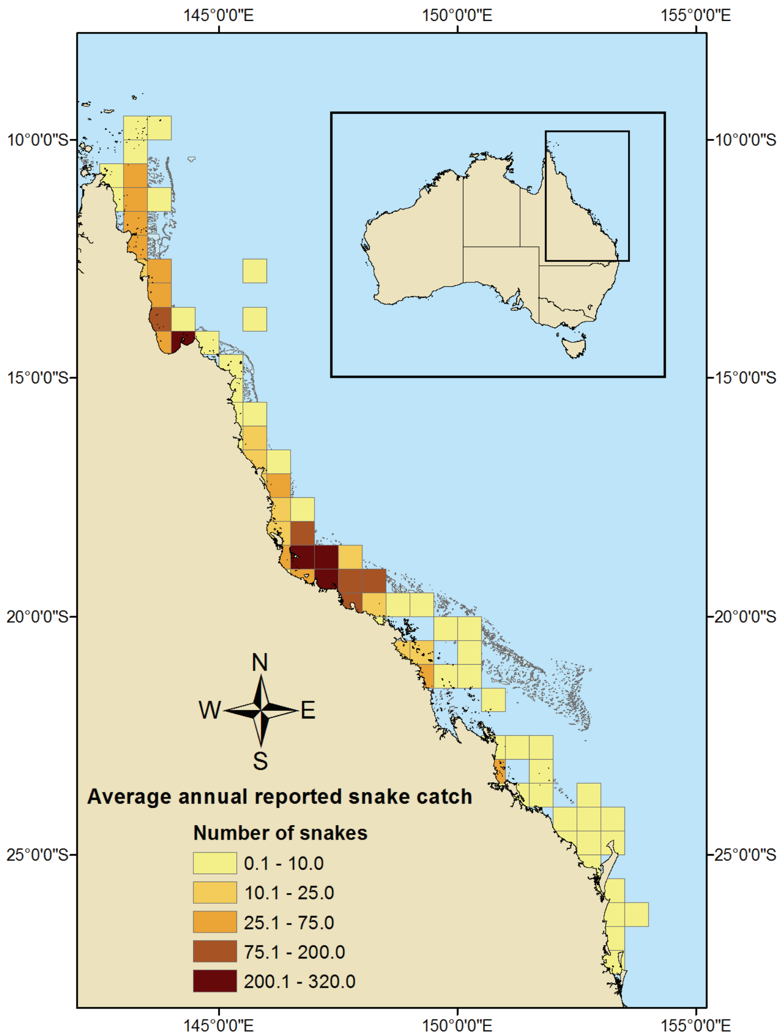


Figure 5.1.2. The average annual reported incidental catches of sea snakes from 2003–08 inclusive, based on the SOCI database.

6 Objectives 2 and 3. Quantifying the incidental catch and mortality of sea snakes in the Queensland East Coast Trawl Fishery

6.1 ABSTRACT

The total number of sea snakes caught and killed incidentally by the Queensland East Coast Trawl Fishery was estimated. Sixty-seven otter trawl and beam trawl fishers participated in a voluntary program providing detailed information on their sea snake catch rates and within-trawl mortality, including digital photographs of the snakes caught. Data were collected for 3910 snakes from 8289 trawls. Twelve sea snake species were recorded; the most common were the spine-bellied sea snake (*Lapemis curtus*), the olive sea snake (*Aipysurus laevis*) and the reef shallows or Dubois's sea snake (*Aipysurus duboisii*). Adjusted mean catch and mortality rates were derived for each trawl sector using generalised linear modelling (GLM). Annual total catches and mortalities were estimated from the samples for each sector by extrapolation based on average annual fishing effort. The mean catch rate of sea snakes across all sectors of the Queensland trawl fishery was 105 210 s.e. 18 288 year^{-1}. About 8.5% of snakes were reported as dead when the nets were brought to the surface (i.e. within-trawl mortality rate) and another 17.4% were estimated to die in the following hours and days after trawling (i.e. post-trawl mortality rate), giving a combined incidental mortality rate of 25.9%. Most post-trawl mortality occurred in the first 24 hours and larger snakes experienced significantly higher post-trawl mortality than smaller individuals. Catch and mortality rates differed significantly between sectors. The redspot king prawn fishery, which is a reef-associated prawn, accounted for 58.9% of all snake catches and 84.5% of mortalities.

6.2 INTRODUCTION

Tropical and subtropical prawn trawl fisheries have historically produced large amounts of bycatch, which is composed of hundreds of fish and invertebrate species (Alverson et al. 1994; Brewer et al. 1998; Kennelly et al. 1998; Steele et al. 2002; Stobutzki et al. 2001; Watson et al. 1990). The bycatch can also include threatened, endangered, vulnerable and protected species, such as sea turtles, sea snakes and certain elasmobranchs (i.e. sharks and rays). Throughout the 1990s, national and international political and trade-related pressure on Australian fisheries' management agencies increased over the incidental catch of sea turtles. Consequently, by the early 2000s, TEDs were mandatory in all Australian prawn trawl fisheries where turtle bycatch was considered to be an issue, including the Queensland East Coast Trawl Fishery.

At-sea observer-based data and other anecdotal data indicate that the use of TEDs in these fisheries has greatly reduced the number of incidental turtle captures. TEDs have also been shown to significantly reduce catch rates of other large bycatch, including sharks, rays and sponges, although catch rates of small individuals of these species have generally remained unaffected (Brewer et al. 2006; Courtney et al. 2006). As part of the *Fisheries (East Coast Trawl) Management Plan 1999*, Queensland trawler operators are also required to have a second BRD installed in every net, in addition to a TED, as a means of further reducing finfish and invertebrate bycatch. At present, there are seven recognised BRDs listed in the management plan, in addition to TEDs, that fishers can choose from—the fisheye, bigeye, square mesh panel, square mesh codend, radial escape section, Popeye fishbox and the V-cut. While the effectiveness of TEDs and BRDs has been documented for many species, very little information is available for their effect on sea snake catches.

At the time of writing (i.e. 2009) extinction threats to sea snake species were being assessed under the IUCN Red List criteria. In Australian waters, sea snakes are 'listed marine species' under the Australian Commonwealth *Environment Protection and Biodiversity Conservation Act 1999*, meaning that it is an offence to kill, injure, take, trade, keep or move sea snakes without a specific permit. They are also protected under the Queensland *Marine Parks Act 2004* and the Commonwealth *Great Barrier Reef Marine Park Act 1975*. The number of sea snakes incidentally caught and killed by the Queensland trawl fishery annually has not previously been estimated. In the GOC, Wassenberg et al. (1994) estimated that 119 571 (CI±45 988) sea snakes were caught in 1991, with an estimated 40.5% or 48 426 (CI±18 625) dying in 6–8 hours following capture. Ward (1996b) estimated 81 080 sea snakes were caught across the entire NPF in 1990.

This section of the report quantified the catch rates, species composition and mortality rates of sea snakes caught as bycatch in the Queensland trawl fishery. Several hypotheses were tested, including: a) sea snake catch rates did not differ significantly between trawl fishing sectors or between sea snake species, and b) sea snake mortality rates were independent of fishing sector and sea snake species. Using the sampled data, models of sea snake catch rates and mortalities were developed and used to derive adjusted means that were then used to extrapolate total annual catches and mortalities of sea snakes for the whole Queensland trawl fishery.

6.3 MATERIALS AND METHODS

Since 1988, Queensland trawler operators have been required to record their fishing effort and target species catch on a daily basis, or more frequently (i.e. shot by shot) in logbooks provided by the Queensland Government. In 2003, fishery managers introduced an additional mandatory logbook in the trawl fishery—known as the SOCI logbook—to record commercial fishing gear interactions with protected, threatened or endangered species (including sea turtles, sea snakes, whales, dugongs, dolphins and syngnathids). However, observer data, at-sea experiments and monitoring surveys strongly indicate that the number of incidental snake captures reported by fishers in the SOCI program for the period 2003–08 was well below reality.

While some fishers may deliberately misreport their catches of these species, there are several reasons for the inaccuracies, including a lack of awareness, lethargy, and frustration with logbook requirements to record data on numerous non-target species, in addition to the targeted and permitted (i.e. byproduct) species. In order to obtain more reliable information on the interactions between the fleet and sea snakes, a separate, purposely designed crew member program (CMP) was implemented as part of the current FRDC research project.

6.3.1 Crew member program (CMP)

An underlying assumption of the CMP was that it would result in more detailed and accurate sea snake bycatch data compared to the existing SOCI logbook database. This assumption is valid because:

1. the CMP was voluntary. Fishers were given the choice to participate in the program and those who were opposed chose not to be involved. Using this approach, disgruntled fishers, who were likely to provide erroneous data, were excluded from the program. This is in contrast to the SOCI program which, because it is mandatory, includes records from all fishers.
2. participation by individuals was requested over short periods (i.e. a few weeks) to ensure interest, and therefore accuracy in the recording of data, was maintained. Participating fishers were not required to maintain their interest in the research over long or indefinite periods, as the SOCI program mandates.
3. the CMP was focused solely on sea snakes. Fishers were not confronted with the problem of sorting, searching and recording their incidental catches for several non-target species, which is required under the SOCI program, and
4. the CMP provided fishers with digital cameras that were used to photograph snakes and later determine their identity in the laboratory. There is no requirement for fishers to identify sea snakes under the SOCI program. The SOCI database provides no information on sea snake species composition, and therefore, no information on the distribution, catch rates or incidental mortality of individual snake species.

The CMP involved the project research staff from the Agri-Science Queensland (formerly the Department of Primary Industries and Fisheries) asking trawler crews to voluntarily participate in the program. SeaNet extension services also assisted with recruiting fishers in Far North Queensland. All sectors of the Queensland trawl fishery were included: the shallow and deepwater eastern king prawn sectors, the scallop fishery, the banana prawn fishery, the redspot king prawn fishery, the North Queensland tiger/endeavour prawn fishery, Moreton Bay, the black tiger prawn (*Penaeus monodon*) broodstock collection fishery and the beam trawl fishery. If crews were agreeable, they were provided with a sea snake bycatch kit (Figure 6.3.1) which included a digital camera with memory to store approximately 200 images.

The kits included pencils and a waterproof booklet, referred to as the ‘wheelhouse data booklet’, which remained in the vessel wheelhouse for the skipper to record details about each trawl, including the sector fished, the number of nets towed by the vessel (i.e. single, twin, triple, quad or five nets) and the total headrope length of the nets (m), the type of BRD used in the nets, the date the trawl was undertaken and a unique numbered trawl identifier. Accurate details of the starting and end a) location (i.e. latitude and longitude), b) depth (m), c) time and d) speed (knots) were recoded for each trawl, as well as the total number of sea snakes caught. Photographs of the wheelhouse data booklet are provided in Appendix 1. Importantly, crews were asked to record these details for all trawls, irrespective of whether or not they caught a sea snake, for as long as they were prepared to or until the wheelhouse data booklet was completely filled.

Figure 6.3.1. The sea snake bycatch kits provided to trawler crews. Each kit included waterproof record booklets, safety and first aid equipment and a digital camera that could record over 200 images.

Kits also included a second, smaller waterproof booklet, referred to as the 'back deck data booklet', which generally remained on the back deck for recording catch details. The purpose of this booklet was to record the number of live and dead sea snakes specific to the particular vessel, trawl identifier number, and date. Photographs of the back deck data booklet are provided in Appendix 2. Once these details were written in the back deck data booklet, the crews were asked to place the open page next to the live snake/s caught from the trawl and take one or more photographs of both the snakes and the booklet at close proximity, so the snakes could later be identified to species by a researcher with the specific trawl details from which they were caught (exemplified in Appendix 3). Only photographs of the live snakes were requested as crews were asked to label, store and freeze all dead sea snakes and provide them to project staff when they returned to port. Labels and plastic bags were provided in the kits for this purpose. In this way, all catch details for both live and dead snakes were obtained. Once they returned to port, crews would contact project staff to collect the kits and any dead snakes. The images were transferred from the cameras to computers at the Southern Fisheries Centre, stored in a photographic database and identified to species level using Cogger (1975).

The wheelhouse data booklet and back deck data booklet were designed to collect detailed information on a maximum of 120 trawls. If an average otter trawl vessel undertook six trawls night^{-1}, this would facilitate the collection of data for approximately 20 nights of fishing. This was considered long enough to obtain a representative 'snapshot' of fishing effort and short enough to maintain crew member interest and data recording accuracy. This period also generally reflected the duration of typical otter trawl fishing trip of 2–3 weeks. All wheelhouse data, back deck data and sea snake identification data were entered into a Microsoft Access database, checked and corrected.

Thick leather gloves, snake tongs, pressure bandages and first aid information were also provided in the kits (Figure 6.3.1) for crews concerned about the extra handling of snakes possibly increasing their risk of being bitten. Provision of this safety equipment also demonstrated research staff awareness of, and commitment to, workplace safety and reduced the potential for legal action if a crew member was envenomated.

In addition to the CMP, information on the catch rate and within-trawl mortality of sea snakes caught in the fishery was obtained from the Fisheries Queensland Observer Program and Long Term Monitoring Program surveys, and Agri-Science Queensland project staff who undertook field trips aboard trawlers during the project. Data from all of these sources were entered into the project Access database in a format that was consistent with that of the CMP.

6.3.2 Quantifying post-trawl mortality rates

The mortality rates experienced by sea snake populations on the Queensland coast can be attributed to natural and anthropogenic causes. While there are several sources of anthropogenic mortality (including habitat disturbance, pollution, boat-strikes, capture in pot and other net fisheries), the largest source of anthropogenic mortality is almost certainly due to incidental capture in trawl nets. This can be divided further to within-trawl mortality and the post-trawl mortality (Wassenberg et al. 2001).

Within-trawl mortality occurs in the nets after the snakes are caught and can be measured as the number of snakes that are observed to be dead when the nets are retrieved and emptied onto the sorting tray. Post-trawl mortality occurs after the snakes have been caught and released back into the water. It can be measured as the number that die in the following hours and days after being trawled, as a direct consequence of being trawled. The units for mortality rates can be number net^{-1} $trawl^{-1}$, number $trawl^{-1}$ (i.e. nets pooled) or number $boat\text{-}day^{-1}$ of fishing effort. While data required to quantify the within-trawl mortality rates were obtained from the CMP, an additional program was required to measure the post-trawl mortality rates.

The post-trawl mortality data were obtained by project research staff on board Queensland prawn and scallop trawlers during their normal commercial fishing activities. As such, the condition of the snakes and subsequent mortality rates can be considered as representative of commercial trawling. A relatively small amount of additional data was obtained by project staff aboard the Queensland Government *RV Gwendoline May* during the research charter that tested the effects of bycatch reduction devices on sea snake catch rates in May–June 2006 (Section 7).

The mortality rates derived from the charter might be considered to be slightly lower than those from commercial vessels, due to the relatively short duration of the research trawls (i.e. standardised two-nautical mile trawls of ~50 minutes), but nevertheless provide valuable additional information on mortality. Methods used were similar to those described by Wassenberg et al. (2001) for determining the survival rates of trawl-caught snakes in the NPF. Project staff approached commercial trawler operators and sought their permission to work on their vessels during their normal fishing activities. To prevent undertaking costly field trips that yielded little or no data, the project targeted sectors known to encounter sea snakes and, as a result, the post-trawl mortality observations were limited to four sectors of the trawl fishery: banana prawn, North Queensland tiger/endeavour prawn, redspot king prawn and black tiger prawn broodstock collection fisheries.

Sea snakes were removed from the catch immediately after the nets were brought to the surface and emptied onto the sorting tray (i.e. time zero, t_0). Each snake was examined for any obvious physical injury, identified to species and categorised into one of the five following initial condition grades: Grade 0 = Dead, Grade 1 = Alive, inactive and non-responsive, Grade 2 = Alive, inactive and responsive, Grade 3 = Alive, active and responsive, Grade 4 = Alive, very active and responsive.

When live snakes were present, one or more were selected for holding in one of two types of plastic containers—75 L green bin and 140 L blue drum (Figure 6.3.2). Up to three snakes were held in each container simultaneously for a minimum of 96 hours. This duration was chosen because Wassenberg and Hill (1993) found negligible mortality for several trawl-caught species after three days, and therefore suggested that four days in captivity was adequate to quantify survival rates.

Complete water exchange was undertaken every 3–4 hours, concurrently with re-assessment of the condition of each snake. In this way, a time series of the condition of each snake was derived over a period of 96 hours (i.e. t_0, t_3, t_6 … $t_{96\ \text{hours}}$) or until the individual died. The sex, weight (g) and length (mm) of each snake were determined, either when it died, or at the completion of the holding period. A piece of tissue approximately 4 mm long was removed from each snake's tail for genetic analyses. All live snakes were released at the surface after the holding period.

Figure 6.3.2. Containers used to hold sea snakes in order to determine their mortality rates after being caught in trawl nets. 75 L bins on the left and 140 L drums on the right. Between one and three snakes were placed in each container for a minimum of 96 hours.

6.3.3 Statistical methods

Two estimates of sea snake incidental catch rates were derived using GLM. The first expressed catch rates in terms of area swept by the trawl gear (i.e. number of snakes caught ha^{-1}) while the second was expressed in terms of fishing effort (i.e. number of snakes caught boat-day^{-1}).

The first estimate is more robust because it includes absolute units (i.e. area swept in hectares). These units were chosen so that the catch rates would remain as meaningful reference points for decades into the future. In contrast to catch rates expressed in terms of $trawl^{-1}$, boat-day^{-1} or $hour^{-1}$ fished, catch rates expressed in terms of area trawled^{-1} (i.e. ha^{-1}) are less-affected by technological improvements in fishing power over time that can, and do, affect catch rates. Catch rates expressed as trawl^{-1}, boat-day^{-1} or hour^{-1} fished are not absolute and are subject to change over time as the fleet adopt advances in fishing power (Bishop et al. 2000; O'Neill et al. 2003; O'Neill & Leigh 2007). For example, a catch rate of 10 sea snakes boat-day^{-1} in 1987, 2007 and 2027 does not represent the same catch rate, or index of abundance, because the fishing power of one boat-day of effort will have changed over this 40-year period. Similar arguments apply to catch rates reported as trawl^{-1} and hour^{-1}. Reporting catch rates in terms of number caught ha^{-1} largely mitigates this problem.

The second estimate, expressed as number of snakes caught boat-day^{-1}, was derived specifically for estimating total annual incidental catches and mortalities. Estimating the total number of snakes caught annually by the fleet requires extrapolation, based on fishing effort (i.e. boat-days), hence the reason for reporting in boat-day^{-1}. While GLMs were used to derive both estimates (i.e. ha^{-1} and boat-day^{-1}), slightly different models were required for each. The models were developed and compared using GenStat (2007) software to detect significant factors and covariates, and to predict catch rates and within-trawl mortality rates, and their standard errors, based on the sampled data. Model types included normal distribution with identity link, Poisson distribution with logarithm link and binomial distribution with a logit link. Log and square root transformations were applied to produce normally distributed data, while non-transformed data were also used. Response variables modelled were:

1. number of snakes caught in a trawl, either from all nets pooled (i.e. CMP data) or single nets (i.e. when research project staff were aboard), using a Poisson distribution
2. presence or absence of snakes in a trawl, either from pooled or individual nets, using a binomial distribution
3. number of snakes caught in swept area^{-1} (ha^{-1}), modelled using a normal distribution with various transformations
4. presence or absence of dead snakes in the trawl, again using a binomial distribution.

Factors considered in the models were:

1. fishery (i.e. shallow and deepwater eastern king prawn sectors, scallop fishery, banana prawn fishery, redspot king prawn fishery, North Queensland tiger/endeavour prawn fishery, Moreton Bay, the black tiger prawn broodstock collection fishery and the beam trawl fishery)
2. sampling program type, which consisted of three levels (CMP, Fisheries Queensland Observer Program, and when project researchers were aboard during normal commercial trawling operations)
3. BRD type (i.e. bigeye, bigeye with square mesh panel, fisheye, fisheye with square mesh panel, no BRD (i.e. control), Popeye fish box, radial escape section, square mesh codend and square mesh panel.

Covariates included in the models were:

1. swept area (ha)—the area swept for each trawl was estimated based on the product of the headrope length of the net/s, the speed and duration of the trawl and net-spread factors based on the work of Sterling (2005)
2. depth (m)—average depth of the trawl, determined from depth measures at the start and end of each trawl

3. latitude and longitude, also averaged from global position system (GPS) measures at the start and end of each trawl
4. mesh size, which ranged between approximately two inches in the prawn sectors up to four inches in the scallop fishery.

Preliminary analyses of factors and covariates were explored using the RSEARCH procedure in GenStat (2007). This procedure sequentially considers which factors, covariates and their interaction terms are significant and helps determine the order in which they should be added in the model to minimize the residual deviance. The best goodness-of-fit for the final models was obtained by checking for normality and constant variance of the standardised residuals. If these assumptions were not met then the distribution type or transformation was changed until they were satisfied. Final models were used to derive adjusted mean catch and mortality rates, and their standard errors (s.e.).

GLM was also deployed to quantify post-trawl mortality rates and examine influential factors and covariates. Two analyses were undertaken. The first quantified the probability of death within 96 hours after trawling. The response variable for this model was the survival (or death) of each individual snake held in the containers. The model distribution type was binomial with a logit link function. The second analysis modelled time-to-death (hours) and therefore only included those snakes that died during the holding period. As the response variable was continuous, a normal distribution with identity link function, and a gamma distribution with a logarithm link function, were trialled. The final model was chosen based on the goodness-of-fit, normality and constant variance of the standardised residuals. Explanatory factors and covariates included trawl sector, sea snake species, length and sex, duration of the trawl used to catch the snake (in hours), an estimate of the weight of the bycatch in the net the snake was caught in and holding container type (i.e. 75 L bin or 140 L drum). Because many factors could not be controlled (i.e. the data were largely observational with little experimental control over which species, sex, etc. were caught), the number and level of interactions that could be examined was limited.

6.3.4 Estimating total annual catches and mortalities

Total annual catch of sea snakes by the fleet was derived from the product of the adjusted mean sea snake catch rate (in numbers boat-day^{-1}) from the GLMs described above, and the observed mean annual fishing effort (in boat-days) obtained from the CFISH logbook database. Similarly, total annual mortality was derived using estimates of adjusted mean daily reported within-trawl mortality, adjusted mean post-trawl mortality and mean annual effort. Adjusted means from the GLMs were used wherever possible because they are more accurate than observed means and have more stable standard errors. Wassenberg et al. (1994) used the product of mean catch rate of sea snakes m^{-1} head rope length hour^{-1} and a measure of effort based on assuming an average net head rope length of 12 m and an average 13.4 hour day^{-1} for vessels that fished in the GOC in 1991. Ward (1996b) used the product of mean catch rate of sea snakes hr^{-1} trawled and an estimate of the total number of hours trawled by the fleet in 1990, based on the average 13.4 hour day^{-1} assumption. Robins (1995) estimated the number of incidentally-caught turtles by the Queensland trawl fleet from the product of mean catch rate boat-day^{-1} and an estimate of annual fishing effort in boat-days.

The mean annual fishing effort in each sector was based on an analysis of the Queensland otter and beam trawl logbook database (CFISH) for the five-year period from 2003–07 (inclusive). Every boat-day that an individual vessel fished was allocated to one of the nine sectors listed above. Because the trawl sectors are not completely separated in space and time (i.e. there is some spatial and temporal overlapping), decision rules were derived to allocate the effort. The decision rules considered the dominant (by weight) reported target species in the catch for the day in question, the location of the effort (i.e. latitude and longitude) on the day and the depth (Table 6.3.1) the trawling was undertaken in.

Table 6.3.1. Decision rules for allocating fishing effort to specific sectors. These were required to derive accurate estimates of the mean level of effort in each sector, which were then used to estimate the numbers of sea snakes caught and killed annually.

Trawl sector	Logbook species codes	Additional criteria
General rules Years = 2003–07 (inclusive), applied to all sectors *Otter trawling criteria* • Trawl fishing license symbols = T1, T2, M1 or M2 • Fishing method = 7 (otter trawl) • Longitude derived east of 142.5°E (east coast) • Log type = OT		Effort allocated according to the target species that dominated the reported catch (i.e. maximum catch by weight) except Moreton Bay and broodstock collection fisheries
Scallop	23270000, 23270001, 23270005	
Banana prawn	28711050	
North Queensland tiger/endeavour prawn	28711906, 28711902	
Redspot king prawn	28711910, 28711052, 28711048, 28711908, 28711047	All effort located north of 22°S and west of 152.5°E
Shallow water eastern king prawn	28711910, 28711052, 28711048, 28711908, 28711047	All effort located south of 22°S in grid sites within the 100m depth contour. Excluding Moreton Bay
Deepwater eastern king prawn	28711910, 28711052, 28711048, 28711908, 28711047	All effort located south of 22°S in grid sites deeper than the 100m depth contour plus all effort located east of 152.5°E between 21°S and 22°S
Moreton Bay		All effort recorded by M1 and M2 fishery license symbols in grids W37 and W38
Black tiger prawn broodstock collection fishery	28711051	This sector records numbers (not weight) of broodstock collected. Between 15.5 °S and 18°S
Beam trawl criteria • Fishing method = 47 • Fishery symbol = T5, T6, T7, T8 or T9	All prawn species codes	
Stout whiting trawl fishery		All effort for license symbol = T4.

When undertaking a sampling survey it is generally advised to stratify the sampled population because it can reduce the variance of an estimator of a population mean or total (Pollock et al. 1994). Trawl sectors were therefore considered as strata and the numbers of snakes that were caught and killed annually were firstly estimated for each stratum and then added to give the totals for the whole fishery. The variance (Var) estimate of the mean for sector s_1 was based on Bohrnstedt and Goldberger (1969):

$$\mathrm{Var}\,(s_1) = \bar{x}_1^2 \text{ x } \mathrm{Var}(\bar{x}_2) + \bar{x}_2^2 \text{ x } \mathrm{Var}(\bar{x}_1) + \mathrm{Var}(\bar{x}_1) \text{ x } \mathrm{Var}(\bar{x}_2)$$

where $\bar{x}_1$ is the mean effort in boat-days and $\bar{x}_2$ is the mean catch rate of snakes boat-day^{-1}, in the case of estimating the number of snakes caught, or $\bar{x}_2$ is the mean daily within-trawl mortality, in the case of estimating the number of snakes that die. The standard error (SE) of the mean for sector s_1 is calculated:

$$\mathrm{SE}(s_1) = \sqrt{(\bar{x}_1 \text{ x } se_2)^2 + (\bar{x}_2 \text{ x } se_1)^2 + (se_1 \text{ x } se_2)^2}$$

Mean annual catch and mortality for the whole fishery (w) were derived by summing sector means. Similarly, the variances for means or totals of the whole fishery were derived by summing the sector variances (Snedecor & Cochran 1967):

$$\mathrm{Var}(w) = \mathrm{Var}(s_1) + \mathrm{Var}(s_2) + \mathrm{Var}(s_3) + ... + \mathrm{Var}(s_n)$$

and the SE of w calculated as

$$\mathrm{SE}(w) = \sqrt{\mathrm{SE}(s_1)^2 + \mathrm{SE}(s_2)^2 + \mathrm{SE}(s_3)^2 + ... + \mathrm{SE}(s_n)^2}$$

where s_1, s_2, s_3... s_n are individual sectors.

6.4 RESULTS

Detailed information on sea snake bycatch was obtained from a total of 8289 trawls in the Queensland east coast otter trawl and beam trawl fisheries between 27 July 2005 and 26 October 2007 (Table 6.4.1). The majority of data (i.e. 6429 trawls) were provided by commercial crews participating in the CMP during their normal fishing activities.

Otter trawlers targeting prawns and scallops tow 2–5 nets, while the smaller inshore beam trawlers tow a single net. Vessels operating in the stout whiting trawl fishery generally tow a single large net. Otter trawl crews participating in the program did not separate their sea snake catches, or record details of their catches, from individual nets, but rather provided pooled-net catch details from each trawl. Fishers did provide details on the size (i.e. head rope length) of the individual nets, thus enabling the total area swept by the gear to be calculated.

In addition to the CMP, sea snake bycatch data were obtained from 461 trawls provided by the Fisheries Queensland Observer Program, 445 trawls from research charters and surveys—including the sea snake BRD charter in May–June 2006

(Section 7)—and 954 trawls recorded by project research staff aboard commercial vessels during their normal fishing operations. Not all of the 8289 trawls had sea snake bycatch (i.e. zero catches are included). Figure 6.4.1 shows the location of the trawls undertaken for each sampling program type.

Table 6.4.1. Summary of the number of trawls that were used to collect information on sea snake bycatch (including zero catches) for each sector of the Queensland East Coast Trawl Fishery and each sampling program type.

Trawl sector	Sampling program	Number of trawls
Banana prawn	Crew member program (FRDC project)	105
Beam trawl	Crew member program (FRDC project)	1423*
Deepwater eastern king prawn	Crew member program (FRDC project)	870
Shallow water eastern king prawn	Crew member program (FRDC project)	812
Moreton Bay	Crew member program (FRDC project)	238
Black tiger prawn broodstock collection fishery	Crew member program (FRDC project)	146
Redspot king prawn	Crew member program (FRDC project)	464
Saucer scallop	Crew member program (FRDC project)	1232
Tiger/endeavour prawn	Crew member program (FRDC project)	1139
Banana prawn	Fisheries Queensland Observer Program	35
Beam trawl	Fisheries Queensland Observer Program	97*
Deepwater eastern king prawn	Fisheries Queensland Observer Program	16
Shallow water eastern king prawn	Fisheries Queensland Observer Program	48
Moreton Bay	Fisheries Queensland Observer Program	31
Redspot king prawn	Fisheries Queensland Observer Program	97
Tiger/endeavour prawn	Fisheries Queensland Observer Program	64
Stout whiting trawl	Fisheries Queensland Observer Program	73
Saucer scallop	Research charter or survey	113
Tiger/endeavour prawn	Research charter or survey	332*
Banana prawn	Project research staff on board	238*
Beam trawl	Project research staff on board	44*
Black tiger prawn broodstock collection fishery	Project research staff on board	40*
Redspot king prawn	Project research staff on board	260*
Tiger/endeavour prawn	Project research staff on board	372*
Total		**8289**

* Indicates individual nets, which usually resulted when research staff were on board and therefore able to separate and record the catches from individual nets. All other trawls were from pooled nets. Beam trawlers only tow a single net. The stout whiting vessels generally tow a single large net.

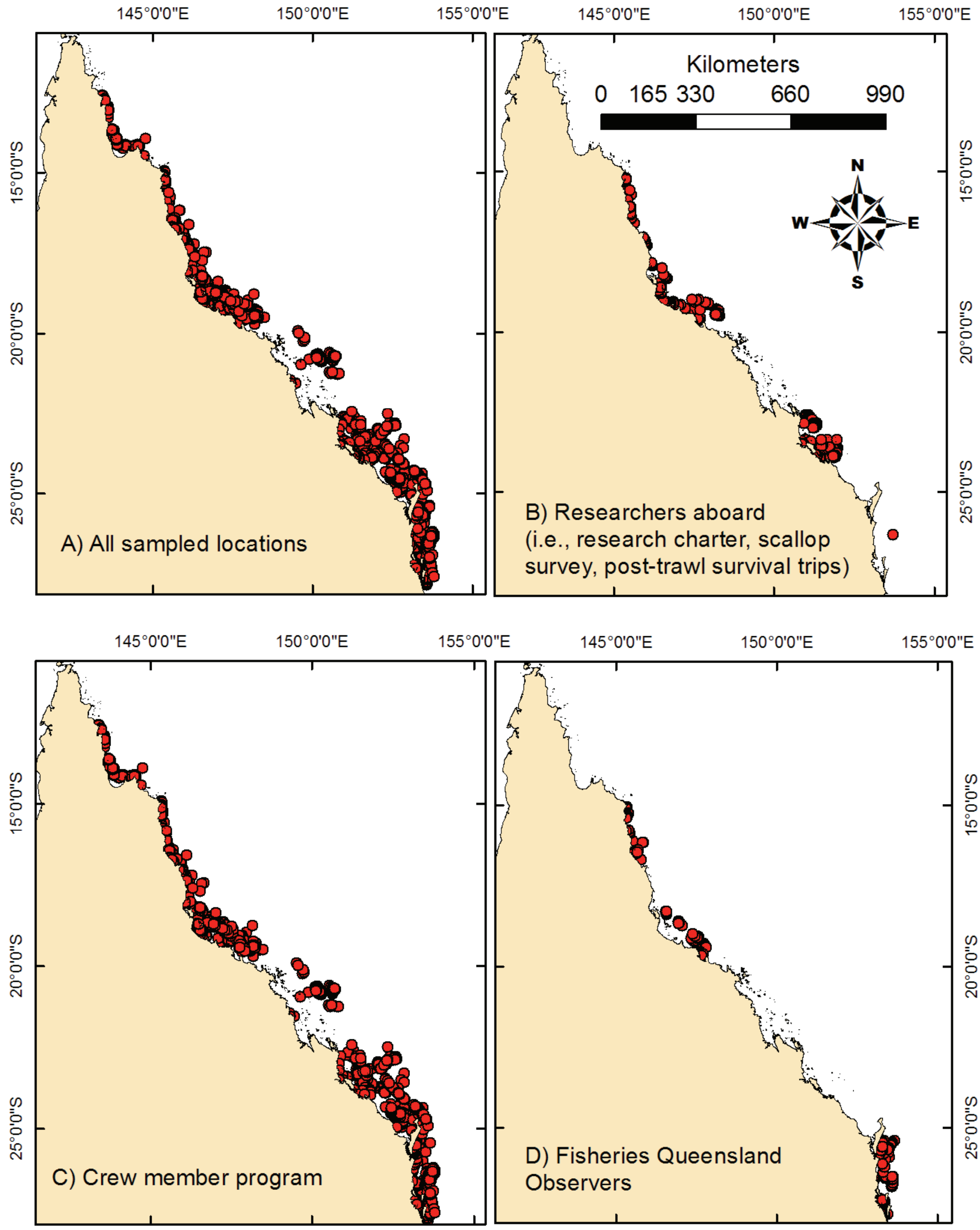


Figure 6.4.1. Trawl locations where sea snake bycatch data were obtained. (A) shows all 8289 trawls from all sampling programs; (B) shows locations when project research staff were aboard vessels during the research charter, one of the long-term monitoring annual pre-recruit surveys of the scallop fishery and during the project's sea snake post-trawl survival trips; (C) shows the CMP; (D) shows locations where Fisheries Queensland observers recorded data. The majority of data were obtained from the CMP.

A total of 3910 sea snakes were reported from all sectors and sampling program types. About 26% of snakes were not identified due to camera problems (e.g. flat batteries, malfunctions), failure of the crew to take a photograph (i.e. forgot, not enough time, sea conditions were too rough) or blurred images. The most numerous species sampled were the spine-bellied sea snake *Lapemis curtus* (931), the olive sea snake *Aipysurus laevis* (515), Dubois' sea snake *Aipysurus duboisii* (465), the horned sea snake *Acalyptophis peronii* (271), the elegant sea snake *Hydrophis elegans* (186) and the small-headed sea snake *Hyrdophis mcdowelli* (153) (Table 6.4.2). These six species comprised about 87% of all identified snakes. *Hydrophis elegans* was sampled from every sector of the fishery, reflecting a distribution which includes a large range in latitude and depth (Figure 6.4.2). The least common species sampled were Stoke's sea snake *Astrotia stokesii* and the spectacled sea snake *Disteira kingii*, both represented by only 30 individuals.

Over half of the snakes (i.e. 2445) were caught in the redspot king prawn sector. The banana prawn sector produced the second highest number of snakes (456) followed by the black tiger prawn broodstock collection fishery (366) and the beam trawl fishery (274). Extremely few sea snakes were sampled from the stout whiting fishery (6), deepwater eastern king prawn sector (5) and Moreton Bay (2). *Lapemis curtus* greatly dominated the sea snake bycatch in the banana prawn and black tiger prawn collection fisheries. The beaked sea snake *Enhydrina schistosa*, the spine-tailed sea snake *Aipysurus eydouxii* and *L. curtus* dominated the beam trawl fishery. These three sectors occur in shallow, inshore waters that generally do not exceed 20 m in depth. In the redspot king prawn fishery, which occurs in offshore reef areas between 30–60 m (Courtney & Dredge 1988; Dredge 1990), *A. laevis* was the most commonly caught snake, followed closely by *A. duboisii* and then *L. curtus* and *A. peronii*. *Lapemis curtus, H. elegans* and *A. eydouxii* were the most abundant sea snake species in the tiger/endeavour prawn fishery.

The stout whiting (*Sillago robusta*) fishery consisted of five license holders who specifically targeted this species. The main management measure for the fishery is a total allowable catch of approximately 1100 tonnes annually and a limited fishing area from Fraser Island south to Caloundra off southern Queensland. In recent years, one operator has adopted Danish seine gear to harvest the catch, rather than benthic otter trawls. Although this is a relatively minor sector of the Queensland trawl fishery with low sea snake interactions (Table 6.4.2), the change is likely to affect sea snake catch rates and complicates estimation of the catch rate expressed as number ha^{-1}, because of the difficulty in calculating swept area for Danish seine gear. For this reason, no estimate of the swept area catch rate is provided for this sector, although catch rates expressed as number boat-day^{-1} are presented.

Of the total of 3910 sea snakes caught, 8.2% were reported as dead (i.e. within-trawl mortality) when the nets came to the surface immediately after trawling (Table 6.4.2). *Hydrophis mcdowelli* had the highest within-trawl mortality rate at 33.3%, followed by the ornate sea snake *Hydrophis ornatus* at 27.2%. *Disteira kingii* also had a relatively high within-trawl mortality rate of 26.7%, although this was based on a total capture of only 30 individuals. Species with comparatively low within-trawl mortality rates were *E. schistosa* (1.2%), *A. duboisii* (5.0%) and *A. eydouxii* (5.3%). Unidentified snakes also had low within-trawl mortality (1.6%).

Table 6.4.2. The total number of sea snakes sampled from each sector of the Queensland trawl fishery for all sampling program types combined. Numbers in brackets are the observed percentage reported dead when the nets came to the surface (i.e. reported within-trawl mortality).

Sector	*Acalyptophis peronii*	*Aipysurus duboisii*	*Aipysurus eydouxii*	*Aipysurus laevis*	*Astrotia stokesii*	*Disteira kingii*	*Disteira major*	*Enhydrina schistosa*	*Hydrophis elegans*	*Hydrophis mcdowelli*	*Hydrophis ornatus*	*Lapemis curtus*	Unidentified	Total
Banana prawn	0	3 (0)	4 (0)	0	1 (0)	1 (0)	5 (0)	0	15 (13.3)	5 (0)	1 (0)	199 (5.0)	222 (0)	456 (2.6)
Beam trawl	0	0	42 (0)	0	1 (0)	0	1 (0)	63 (0)	4 (0)	0	0	24 (0)	139 (0)	274 (0)
Deepwater eastern king prawn	0	0	0	0	0	0	1 (0)	0	3 (33.3)	0	0	0	1 (0)	5 (20.0)
Shallow water eastern king prawn	0	4 (0)	0	15 (13.3)	1 (0)	0	10 (0)	0	21 (14.3)	0	6 (0)	0	57 (0)	114 (4.4)
Moreton Bay	0	0	0	0	0	0	0	0	2 (0)	0	0	0	0	2 (0)
Black tiger prawn (broodstock collection fishery)	0	0	0	0	1 (0)	0	3 (0)	17 (0)	23 (0)	0	0	293 (0.7)	29 (0)	366 (0.6)
Redspot king prawn	262 (17.6)	437 (5.0)	23 (8.7)	478 (9.2)	22 (22.7)	27 (29.6)	27 (37.0)	1 (100)	71 (14.1)	148 (34.5)	77 (31.2)	324 (11.7)	548 (2.6)	2445 (11.3)
Scallop	1 (0)	20 (5.0)	2 (50.0)	10 (40.0)	1 (0)	0	0	0	4 (0)	0	3 (0)	0	0	41 (14.6)
Tiger/endeavour	8 (12.5)	1 (0)	24 (8.3)	11 (0)	3 (0)	2 (0)	7 (0)	0	39 (15.4)	0	7 (28.6)	91 (4.4)	8 (25.0)	201 (8.5)
Stout whiting trawl fishery	0	0	0	1 (0)	0	0	1 (0)	0	4 (25.0)	0	0	0	0	6 (16.7)
All sectors	**271 (17.3)**	**465 (5.0)**	**95 (5.3)**	**515 (9.7)**	**30 (16.7)**	**30 (26.7)**	**55 (18.2)**	**81 (1.2)**	**186 (12.4)**	**153 (33.3)**	**94 (27.7)**	**931 (5.8)**	**1004 (1.6)**	**3910 (8.2)**

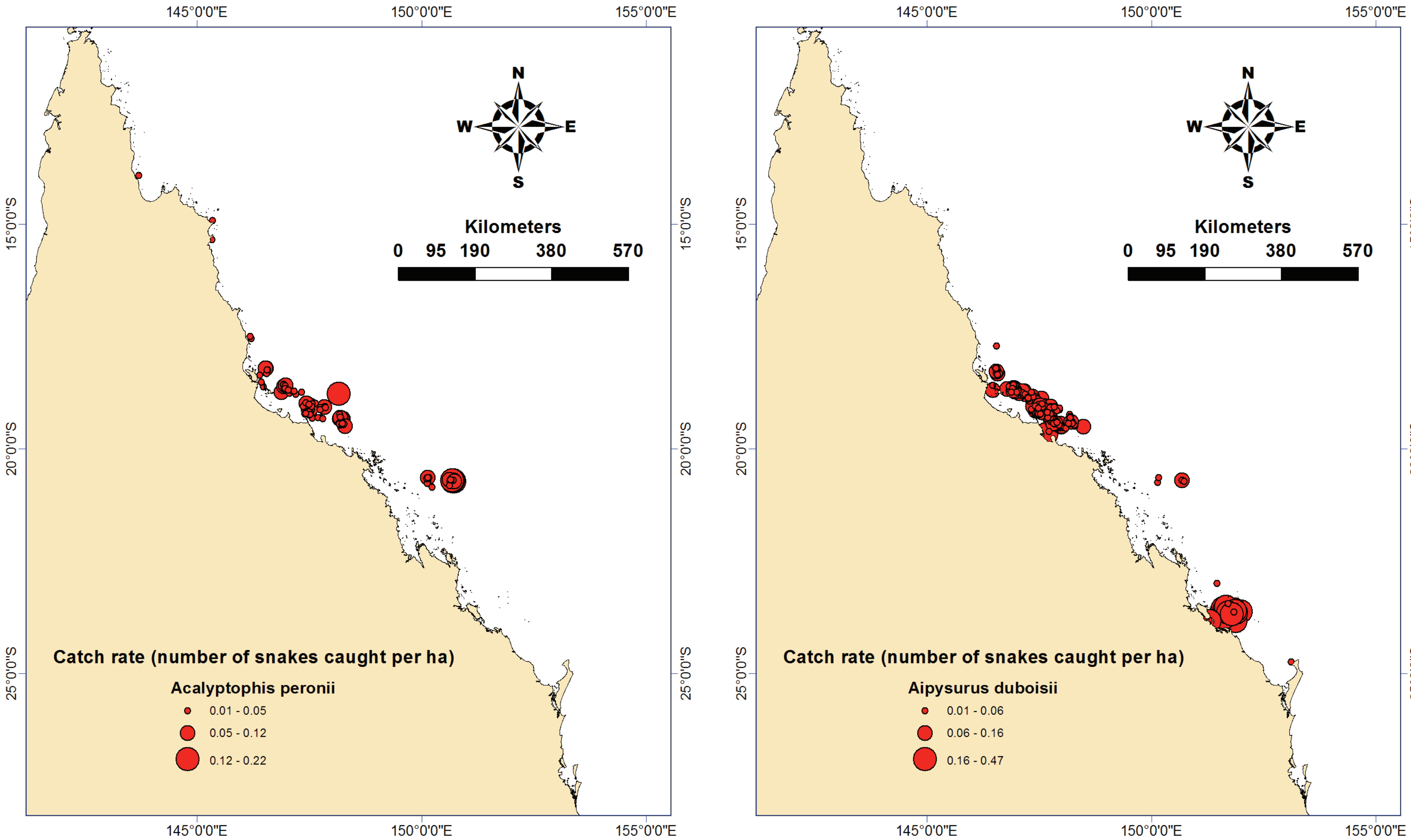
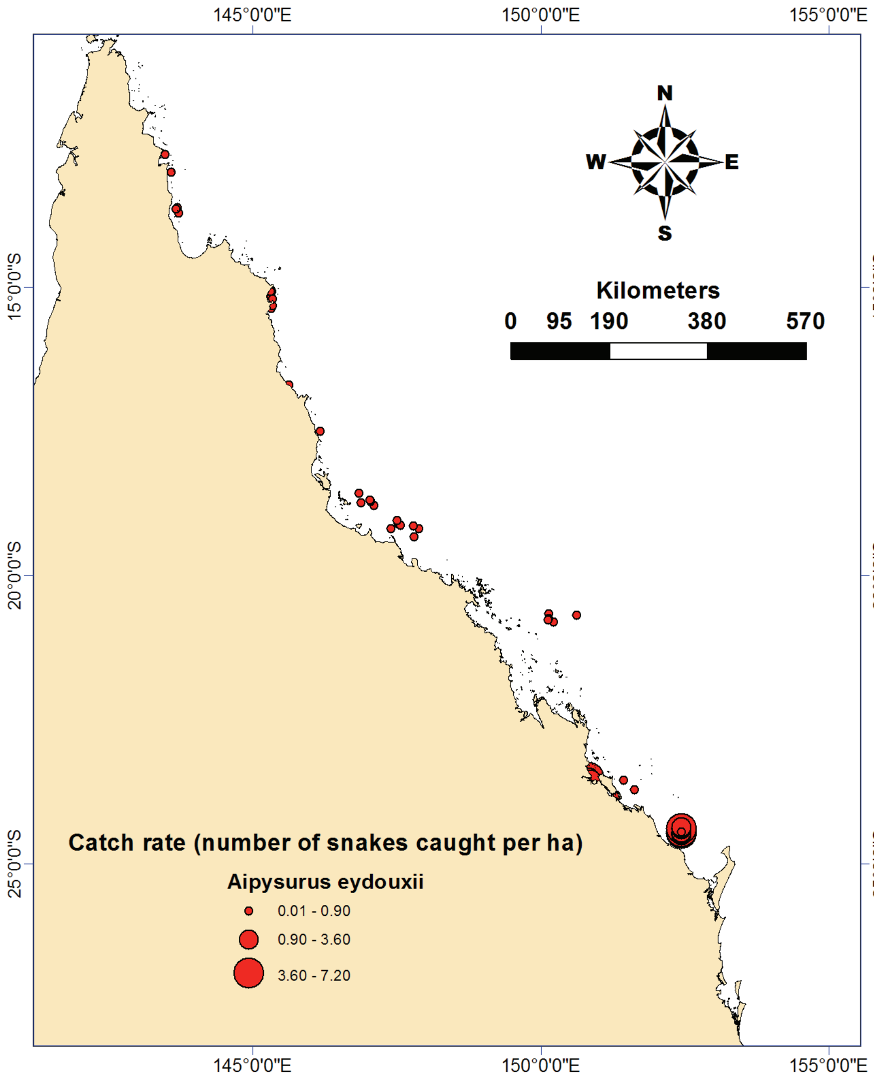


Figure 6.4.2. Distribution and relative abundance of sea snakes caught as bycatch in the Queensland beam trawl and otter trawl fisheries. Locations where no snakes were caught (i.e. zero catch rates) are omitted.



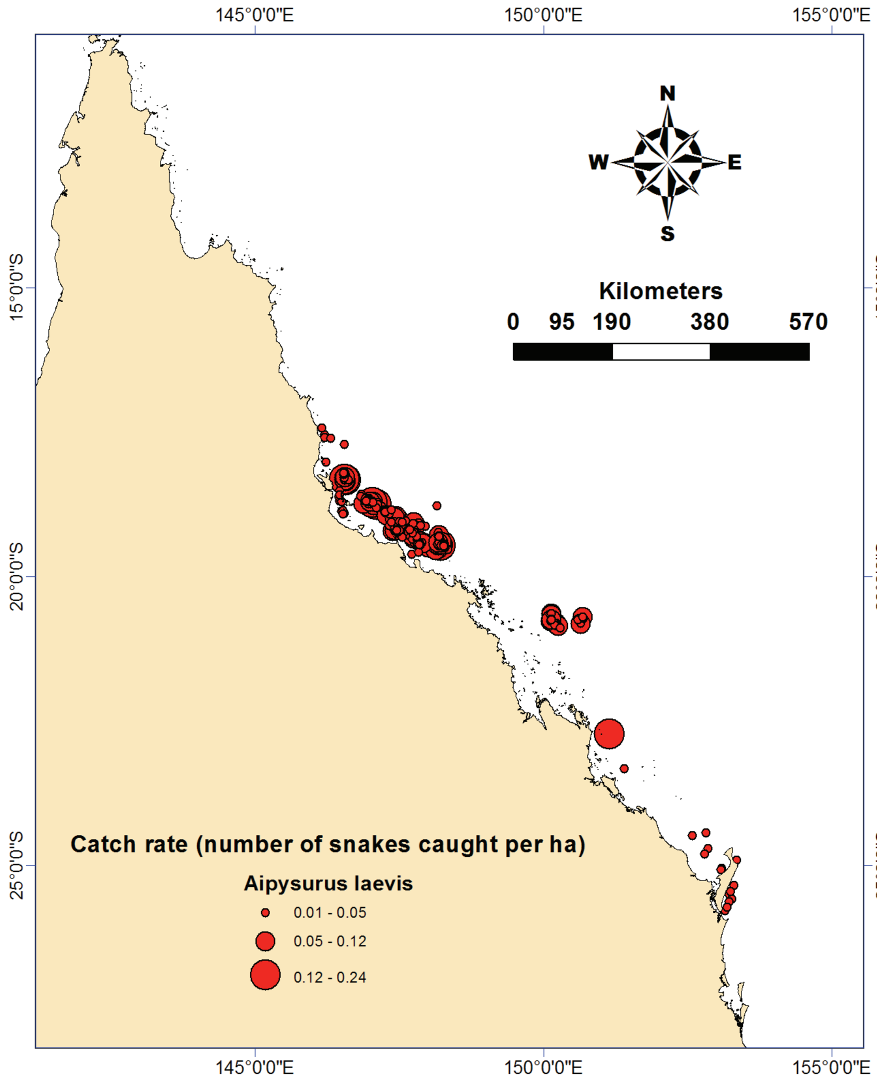
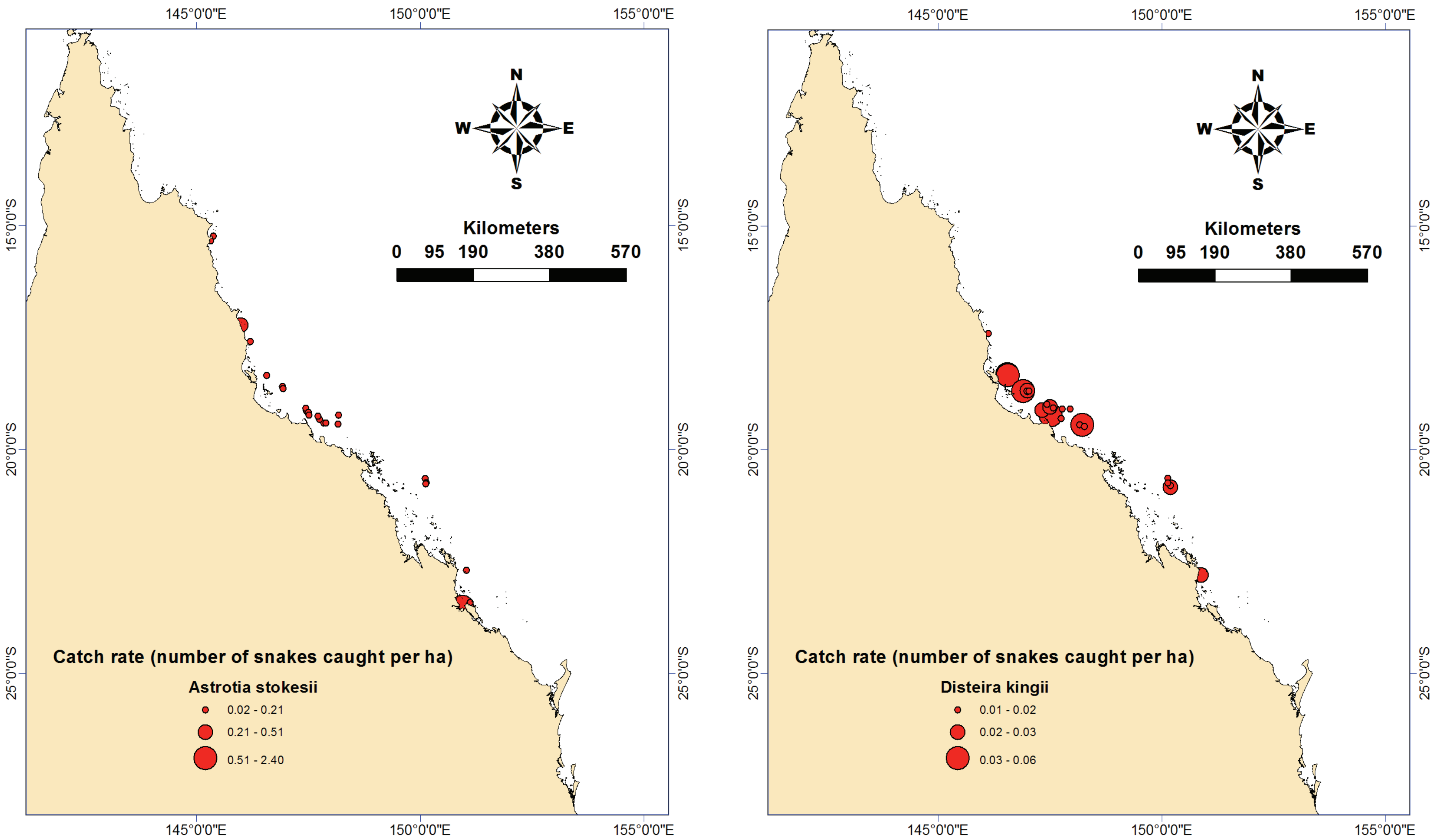


Figure 6.4.2 continued



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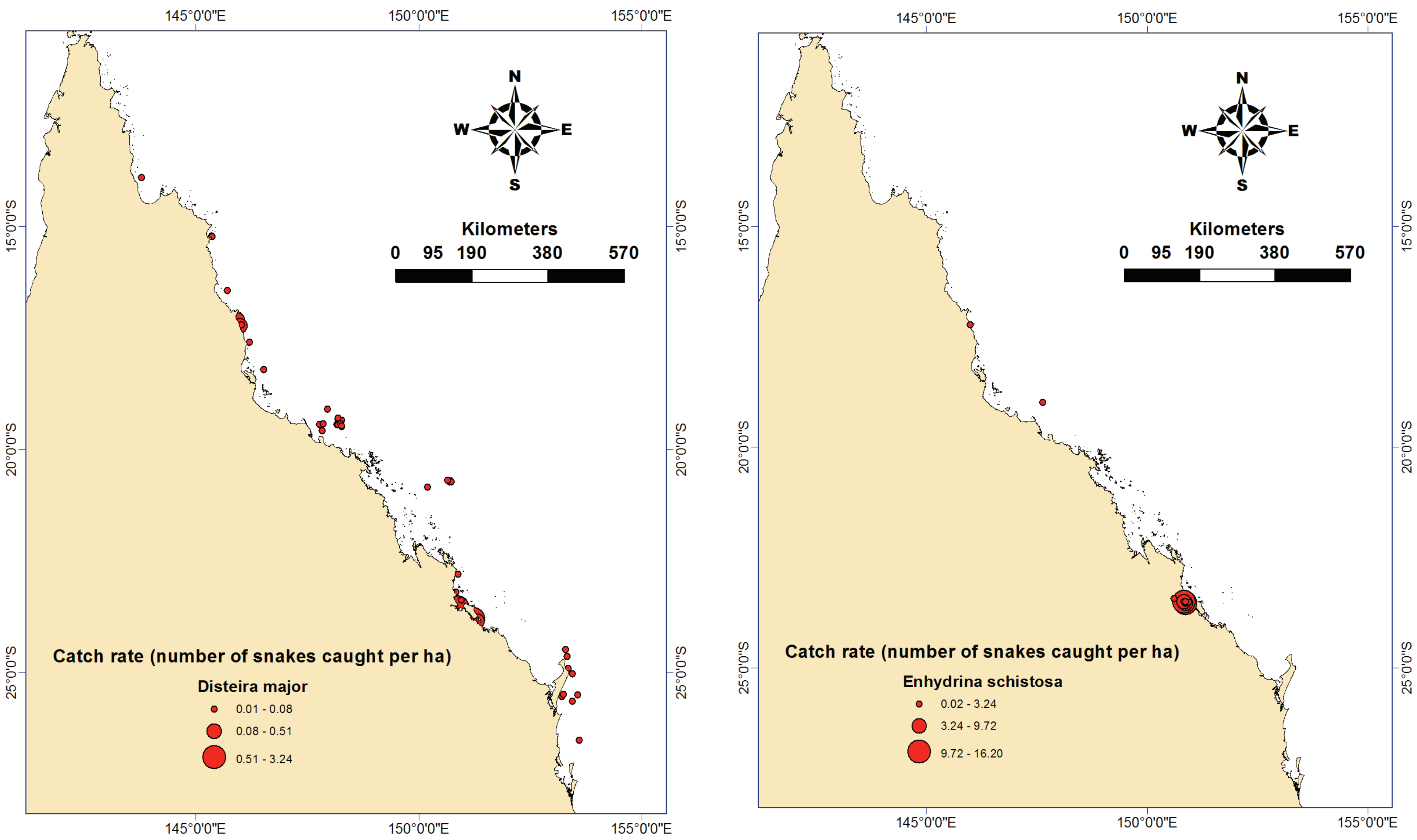

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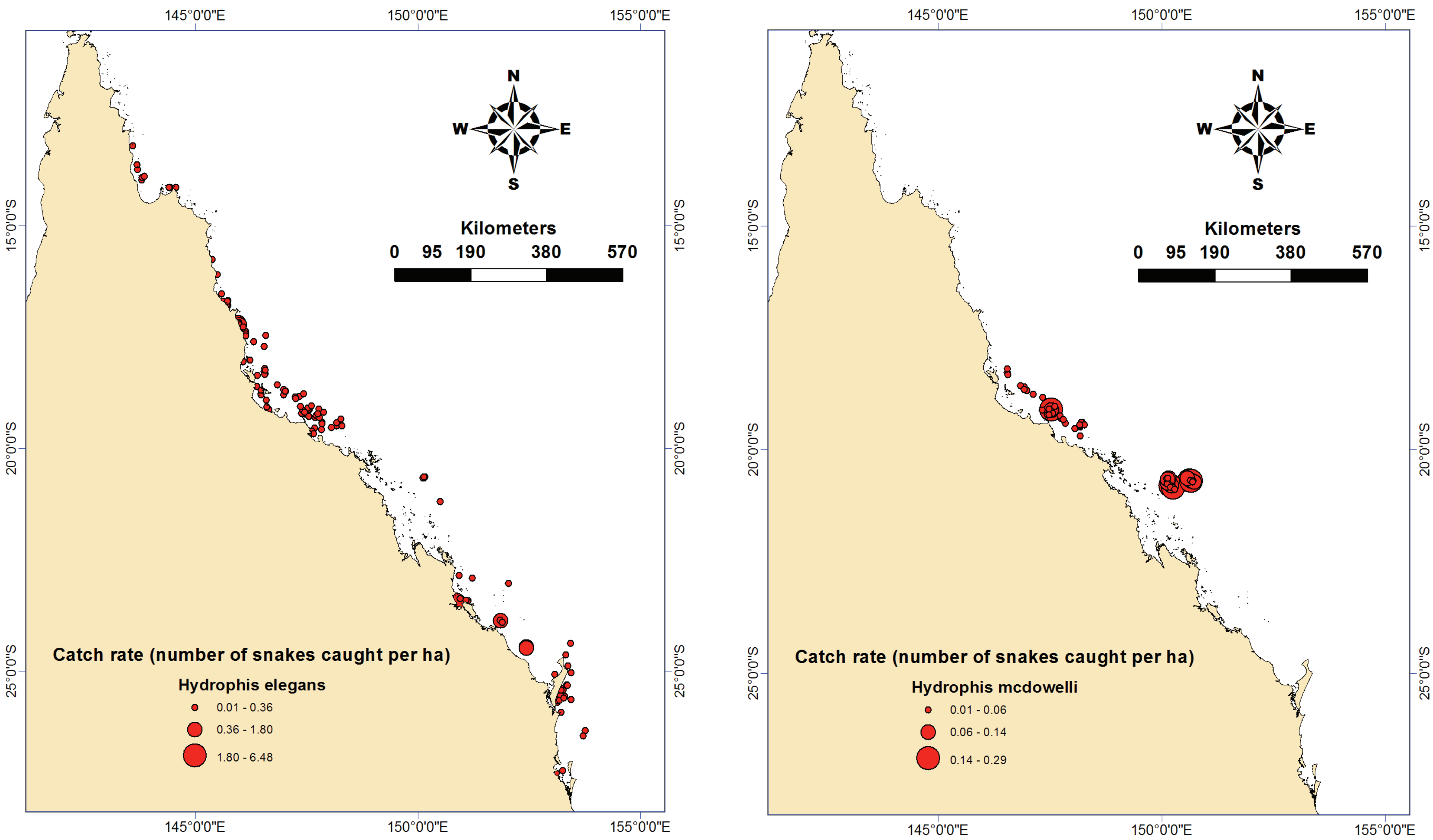

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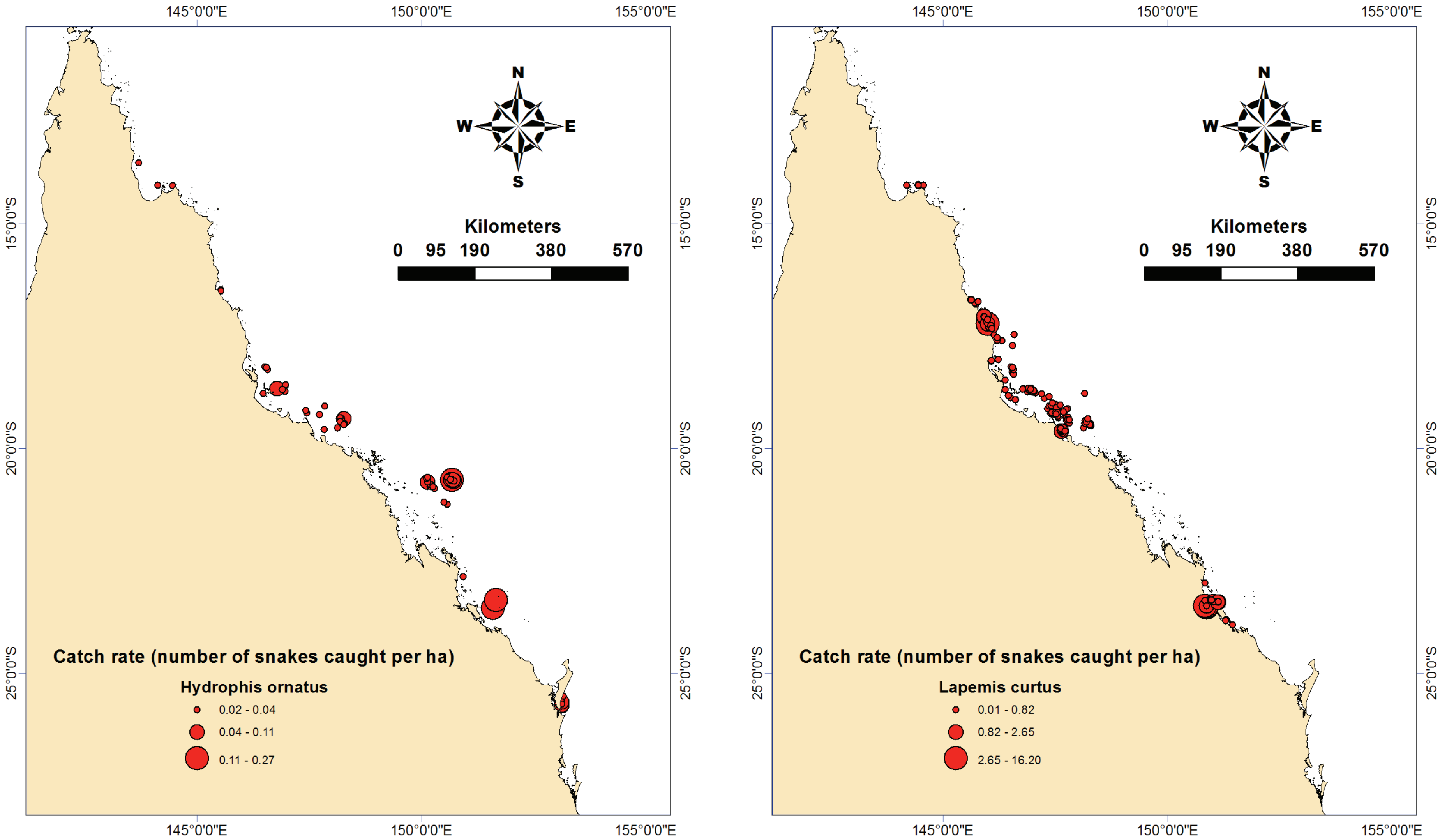

Figure 6.4.2 continued

6.4.1 Modelling catch rates

Catch rates expressed as number swept area^{-1}

The best goodness-of-fit was obtained using a Poisson model with the number of sea snakes caught as the response variable and a logarithm link function (Table 6.4.3). Sea snake catch rates varied significantly with sampling program type, latitude, longitude, and fishery.swept area and fishery.depth interactions. Mesh size was not significant. Catch rates generally declined with increasing latitude and depth (Figure 6.4.3).

Table 6.4.3. Analysis of deviance table for the incidental capture of sea snakes. The model used a Poisson distribution with a logarithm link function. The response variable was number of snakes caught trawl^{-1}. The analysis included all snakes (i.e. live and dead) and only data from commercial trawlers that were undertaking normal trawling operations (i.e. research charters and surveys were omitted).

Term	d.f.	Deviance	Mean deviance	Deviance ratio	Approx. chi prob.
Fishery	8	9023.4582	1127.9323	1127.93	< 0.001
Swept area (ha)	1	552.4291	552.4291	552.43	< 0.001
Depth (m)	1	216.2221	216.2221	216.22	< 0.001
Program	2	418.2721	209.1361	209.14	< 0.001
Fishery.swept area	8	249.1098	31.1387	31.14	< 0.001
Longitude	1	45.5004	45.5004	45.50	< 0.001
Latitude	1	63.6039	63.6039	63.60	< 0.001
Fishery.depth	8	34.7504	4.3438	4.34	< 0.001
Residual	7640	5779.9519	0.7565		
Total	7670	16383.2980	2.1360		

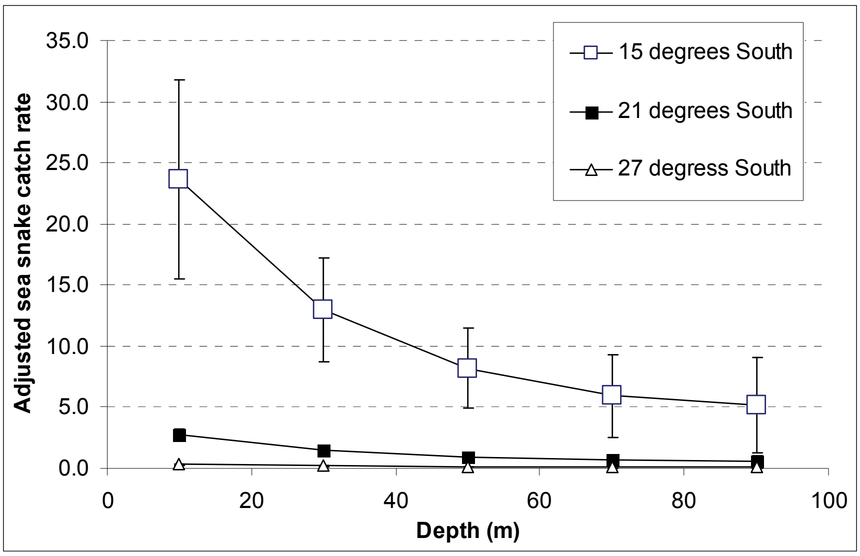

Figure 6.4.3. Adjusted mean catch rates of sea snakes for different latitudes and depths. These means were estimated and based on a fixed value for swept area of 32.16 ha (i.e. the observed mean of the samples) and a longitude of 150.4°E and averaging over levels of sampling program and fishery.

Adjusted catch rates for each fishing sector, standardised for an average swept area of 32.16 ha and longitude of 150.4°S, are provided in Table 6.4.4. Adjusted catch rates for the banana prawn and redspot king prawn sectors were relatively high and generally larger than 1.0, while the scallop, shallow water and deepwater eastern king prawn sectors were low and generally less than 0.02. The tiger/endeavour prawn sector displayed intermediate catch rates that generally varied between 1.0 and 0.1. Catch rates for some sectors were associated with high standard errors and therefore should be considered with caution.

The high variances for Moreton Bay and the deepwater eastern king prawn sector were likely due to extremely few snakes reported for these sectors, while the high variance for the broodstock collection fishery is more difficult to explain. The influence of swept area on catch rates requires some clarification because while sea snake catches might be expected to increase with the area swept by the trawl, this is not always the case. The largest areas swept by trawls occur in the deepwater eastern king prawn sector where the total net head rope lengths are large (i.e. generally larger than 50 m) and the trawl durations are long, frequently exceeding three hours, but because this sector occurs at higher latitudes (i.e. 22–27°S) and in greater depths (> 100 m), the sea snake catch rates are very low, hence the significant fishery.swept area interaction.

Table 6.4.4. Adjusted incidental sea snake catch rates (includes both live and dead snakes) in the Queensland trawl fishery. Adjusted means are provided for seven depths (10 m, 30 m, 50 m, 70 m, 90 m, 130 m and 150 m) and five latitudes (15 °S, 18 °S, 21°S, 24 °S and 27°S) and standardised for a mean swept area of 32.16 ha and longitude of 150.4°S. Means are provided only for those depths and latitudes that characterise individual sectors (e.g. the deepwater eastern king prawn sector mainly occurs at latitudes ≥20°S and depths >100 m). Standard errors in brackets.

Depth (m)	Latitude (°S)	Banana prawn	Beam trawl*	Black tiger prawn (broodstock collection)*	Tiger/endeavour prawn	Redspot king prawn	Scallop	Moreton Bay*	Shallow water eastern king prawn	Deepwater eastern king prawn
10	15				1.091 (0.384)					
10	18			10.349 (5.191)	0.373 (0.104)					
10	21	11.279 (1.355)		2.815 (1.335)	0.127 (0.032)					
10	24	3.854 (0.519)	0.093 (0.010)							
10	27	1.317 (0.302)	0.025 (0.005)					0.002 (0.002)		
30	15				1.034 (0.404)					
30	18			1.131 (3.030)	0.353 (0.113)					
30	21	10.545 (3.395)		0.308 (0.821)	0.121 (0.035)		0.01 (0.004)			
30	24	3.603 (1.155)					0.003 (0.001)		0.073 (0.010)	
30	27	1.231 (0.449)						0.001 (0.005)	0.025 (0.005)	
50	15				0.98 (0.751)					
50	18				0.335 (0.245)	12.818 (1.945)				
50	21				0.114 (0.082)	4.38 (0.216)	0.035 (0.012)			
50	24					1.497 (0.169)	0.012 (0.004)		0.048 (0.007)	
50	27								0.016 (0.004)	
70	15									
70	18					6.351 (0.863)				
70	21					2.17 (0.143)				
70	24					0.742 (0.108)			0.031 (0.009)	
70	27								0.011 (0.003)	
90	15									
90	18									
90	21									
90	24								0.02 (0.009)	
90	27								0.007 (0.003)	
130	15									
130	18									
130	21									0.002 (0.001)
130	24									
130	27									
150	15									
150	18									
150	21									0.001 (0.001)
150	24									
150	27									

* Adjusted means for these sectors were obtained using a slightly different model to Table 6.4.3 (i.e. the fishery.swept area interaction was dropped) due to aliasing problems affecting predictions. Adjusted means for Moreton Bay should be considered with caution as only two snakes were caught in this sector, despite considerable sampling effort.

Catch rates expressed as number boat-day^{-1}
Sea snake catch rate data were obtained from a total of 1759 boat-days of commercial fishing effort (Table 6.4.5). The largest amount of sampling was 380 boat-days in the tiger/endeavour prawn sector, followed by the deepwater eastern king prawn sector (362 boat-days), the scallop fishery (251 boat-days) and the beam trawl fishery (232 boat-days). The banana prawn sector (44 boat-days), Moreton Bay (42 boat-days), black tiger prawn broodstock collection (28 boat-days) and stout whiting fisheries (21 boat-days) received relatively low levels of sampling effort.

The frequency of sea snake catches was generally skewed and dominated by zero catches (Figure 6.4.4). Of the 1759 boat-days sampled, 1294 boat-days (74%) recorded no sea snake bycatch, 149 boat-days (9%) reported catching one sea snake and 56 boat-days (3%) reported catching two snakes. The maximum number of snakes caught by a single vessel on one day was 51 and occurred in the banana prawn fishery (Table 6.4.5). Occasionally, catch rates exceeded 40 snakes boat-day^{-1} in the banana prawn, black tiger prawn brood stock collection and the redspot king prawn fisheries (Figure 6.4.4). Sea snake catches in the redspot king prawn fishery were both relatively frequent and high, and generally ranged from 2–25 snakes boat-day^{-1}.

When all sectors were pooled, the overall observed mean sea snake catch rate was 2.12 s.e. 0.14 boat-day^{-1}. This overall mean should be considered carefully because the sampling effort may not have been stratified enough to reflect the level of fishing effort in each sector. This is because the researchers did not have total control over the sampling effort (e.g. participation by fishers was voluntary). Nevertheless, it can be referred to as the overall observed sample mean.

The observed catch rates and their standard errors (Table 6.4.5) should be interpreted with further caution because the data were skewed, and hence do not conform to a normal distribution. (The adjusted catch rates and standard errors of Table 6.4.7 should be considered as more robust as they were derived from the GLM which took account of the distribution of the data).

The highest observed sea snake catch rate was 13.07 s.e. 2.24 boat-day^{-1} in the broodstock collection fishery, followed by the redspot king prawn fishery with a catch rate of 12.49 s.e. 0.63 boat-day^{-1} and the banana prawn fishery with a catch rate of 8.82 s.e. 2.05 boat-day^{-1}. The lowest catch rate was 0.01 s.e. 0.01 boat-day^{-1} in the deepwater eastern king prawn sector. The scallop fishery and Moreton Bay also had very low observed catch rates.

Table 6.4.5. The observed mean catch rate of sea snakes (number boat-day^{-1}) for each sector of the Queensland trawl fishery and details of the sampling program. Only data from commercial trawlers that were undertaking their normal fishing activities were included (i.e. research charters and surveys were omitted). Includes both live and dead snakes.

	Banana prawn	Beam trawl	Black tiger prawn (broodstock collection)	Tiger/endeavour prawn	Redspot king prawn	Scallop	Moreton Bay	Shallow water eastern king prawn	Deepwater eastern king prawn	Stout whiting	All sectors
Number of boat-days sampled	44	232	28	380	194	251	42	205	362	21	1759
Mean sea snake catch rate (number boat-day^{-1})	8.82	1.18	13.07	0.35	12.49	0.06	0.05	0.55	0.01	0.14	2.12
Maximum number of snakes caught in a day by a vessel	51	25	50	9	48	3	1	11	1	2	51
Standard deviation	13.62	3.09	11.87	0.90	8.75	0.28	0.22	1.26	0.12	0.48	5.87
Standard error	2.05	0.20	2.24	0.05	0.63	0.02	0.03	0.09	0.01	0.10	0.14

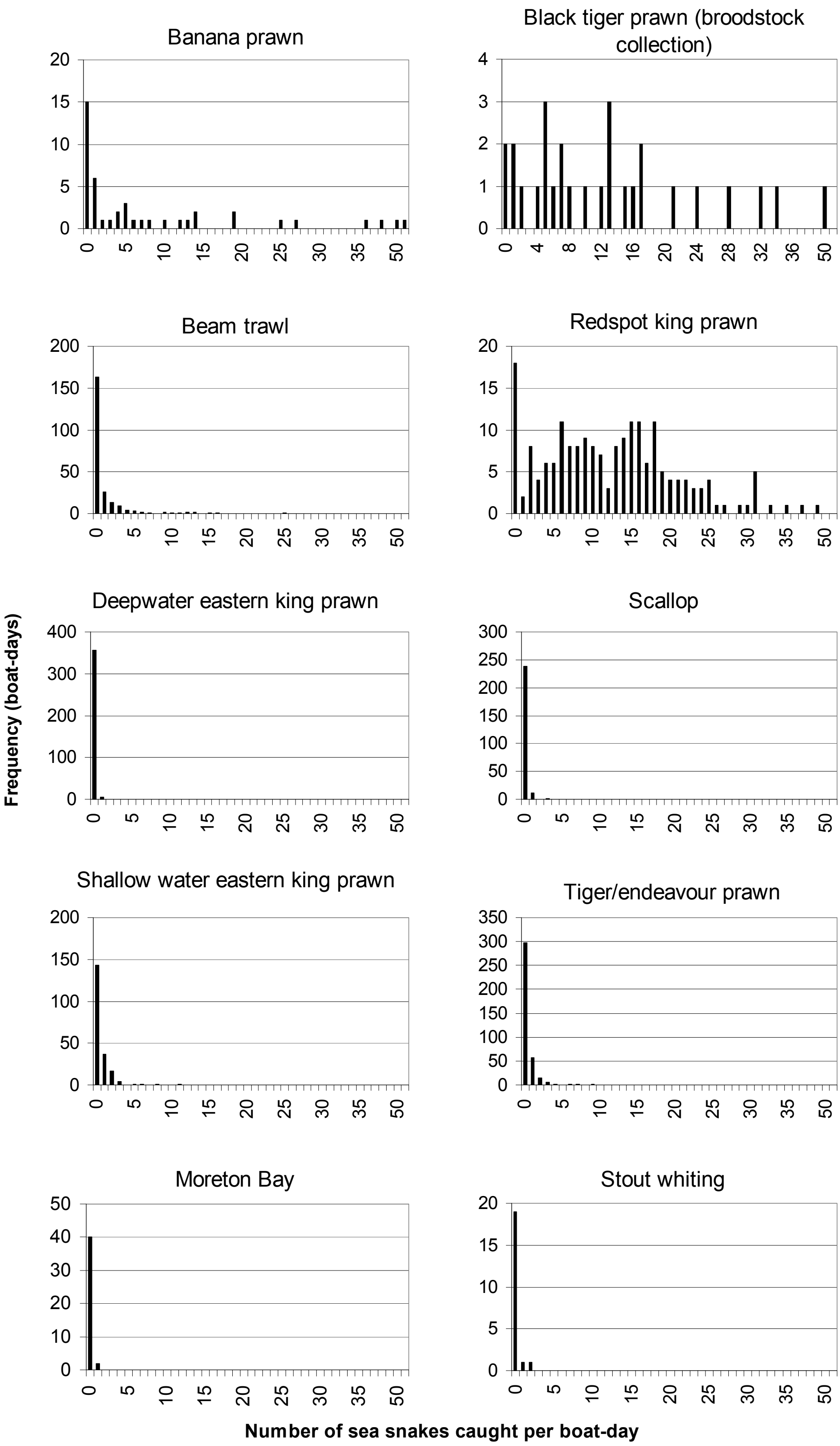

Figure 6.4.4. The frequency distribution of sea snake catches in each sector of the Queensland trawl fishery. The distributions were generally skewed and dominated by a high number of days when no (i.e. zero catches) snakes were caught, although occasionally in the banana prawn, black tiger prawn and redspot king prawn sectors catch rates exceeded 40 snakes boat-day^{-1}. Note the relatively high frequencies and catch rates for the redspot king prawn fishery. The fishing power of the vessels differs greatly between sectors and therefore caution is required when making between-sector comparisons.

Catch rates expressed as number boat-day^{-1} were modelled to identify influential factors and covariates. The adjusted means were then used to estimate total annual catches and mortalities. Because catches from individual vessels were summed for each day, the range of explanatory factors and covariates, which were measured for individual trawls, was reduced. Factors considered in the modelling were fishery, vessel, month and season. Although depth, BRD type, swept area, latitude and longitude were not considered, some of these descriptors were at least partially captured by the fishery term. Vessel (i.e. the vessel's unique identification) was initially found to be significant; however, as most vessels only fished in one, two or at most three sectors, this resulted in a high degree of aliasing between vessel and fishery, and so it was not appropriate to fit constants based on the assumption that vessels fished across sectors. For example, it was impossible to determine whether a vessel that fished in the redspot king prawn fishery had high sea snake catch rates because of the vessel's properties or because of the sector it was fishing in. Vessel was therefore omitted from the model. The final model was a two-part conditional model (Mayer et al. 2005), which firstly considered the binomial data (i.e. presence or absence) using a logit link function, and then the non-zero catch data using a gamma distribution with a logarithm link function. Final adjusted means were calculated as the product of means from the two-model parts. This model resulted in better fitting residuals, and hence more accurate adjusted means and standard errors, compared to any other model type trialled. The analyses of deviance tables for the binomial and gamma models (Table 6.4.6) both indicated that fishery explained most of the variation and that season explained comparatively little variation. The fishery.season interaction explained a similar amount of variation as the season main effect alone.

Table 6.4.6. Analysis of deviance for the two-part conditional model used for analysing sea snake catch rates. Part 1 used a binomial distribution with logit link function to model presence/absence of sea snakes boat-day^{-1}. Catch rate data were obtained for a total of 1759 boat-days. Part 2 used a gamma distribution with log link function to model the number of snakes caught boat-day^{-1}, based on 465 days when sea snakes were caught. The analyses included all snakes (i.e. live and dead) and only data from commercial trawlers undertaking their normal trawling operations (i.e. research charters and surveys were omitted).

Part 1 – Binomial model

Term	d.f.	Deviance	Mean deviance	Deviance ratio	Approx. chi prob.
Fishery	9	732.6207	81.4023	81.4	<.001
Season	3	7.2815	2.4272	2.43	0.063
Fishery.season	24	68.5317	2.8555	2.86	<.001
Residual	1722	1223.432	0.7105		
Total	1758	2031.866	1.1558		

Part 2 – Gamma model

Term	d.f.	Deviance	Mean deviance	Deviance ratio	Approx. F prob.
Fishery	9	375.8543	41.7616	83.42	<.001
Season	3	5.4877	1.8292	3.65	0.013
Fishery.season	18	33.722	1.8734	3.74	<.001
Residual	434	217.2661	0.5006		
Total	464	632.33	1.3628		

Adjusted catch rates were consistently high (i.e. > 10 sea snakes boat-day^{-1}) in the black tiger prawn broodstock collection fishery for all seasons, although two of the four adjusted means were associated with very high standard errors (Table 6.4.7). Although this sector had the highest catch rates, it receives relatively little fishing effort and therefore catches relatively few snakes annually. The redspot king prawn fishery had the next highest catch rates, ranging from 3.833 s.e. 3.671 boat-day^{-1} in summer to 14.180 s.e. 0.920 boat-day^{-1} in winter. This fishery mainly takes place in reef-associated areas in winter and spring. Trawl fishing effort is low in summer and autumn and the sampling effort reflected this seasonal pattern, which may explain the high variances during these seasons. The banana prawn fishery had similar relatively high catch rates that ranged from 12.126 s.e. 3.865 boat-day^{-1} in summer to 2.998 s.e. 2.123 boat-day^{-1} in spring. This fishery mainly takes place in summer and autumn, usually following high rainfall. Again, the high variances associated with winter and spring catch rates probably reflect low sampling effort.

Table 6.4.7. The adjusted catch rates of sea snakes (i.e. number caught boat-day^{-1}) from the two-part conditional model for each sector and season. Standard errors in brackets.

Season	Banana prawn	Beam trawl	Black tiger prawn (broodstock collection)	Tiger/endeavour prawn	Redspot king prawn	Scallop	Moreton Bay	Shallow water eastern king prawn	Deepwater eastern king prawn	Stout whiting
Winter	8.000 (4.052)	3.997 (2.830)	18.000 (7.401)	0.500 (0.149)	14.180 (0.920)	*	*	0.556 (0.236)	0.023 (0.018)	0.300 (0.223)
Spring	2.998 (2.123)	1.976 (0.565)	12.857 (2.692)	0.291 (0.067)	10.231 (1.162)	0.091 (0.038)	*	0.500 (0.237)	*	*
Summer	12.126 (3.865)	1.638 (0.311)	10.118 (2.533)	*	3.833 (3.671)	*	0.053 (0.052)	0.407 (0.087)	0.012 (0.012)	*
Autumn	6.53 (1.322)	0.347 (0.083)	14.989 (10.613)	0.330 (0.056)	5.996 (4.245)	0.074 (0.042)	0.050 (0.049)	0.708 (0.152)	0.012 (0.01)	*

* Indicates insufficient or missing data, resulting in aliasing or the inability to derive a catch rate estimate in certain sectors and seasons. This was due to a) not obtaining adequate samples and b) low or no fishing effort to sample from.

6.4.2 Modelling within-trawl mortality rates

Mortality rates expressed as number trawl^{-1}
The within-trawl mortality analysis was based on 1179 trawls from commercial fishing vessels where one or more snakes were caught. Where more than one snake species was recorded from a particular trawl, the trawl details were repeated in the data matrix for each subsequent species so that the influence of 'species' could be examined (hence the d.f. in Table 6.4.8 exceeds 1179). Zero catch data were omitted as these records provided no information on mortality rates. The proportion of dead snakes caught in each trawl was defined as the number observed dead divided by the total number of snakes caught (for each species). The model used a binomial distribution with logit link function.

Relatively few factors significantly affected within-trawl mortality, possibly because most of the variance was explained by a single factor—species (DR = 22.62, d.f. = 12, $P < 0.001$, Table 6.4.8), followed by fishery (DR = 10.80, d.f. = 8, $P < 0.001$). The species.fishery interaction term was not significant and therefore dropped from the model. The influence of sampling program type was marginal (DR = 2.29, d.f. = 2, $P = 0.102$). The overall adjusted within-trawl mortality rate from this model was 0.0710 s.e. 0.0074, which is similar to the overall observed rate of 0.082 (8.2%, Table 6.4.2).

Within-trawl mortality increased significantly with increasing trawl duration (DR = 5.46, d.f. = 1, $P = 0.019$) and depth (DR = 4.73, d.f. = 1, $P = 0.030$), although both covariates were not completely independent of fishery (i.e. the black tiger prawn broodstock collection fishery generally undertakes short trawls of 15–30 minutes in depths less than 20 m, while the deepwater eastern king prawn sector trawls generally exceed two hours in depths greater than 100 m). The adjusted within-trawl mortality rate approximately doubled with every 50 m increase in depth (e.g. the within-trawl mortality rate was 0.0510 s.e. 0.01176 in 10 m and 0.1116 s.e. 0.01993 in 60 m).

Table 6.4.8. Analysis of deviance for the proportion of snakes that were observed as dead immediately after each trawl. Only data from commercial trawlers that were undertaking their normal trawling operations were included (i.e. research charters and surveys were omitted).

Term	d.f.	Deviance	Mean deviance	Deviance ratio	Approx. chi prob.
Species	12	271.4428	22.6202	22.62	<0.001
Fishery	8	86.3857	10.7982	10.80	<0.001
Program	2	4.5719	2.2859	2.29	0.102
Hours trawled	1	5.4622	5.4622	5.46	0.019
Depth	1	4.7329	4.7329	4.73	0.030
Residual	1809	1263.1178	0.6982		
Total	1833	1635.7132	0.8924		

Adjusted within-trawl mortality rates for each species are shown in Table 6.4.9. The small-headed sea snake (*H. mcdowelli*), which was mainly caught in the redspot king prawn fishery, had the highest adjusted mean within-trawl mortality rate (0.2220 s.e. 0.03354), followed by *H. ornatus* (0.1913 s.e. 0.03805), *D. kingii* (0.1749 s.e. 0.05809) and *D. major* (0.1494 s.e. 0.04634). The beaked sea snake (*E. schistosa*) had the lowest observed within-trawl mortality rate (overall observed rate was 1.2%, Table 6.4.2).

Of the 81 *E. schistosa* caught, only one was reported dead. The 80 live individuals were caught in the shallow water beam trawl and black tiger prawn broodstock collection fisheries, where trawl durations are typically very short, while the dead individual was caught in the redspot king prawn sector. This one individual resulted in a 100% (i.e. one from one) mortality rate for *E. schistosa* in the redspot king prawn fishery and the influence of this one individual appears to prevent the model from deriving a reliable adjusted mean. Thus, while the observed within-trawl mortality rate for this species was very low, no reliable adjusted mean rate could be obtained. Interestingly, all three *Aipysurus* species were associated with relatively low (i.e. < 0.05) adjusted within-trawl mortality rates (Table 6.4.9). The adjusted within-trawl mortality rate for *L. curtus*, which was the most commonly encountered sea snake, was 0.0754 s.e. 0.01072.

Table 6.4.9. Adjusted within-trawl mortality rates for each snake species, based on the analysis of deviance shown in Table 6.4.8. These adjusted means are based on the fixed mean variate values of hours trawled = 2.681 h and depth = 30.69 m, and are standardised by averaging over factor levels for sampling program type and fishery.

Species	Adjusted within-trawl mortality rate	Standard error
Acalyptophis peronii	0.1066	0.01751
Aipysurus duboisii	0.0308	0.00677
Aipysurus eydouxii	0.0472	0.02430
Aipysurus laevis	0.0589	0.00919
Astrotia stokesii	0.1048	0.04616
Disteira kingii	0.1749	0.05809
Disteira major	0.1494	0.04634
Enhydrina schistosa	-	-
Hydrophis elegans	0.1143	0.02457
Hydrophis mcdowelli	0.2220	0.03354
Hydrophis ornatus	0.1913	0.03805
Lapemis curtus	0.0754	0.01072
Unidentified	0.0133	0.00365

The adjusted within-trawl mortality rates, based on the analysis of deviance (Table 6.4.8) and the pooling of species, are shown for each sector in Table 6.4.10. The lowest mortality rates (i.e. < 0.008) were for the beam trawl and black tiger prawn broodstock collection fisheries, probably because of the short trawl durations in these sectors. Adjusted means for the banana prawn, tiger/endeavour prawn and redspot king prawn sectors varied between 0.0448 to 0.0686, 0.0647 to 0.1657 and 0.0836 to 0.1339, respectively. Means for Moreton Bay, the deepwater eastern king prawn and scallop sectors were based on extremely few sea snake catches with generally very large standard errors and should be interpreted with caution.

Table 6.4.10. Adjusted mean within-trawl mortality rates of sea snakes in the Queensland beam and otter trawl fisheries. Means are provided for the observed ranges of trawl depths and durations for each sector. For example, the beam trawl fishery generally occurs in depths less than 20 m and for trawl durations of less than one hour.

Hours trawled	Depth (m)	Beam trawl	Banana prawn	Black tiger prawn broodstock collection	Tiger/endeavour prawn	Redspot king prawn	Scallop[1]	Moreton Bay[1]	Shallow water eastern king prawn	Deepwater eastern king prawn[1]
0.5	10	0.0001 (0.00021)	0.0448 (0.01435)	0.0052 (0.00378)						
0.5	20	0.0001 (0.00026)	0.0531 (0.017)	0.0063 (0.0046)						
0.5	30		0.0627 (0.02115)	0.0076 (0.00567)						
0.5	50									
0.5	70									
0.5	90									
0.5	120									
0.5	130									
1	10		0.0491 (0.01538)		0.0647 (0.0196)			0 (0.00243)		
1	20		0.0581 (0.01825)		0.0762 (0.02147)		0.1845 (0.0872)	0.0001 (0.00294)		
1	30		0.0686 (0.02276)		0.0894 (0.02502)		0.2103 (0.09178)	0.0001 (0.00356)	0.0399 (0.0187)	
1	50				0.1214 (0.03917)	0.0836 (0.01515)	0.2688 (0.10425)		0.0561 (0.02558)	
1	70					0.114 (0.02714)			0.0779 (0.03802)	
1	90								0.1066 (0.05818)	
1	120									
1	130									
2	10				0.0772 (0.02093)			0.0001 (0.00299)		
2	20				0.0905 (0.02281)		0.2126 (0.09466)	0.0001 (0.00361)		
2	30				0.1057 (0.02679)		0.2409 (0.09879)	0.0001 (0.00437)	0.048 (0.02168)	
2	50				0.1422 (0.04293)	0.0991 (0.01308)	0.3039 (0.1104)		0.0671 (0.02958)	
2	70					0.1339 (0.02796)			0.0925 (0.0438)	
2	90								0.1255 (0.06643)	
2	120									
2	130									
3	10				0.0917 (0.02312)					
3	20				0.107 (0.02522)		0.2433 (0.10285)			
3	30				0.1244 (0.02984)		0.274 (0.10648)		0.0576 (0.02549)	
3	50				0.1657 (0.04814)		0.3411 (0.11704)		0.08 (0.03465)	
3	70								0.1093 (0.05088)	
3	90								0.1468 (0.07603)	
3	120									0.1122 (0.10633)
3	130									0.1302 (0.12018)
4	10									
4	20									
4	30									
4	50									
4	70									
4	90									
4	120									0.1318 (0.11989)
4	130									0.1522 (0.13449)

[1] Adjusted means for these sectors were based on extremely low catches of snakes and therefore should be considered with caution.

Mortality rates expressed as number boat-day^{-1}

When the data were pooled for each vessel and day, there were 463 boat-days out of the total 1738 commercial fishing vessel boat-days sampled that recorded catching one or more sea snakes. On 344 of the 463 days, fishers recorded no within-trawl mortality (Figure 6.4.5)—that is, 74.0% of days when sea snakes were caught, no within-trawl mortality was observed. On 18 of the 463 days when snakes were caught (i.e. 3.8%), fishers recorded 100% mortality. Overall, of the 3740 snakes caught on commercial fishing vessels during their normal fishing activities, 315 were reported dead when the nets came to the surface—an observed within-trawl mortality of 8.4%. This figure differs slightly from the 8.2% reported in Table 6.4.2 because the table includes all sampling types, including research trawls and surveys.

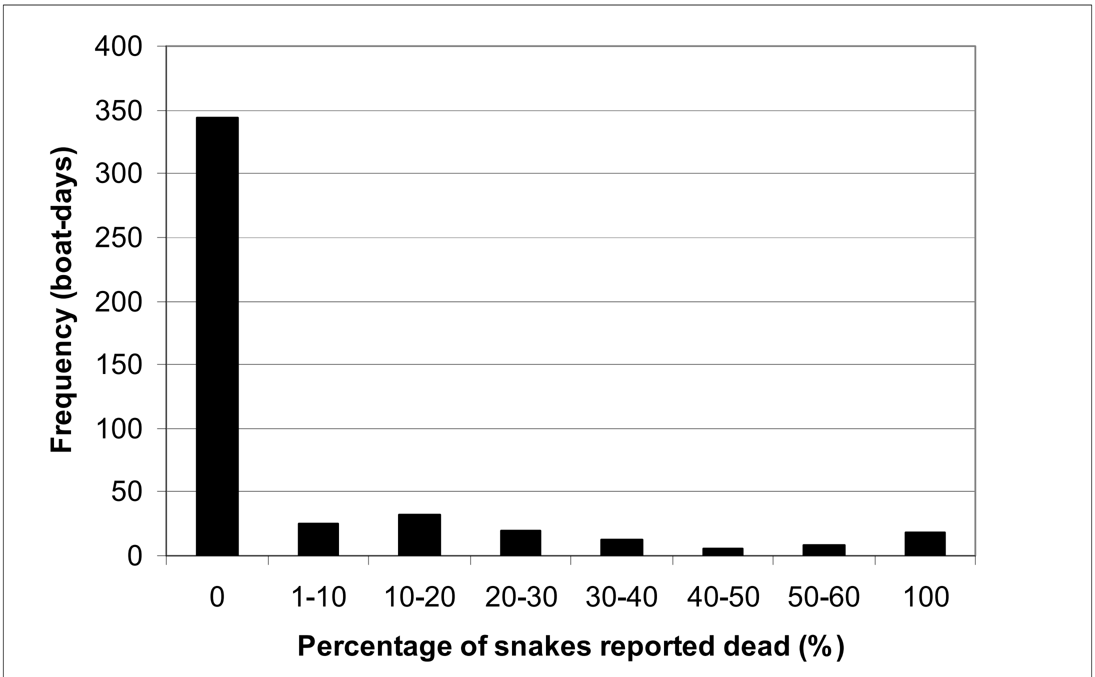

Figure 6.4.5. The frequency distribution for the reported within-trawl mortality rate of sea snakes caught incidentally in trawl nets. For most sampling effort (i.e. 74.0%) no within-trawl mortality was observed. High mortality (i.e. 100%) was recorded for 3.8% of the days sampled. These data are from commercial trawlers undertaking their normal fishing activities and do not include research charters or surveys.

These data were modelled using a binomial distribution with logit link function. The response variable was the proportion of snakes caught boat-day^{-1} that were observed as dead when the nets were brought to the surface (e.g. if a vessel reported catching 10 snakes over a 24-hour period, four of which were dead, then the proportion response variable was 0.4). As with the earlier catch rate analysis, pooling to boat-days reduced the number of factors that could be examined to fishery, season and their interaction term. Fishery explained most of the variation in within-trawl mortality, followed by season (Table 6.4.11). The fishery.season interaction term was also significant.

Table 6.4.11. Analysis of deviance of proportion of snakes that were observed as dead boat-day^{-1} of fishing effort. Only data from commercial trawlers that were undertaking their normal trawling operations (i.e. research charters and surveys were omitted) were included. Sea snake species were pooled.

Term	d.f.	Deviance	Mean deviance	Deviance ratio	Approx. chi prob.
Fishery	9	154.488	17.165	17.17	<.001
Season	3	14.04	4.68	4.68	0.003
Fishery.season	18	43.127	2.396	2.40	<.001
Residual	435	522.788	1.202		
Total	465	734.442	1.579		

Adjusted mean within-trawl mortality rates for fishing sectors and seasons were derived from the model (Table 6.4.12). Most missing values can be attributed to the seasonal nature of the fishing sectors, low fishing effort or closures. The largest adjusted within-trawl mortality rate was in winter in the deepwater eastern king prawn fishery (0.5 s.e. 0.35). However, catch rates for this sector are very low (Table 6.4.5 and Table 6.4.7) and so the estimate was based on extremely few deaths—only five snakes were recorded from this sector over the entire study period, one of which was reported dead. Similarly, relatively high mortality rates were estimated for the scallop fishery in spring and the stout whiting fishery in winter, but again the catch rates in these sectors are very low. The high standard errors associated with these means reflect the small numbers of snakes caught. Apart from the one mortality in winter for the deepwater eastern king prawn fishery, mortality rates in the eastern king prawn fishery were very low.

Table 6.4.12. Adjusted mean within-trawl mortality rates of sea snakes for different sectors and seasons in the Queensland trawl fishery, based on the analysis of deviance model in Table 6.4.11. The adjusted means are the proportion of snakes observed dead in the nets boat-day^{-1}. Standard errors in brackets.

Fishery	Winter	Spring	Summer	Autumn
Banana prawn	0.0875 (0.03159)	0.00001 (0.00132)	0 (0.00009)	0.0339 (0.01666)
Beam trawl	0.00001 (0.00103)	0.00001 (0.00022)	0.00001 (0.00017)	0.00002 (0.00049)
Deepwater eastern king prawn	0.5 (0.35)	-	0.00003 (0.00308)	0.00003 (0.00218)
Shallow water eastern king prawn	0.00003 (0.00138)	0.00002 (0.00098)	0.07895 (0.04374)	0.03175 (0.02209)
Moreton Bay	-	-	0.00003 (0.00308)	0.00003 (0.00308)
Black tiger prawn (broodstock collection fishery)	0 (0.00011)	0.01111 (0.00781)	0.00001 (0.00017)	0 (0.0003)
Redspot king prawn fishery	0.09628 (0.00706)	0.15188 (0.01392)	0.26087 (0.09156)	0.00001 (0.00072)
Scallop	-	0.4 (0.15492)	-	0.00003 (0.00154)
North Queensland tiger/endeavour prawn	0.03226 (0.03173)	0.05882 (0.04035)	-	0.21212 (0.05032)
Stout whiting	0.16667 (0.15215)	-	-	-

Within-trawl mortality rates were high in the redspot king prawn fishery for most seasons. This is noteworthy as this sector has both relatively high sea snake catch rates and relatively high commercial fishing effort. Mortality rates for the banana prawn and tiger/endeavour prawn sectors were relatively low. The adjusted mean mortality rates for the beam trawl fishery were negligible as none of the 274 snakes caught in this sector were reported as dead, probably due to the short trawl durations. Similarly, mortality rates for the black tiger prawn broodstock collection fishery were negligible. Moreton Bay also had negligible within-trawl mortality, although only two snakes were reported from this fishery (Table 6.4.2).

6.4.3 Post-trawl mortality rates

A total of 206 sea snakes that were caught incidentally in trawl nets between 6 February 2006 and 28 June 2007 were held in the containers for a minimum of 96 hours (four days) to assess post-mortality rates (Table 6.4.13). *Lapemis curtus* accounted for almost 50% of all snakes examined, followed by *A. laevis* (16%), *A. duboisii* (9%), *A. peronii* (6%) and *D. major* (6%). Approximately 42% were female and 32% male, while the sex of the remaining 26% could not be determined. The longest and shortest snakes were 2127 mm and 421 mm, respectively; both of these individuals were *D. major*, although several small (i.e. < 500 mm) *L. curtus* were also held in the containers.

The percentage breakdown of the number of snakes by fishery were: banana prawn (23%), black tiger prawn broodstock collection fishery (9%), redspot king prawn (44%) and tiger/endeavour prawn sector (24%). A total of six vessels participated in capturing and holding snakes—five commercial trawlers and the *RV Gwendoline May*. 79% of the snakes were from commercial vessels that were undertaking their normal fishing operations with the remaining 21% obtained from *RV Gwendoline May* during the bycatch reduction device trials (Section 7). The blue 140 L drums proved too large to facilitate rapid and safe water exchange and were therefore abandoned shortly after starting the experiment. For this reason, the majority of snakes (91%) were held in the green 75 L bins (Figure 6.3.2).

Table 6.4.13. Details of the sea snakes held in containers for a minimum of 96 hours to assess post-trawl mortality.

Sea snake species	Number of individuals held	Mean total length mm (se)
Lapemis curtus	101	823.7 (23.7)
Aipysurus laevis	33	977.9 (41.0)
Aipysurus duboisii	18	1038.7 (30.8)
Acalyptophis peronii	12	1049.3 (35.0)
Disteira major	12	1334.9 (148.6)
Hydrophis elegans	8	1412.7 (129.3)
Hydrophis mcdowelli	6	904.0 (21.1)
Hydrophis ornatus	6	1323.8 (49.2)
Disteira kingii	4	1417.0 (261.1)
Aipysurus eydouxii	3	720.0 (39.0)
Astrotia stokesii	3	880.7 (44.3)
Unidentified	1	-
Total	206	

Fishery had the most significant influence on post-trawl mortality (DR = 11.77, d.f. = 3, $P < 0.001$, Table 6.4.14). The length of the snakes was also significant (DR = 7.2, d.f. = 1, $P = 0.007$), while species had a marginal effect (DR = 1.66, d.f. = 10, $P = 0.083$). The sex of the snake, estimated weight of the bycatch in the net, trawl duration and holding container type had no significant effect. The fishery.species interaction term was not significant.

Table 6.4.14. Analysis of deviance of factors affecting post-trawl mortality rates of sea snakes. The response variable was the survival or death (i.e. a binomial response variable with value of 1 or 0) of each snake held for 96 hours after trawling, or until death.

Term	d.f.	Deviance	Mean deviance	Deviance ratio	Approx. chi prob.
Fishery	3	35.3103	11.7701	11.77	<0.001
Species	10	16.633	1.6633	1.66	0.083
Snake length (mm)	1	7.2041	7.2041	7.2	0.007
Residual	178	140.4785	0.7892		
Total	192	199.6258	1.0397		

From the above model, the overall adjusted mean post-trawl mortality rate was 0.2050 s.e. 0.02962 based on a mean snake length of 962.3 mm and averaged over fishing sectors and sea snake species. Table 6.4.16 shows the redspot king prawn fishery had the highest post-trawl mortality rate (0.2829 s.e. 0.063), followed by the North Queensland tiger/endeavour prawn fishery (0.2535 s.e. 0.09195) and the black tiger prawn broodstock collection fishery (0.116 s.e. 0.09694). Of the 42 snakes held after they were trawled in the banana prawn sector, only one died over the 96 hours and, as such, the adjusted mean was very low (i.e. < 0.0001 s.e. 0.00049) and associated with a large standard error. The adjusted mean rate for *L. curtus*, which was the most common snake held during the study, was 0.2011 s.e. 0.06076. *H. elegans* and *A. stokesii* had negligible (< 0.001) post-trawl mortality. Sample sizes for these two species were eight and three, respectively (Table 6.4.13), none of which died. The likelihood of a snake dying increased with body length (Figure 6.4.6).

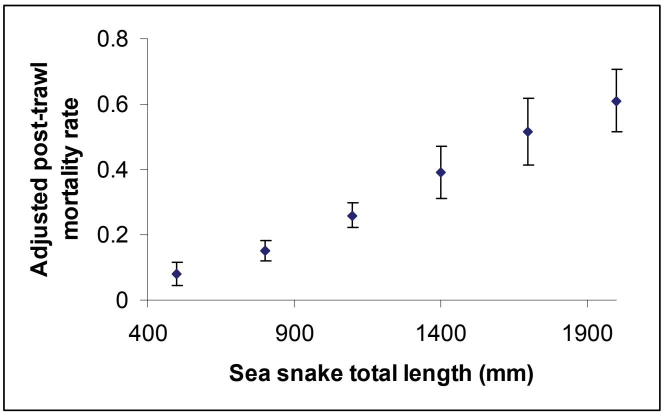

Figure 6.4.6. The relationship between sea snake length and post-trawl mortality rate. Large snakes had significantly higher post-trawl mortality than small snakes. Estimates were derived from the model in Table 6.4.14 and standardized by averaging across sectors and species. Vertical lines are one standard error either side of the adjusted mean.

The response variable 'time-to-death' was best modelled using a normal distribution with identity link function. Approximately 50% of all deaths occurred in the first day after trawling, 21% in the second day, 8% in the third day, 15% in the fourth day and 6% in the fifth day. Time-to-death was significantly affected by the duration of the trawls and fishing sector (Table 6.4.14). No other factors were significant. Most of the variation was explained by trawl duration. Of the four sectors examined, the redspot king prawn sector had the shortest mean time-to-death.

Table 6.4.15. Analysis of variance of factors affecting time-to-death (in hours) for those snakes that died while they were held in seawater-filled containers after they were trawled.

Change	d.f.	Sum of the squares	Mean square	Variance ratio	F probability
Trawl duration (h)	1	15076	15076	20.02	<.001
Fishery	3	8110.1	2703.4	3.59	0.021
Residual	42	31623.8	752.9		
Total	46	54809.9	1191.5		

6.4.4 Estimating total annual sea snake catch and mortality

Estimates of the total number of sea snakes that are caught and killed annually in the fishery were based on the product of the adjusted mean daily catch rates and mortality rates from the models described above, and the observed fishing effort (in boat-days) from the CFISH logbook database. From 2003–07 (inclusive), there was an average of 60 705 s.e. 2881 boat-days of effort in the Queensland otter and beam trawl fisheries (Table 6.4.16). The eastern king prawn sector received the most fishing effort (around 17 000–18 000 boat-days annually), followed by the North Queensland tiger/endeavour prawn sector which received an average of 15 321 s.e. 2488 boat-days. The stout whiting fishery received an average of 262 s.e. 112 boat-days.

The total number of sea snakes caught in the fishery annually, based on the summed product of the adjusted catch rate and observed mean fishing effort for each sector, was 105 210 s.e. 18 288 (Table 6.4.16). The redspot king prawn sector caught an average of 61 941 s.e. 17 430 snakes annually and was responsible for the majority of the catch. The banana prawn sector had the second highest annual catch of 15 362 s.e. 4128, followed by the beam trawl fishery with 11 577 s.e. 3018. Despite the relatively high annual effort in the eastern king prawn fishery, the annual catch in this sector was comparatively low, largely because of the low catch rates. Annual catches were particularly low in the deepwater eastern king prawn fishery. Annual catches in Moreton Bay were also low (i.e. 240 s.e. 191), but the high variability was largely due to the high variance associated with the low catch rate. The summed within-trawl mortality from all sectors was 8939 s.e. 2357, annually (Table 6.4.16). The redspot king prawn fishery accounted for 86.3% of all within-trawl deaths, followed by the banana prawn fishery (8.4%) and the North Queensland tiger/endeavour prawn fishery (2.9%). Within-trawl mortalities attributed to the remaining sectors were negligible. The beam trawl and Moreton Bay sectors both had no (zero) within-trawl mortality. Despite the relatively high annual catches in the beam trawl fishery, this sector imposed no direct incidental fishing mortality (from either within-trawl or post-trawl mortality), probably due to the short trawl durations.

Table 6.4.16. Estimates of the mean number of snakes caught and killed in the Queensland otter and beam trawl fisheries annually. Standard error (s.e.).

Trawl sector	Adjusted mean sea snake catch rate (boat-day^{-1})	s.e.	Observed mean annual fishing effort (boat-days)	s.e.	Mean number of snakes caught annually	s.e.	Adjusted mean within-trawl mortality rate	s.e.	Mean number dead when brought to the surface	s.e.	Adjusted mean post-trawl mortality rate	s.e.	Mean number that die post-trawl	s.e.
Banana prawn	9.568	2.01	1606	263	15 362	4128	0.0486	0.01662	747	332	0	0.00049	0	8
Beam trawl	1.695	0.4269	6830	445	11 577	3018	0	0.00055	0	-	-	-	-	-
Black tiger prawn (broodstock collection)	15.468	3.6535	301	58	4653	1437	0.0029	0.00205	13	11	0.116	0.09684	538	500
Tiger/endeavour prawn	0.297	0.043	15 321	2488	4550	996	0.0573	0.02319	261	122	0.2532	0.09182	1086	496
Redspot king prawn	10.23	2.3327	6055	973	61 941	17 430	0.1246	0.0131	7718	2330	0.2829	0.063	15 340	6383
Scallop	0.049	0.0186	6084	390	298	115	0.3046	0.11796	91	51	*0.205	0.02962	43	25
Moreton Bay	0.037	0.0292	6490	462	240	191	0	0.00223	0	-	-	-	-	-
Shallow water eastern king prawn	0.545	0.0967	11 895	566	6483	1192	0.013	0.00607	84	43	*0.205	0.02962	1312	313
Deepwater eastern king prawn	0.012	0.0061	5862	438	70	36	0.3552	0.25119	25	24	*0.205	0.02962	9	8
Stout whiting	0.138	0.1027	262	112	36	33	0.1667	0.15215	6	9	*0.205	0.02962	6	7
Total			**60 705**	**2881**	**105 210**	**18 288**			**8939**	**2357**			**18 334**	**6430**

* As no measure of the post-trawl mortality rate was obtained for these sectors, the adjusted overall mean rate and its standard error were used.

The number of snakes that die annually in the fishery due to post-trawl mortality, summed across all sectors, was 18 334 s.e. 6430. Again, the redspot king prawn fishery accounted for a very high proportion of all post-trawl deaths (i.e. 83.7%). By combining the within-trawl (8939 s.e. 2357) and post-trawl (18 334 s.e. 6430) mortalities, the total number of snakes that die from trawling in Queensland annually was estimated to be 27 272 s.e. 6848 (i.e. 25.9% of the total catch of 105 210). While reasons for the high mortality rates in the redspot king prawn fishery are unknown, we suspect that they are due to characteristics of the bycatch and trawling in this sector.

It is important to note that while the total numbers of snakes that die within-trawl and post-trawl can be summed to estimate total mortality (as in Table 6.4.16), the adjusted within-trawl mortality rate of 0.0710 reported in section 6.4.2 and adjusted post-trawl mortality rate of 0.2050 reported in section 6.4.3 should not be directly summed. This is because the post-trawl mortality rate only applies to those snakes that are still alive after the nets come to the surface (e.g. if we assume that 100 snakes are caught in the net, then ~93 will be alive when the nets come to the surface, and therefore the post-trawl mortality rate of 0.2050 only applies to the 93 remaining live snakes).

6.5 DISCUSSION

While the present study quantified the incidental catch and mortality of sea snakes in the Queensland trawl fishery, it may not reflect the species composition or relative abundance of each sea snake species from the Queensland east coast. For example, the turtle-headed sea snake *Emydocephalus annulatus,* which inhabits Queensland coral reefs (Lukoschek et al. 2007a) was absent in our samples. Lukoschek et al. 2007a noted that the occurrence of *E. annulatus* in trawl bycatch is extremely rare, possibly due to its highly specialised dietary requirements (i.e., fish eggs) and other behavioural traits reducing its likelihood of encountering trawls.

Heatwole and Burns (1987) examined the population dynamics of sea snakes in northern Australia from 1984–87. They mainly focused on snakes caught in the GOC by NPF trawlers, but also obtained data from Torres Strait and the Queensland east coast. Based on sampling 14 commercial trawlers, they estimated an overall mean catch rate of 1.16 SD 0.73 sea snakes km^{-2}, or 0.0116 SD 0.0073 sea snakes ha^{-1}. For their region 'E', which largely encompassed the North Queensland tiger/endeavour prawn fishery from Cairns to Cape York, they estimated a mean catch rate of 0.71 sea snakes km^{-2} (no SD provided), or 0.0071 sea snakes ha^{-1}, based on observations from a single vessel. Adjusted catch rates derived herein for the North Queensland tiger/endeavour prawn fishery ranged between 0.0339 ha^{-1} and 0.0035 ha^{-1} (reported as 1.091 and 0.114, respectively, for a standardised swept area of 32.16 ha in Table 6.4.4). Hence, the earlier mean catch rate of sea snakes in the North Queensland tiger/endeavour prawn fishery by Heatwole and Burns is within the range estimated herein. While caution should be applied interpreting the data, comparison of the old (1984–87) and recent (2005–07) mean catch rates suggest that a large decline in total sea snake abundance in the region over the intervening 20 years seems unlikely.

Results from the current study suggest that the entire Queensland trawl fishery catches 105 210 s.e. 18 288 snakes annually and that 27 272 (25.9%) die as a result (Table 6.4.16). These estimates were extrapolated using the fishery's average annual effort from 2003–07 and are therefore subject to change with future annual variations in effort. Effort in the otter trawl fishery declined from about 66 000 boat-days in 2003 to about 40 000 in 2007, and declined further in 2008 to about 35 000 boat-days. Most of the sea snake catch and mortality occurs north of 20^{o}S.

Significant variation in catch rates (Table 6.4.6) and mortality rates (Table 6.4.8 and Table 6.4.11) were found between sectors. Those sectors in the southern part of the coast—including the beam trawl, scallop, eastern king prawn, stout whiting and Moreton Bay—have relatively little impact in terms of the numbers of snakes caught and killed. The redspot king prawn fishery accounts for 58.9% of all catches and 84.5% of all sea snake deaths. Sectors with short (i.e. < 30 min) trawl durations—namely, the beam trawl and black tiger prawn broodstock collection fisheries—impose no, or negligible, direct incidental mortality on sea snakes. Sea snakes are probably reasonably abundant in the scallop grounds (i.e. Central Queensland) because the depths (20-60 m) are within the preferred range for many sea snake species, the fishery occurs near several reefs and because scallop bycatch is highly diverse (Courtney et al. 2008). The very low catch rates in the scallop fishery (Table 6.4.7) are most likely attributed to the large 75 mm (3 inch) minimum mesh size that fishers are required to use, excluding a high proportion of snakes. Mesh sizes in the prawn sectors generally do not exceed 50 mm.

The high catch rate of snakes in the redspot king prawn fishery is likely due to spatial overlap in preferred habitats for adult redspot king prawns *M. longistylus*, which is a reef-associated species (Courtney & Dredge 1988; Dredge 1990; Grey et al. 1983) and reef-associated sea snakes, particularly the olive sea snake *A. laevis*, the reef shallow's or Dubois's sea snake *A. duboisii* and the horned sea snake *A. peronii*. Reasons for the high mortality rates in this sector are unknown, although analysis of the within-trawl mortality data suggested that it was partly attributed to trawl duration and depth (Table 6.4.8), while the post-trawl mortality analysis (Table 6.4.14) indicated snake length was also influential. Although speculative, the high mortality rates in the redspot fishery may also be attributed to the composition of bycatch in this sector, which is largely composed of hard, spiky and venomous crustacea, echinoderms, molluscs and teleosts (Watson et al. 1990; Watson & Goeden 1989). Specifically, we suspect the high mortalities may result from 1) the relatively high biomass of bycatch crushing snakes in the codends, 2) the spiny, spiky and venomous composition of bycatch injuring, puncturing and envenomating the snakes, and 3) the relatively long trawl durations, which increase the likelihood of snakes drowning.

Heatwole and Burns (1987) first estimated the incidental catch of sea snakes by prawn trawlers in the NPF at 117 500 in 1986, but warned their estimate should be considered as an order of magnitude only. Later estimates of the mean number of snakes caught annually in the GOC (Wassenberg et al. 1994) in 1991 and across the entire northern Australian continental shelf in 1990 (Ward 1996b), varied between 119 571 and 81 080, respectively. Ward (1996a) also estimated an additional 50 000 snakes were caught by Taiwanese and Thai fish trawlers on the North West Shelf (1980–90) and Arafura Sea (1985–90).

The number of snakes caught in the NPF appears to have declined markedly since, mainly as a result of reductions in fishing effort over the last 18 years. TEDs and BRDs were introduced in the NPF in the early 2000s, but the reduction in sea snake catch rates attributed to the devices has been minor, in the order of 5% (Brewer et al. 2006). Heales et al. (2008) suggested that this was due to a reluctance by fishers to install BRDs within effective distances (i.e. within 70 meshes) of the drawstring. Fishers are generally concerned about losing prawns through BRDs and so they frequently install them as far forward in the codend as regulations permit, reducing their effectiveness.

Estimates of the combined within-trawl and post-trawl mortality rates for sea snakes caught in the NPF have varied between 42.0% (Heatwole & Burns 1987) and 48.5% (Wassenberg et al. 2001). Of the 250 sea snakes observed by Heatwole and Burns, 89 were dead when the nets reached the sorting tray and a further 16 died over the following eight hours. They suggested that trawl duration was the most influential factor affecting mortality. These rates are considerably higher than the combined mortality rate of 25.9% reported herein (Table 6.4.16). The mortality rates derived by Wassenberg et al. should be interpreted with caution because they included a) a high proportion of samples obtained from fish (rather than prawn) trawls, b) a high proportion of short trawl durations (i.e. 30 minutes), and c) trawls obtained from areas outside of the prawn fishing grounds (i.e. the North West Shelf). Hence, it could be argued that the reported impacts on snakes were not representative of commercial prawn trawling in northern Australia. Furthermore, their post-trawl mortality estimate was derived from relatively few snakes (51 from prawn trawls and 16 from fish trawls) that were all caught in trawls of 30 min duration, which is generally much shorter than commercial trawl durations targeting tiger prawns.

The vast majority (79%) of the 206 sea snakes that were utilised for the post-trawl mortality study herein were obtained directly from commercial prawn trawlers undertaking their normal fishing activities on the Queensland east coast. The remaining 21% were from the BRD research charter (Section 7), which was conducted on prawn trawl fishing grounds. Part of the reason why our mortality rate estimate is lower than the earlier studies is also likely due to TEDs and BRDs reducing the bycatch in the codends and therefore reducing the incidence of injury and trauma to the snakes. The two earlier estimates (from 1984 to 1987 and 1995 to 1997), were prior to the mandatory introduction of TEDs and BRDs in the NPF and Queensland east coast, which took place in the early 2000s. All of the within-trawl and post-trawl measures obtained during our study (i.e. 2005 to 2007) were from vessels that had TEDs and BRDs installed in the nets.[1]

Our estimates of the annual sea snake catch and mortality are in the order of 30–40 times higher than what has been reported by fishers in the SOCI database system (Figure 5.1.1 and Figure 5.1.2). While the spatial distribution of the SOCI data generally reflects the sea snake catches reported herein, absolute numbers are several times less. There are probably several reasons for the discrepancy. Our results indicate that the majority of fishers are failing to report their interactions with sea snakes. As the management agency responsible for the fishery, Fisheries Queensland therefore needs to reconsider the value of the SOCI database program in its current form, the value of the data, how the data are used and whether they should be disseminated. At present it could be argued that under a 'best case' scenario, the SOCI data provide

[1] A small number of snakes were caught in the standard net during the research charter described in Section 7, which had a TED but no BRD.

limited information on the distribution of sea snakes and the locations where relatively high incidental catches occur. The ‘worst case’ scenario is that the data are deemed as misleading and grossly underestimate the true catch and mortality of sea snakes in Queensland. If use of the SOCI data is to continue, then initiatives need to be implemented by Fisheries Queensland to enhance their accuracy.

An alternative approach to the current SOCI program may be to abandon the mandatory reporting of sea snake interactions and replace it with a subset of fishers who are prepared to voluntarily provide accurate data. Most commercial fishers approached during the study showed relatively little interest in sea snake bycatch, but a few were enthusiastic, keen, and offered to participate in more than one fishing trip. By utilising supportive fishers, and by avoiding those objectionable fishers who are likely to provide erroneous data, the quality of the SOCI data would improve significantly. This ‘subset of fishers’ is similar to the approach used herein, and because it does not include all fishers, total sea snake bycatch and mortalities would have to be extrapolated based on the sampled means. One of the main problems with the SOCI reporting system, which should not be understated, is the difficulty in maintaining a long-term commitment from fishers to accurately record catch details for protected species. We strongly suspect that more accurate and reliable data are obtained when fishers are asked to provide it for only relatively short temporal ‘windows’ (i.e., a few days), so that their commitment and diligence can be maintained at high levels. While this approach may result in fewer observations, the data are likely to produce more accurate means. We suspect that these improvements to the SOCI data could be achieved at relatively little additional cost.

Another approach may be to abandon the commercial fisher reporting requirements for sea snakes under the SOCI system entirely, and rely solely on the Fisheries Queensland fishery observer data. This is likely to require an increase to the operational budget of the observer program to effectively monitor all sectors of the trawl fishery, in addition to the program’s current tasks. Because the observers only obtain data from a subset of the fleet, this approach would also rely on extrapolating total catches and mortalities from the sampled means. As the data would be obtained by independent observers, both the derived means and the final extrapolated values could be considered as reliable.

7 Objective 4. Evaluating the effects of bycatch reduction devices (BRDs) on the catch rates of sea snakes, bycatch and target species in the Queensland trawl fishery

7.1 ABSTRACT

Sea snakes are protected species under Australian Commonwealth and Queensland legislation; therefore, the Queensland East Coast Trawl Fishery is obliged to minimise its impacts on these species. A research charter was conducted aboard the *RV Gwendoline May* in 2006 to assess the effect of three different BRDs on the catch rate of sea snakes, as well as prawns, Moreton Bay bugs and the remaining bycatch. The charter was undertaken between Cape Upstart and Cairns on fishing grounds known to have high incidental sea snake catch rates. The fisheye and square mesh codend BRDs significantly reduced the catch rate of sea snakes without incurring any significant reduction in marketable (≥ 20 mm carapace length, CL) prawn catch rates. Adjusted mean catch rates of sea snakes were 63% and 60% lower in the net with the fisheye BRD and square mesh codend BRD, respectively, compared to the control net that had no BRD. Although there was no significant difference between these two devices, the fisheye is likely to be more effective as large snakes are probably unable to escape through the square mesh. Our results support another study conducted in the NPF that also showed the fisheye BRD to be highly effective at excluding sea snakes from trawl nets. Several studies have now shown that the distance BRDs are installed from the codend drawstring greatly influences their effectiveness at excluding bycatch, including snakes. If the fisheye BRD is mandated in the Queensland trawl fishery to reduce sea snake bycatch, we recommend that it be installed as close as possible to, and no more than 50 meshes from, the drawstring.

7.2 INTRODUCTION

Benthic trawl fisheries for penaeid prawns and saucer scallops—such as those undertaken in the tropical and subtropical coastal waters of Queensland—produce large amounts of bycatch (Alverson et al. 1994; Kelleher 2005; Stobutzki et al. 2001). The incidental catch of turtles, which have high conservation status, attracted a great deal of research attention globally in the 1980s and 1990s, culminating in the mandatory use of TEDs in the early 2000s in all Australian trawl fisheries where turtle bycatch was deemed problematic. Mandatory use of a second additional (i.e. non-TED) BRD was also implemented in most Australian prawn trawl fisheries at this time to reduce catches of the myriad of other species that comprise the bycatch. Hence, most of Australia's state and commonwealth prawn trawl fisheries must now have both a TED and a second BRD installed in every trawl net.

Despite their protected status under Commonwealth and state laws, several thousand sea snakes are caught and killed incidentally by trawlers in northern Australia annually. Published estimates for the NPF and the GOC vary between 81 080 (Ward 1996b) in 1990 and 119 571 (Wassenberg et al. 1994) in 1991, respectively. Wassenberg et al. (2001) estimated the overall mortality (i.e. within-trawl plus post-trawl mortality) was 48.5%, but this estimate included snakes from experimental fish trawls of relatively short duration (i.e. 30 minutes) and therefore may not be representative of prawn trawling. These studies were conducted using data from the 1980s and 1990s, before TEDs and BRDs were introduced or made mandatory.

Wassenberg et al. (2001) suggested that the mortality rates should decline with the introduction of BRDs due to the reduced weight of the bycatch in nets as well as increased escapement by snakes. On Queensland's east coast the biology and distribution of sea snakes have been investigated by Dunson (1975b), Heatwole (1975), Limpus (1975), Heatwole and Burns (1987), Burns and Heatwole (1998; 2000), Marcos and Lanyon (2004) and Lukoschek et al. (2007a; 2007b). However, very little research has been undertaken on the impact of trawling on individual sea snake survival or at the population level, despite the large size of the Queensland trawl fleet and the protected status of sea snakes.

Brewer et al. (2006) concluded that the TEDs and BRDs used by fishers in the NPF had little effect (i.e. 5%) on excluding snakes from trawl nets. More recently, testing of the Yarrow fisheye (Heales et al. 2008) and the Popeye fishbox (Raudzens 2007) BRDs in the NPF demonstrated that these devices have high potential for reducing sea snake catch rates with no adverse reduction in targeted prawn catch rates.

In this section the effect of BRDs on the catch rates of sea snakes, prawns and other components of the bycatch were evaluated in the Queensland East Coast Trawl Fishery. The objective was to identify one or more devices that effectively exclude sea snakes from trawl nets, without incurring a significant reduction in target species' catch rates. Importantly, should such devices be identified, then it is likely that further extension and possibly mandatory management measures will be required to ensure uptake of the technology and a significant reduction in sea snake incidental fishing mortality.

7.3 MATERIALS AND METHODS

The effects of BRDs on sea snake catch rates were evaluated using a dedicated experimental research charter and by asking selected fishers to trial BRDs on their vessels during normal commercial fishing activities and record their catch rates. Each of these approaches has its own merits as well as shortcomings, but when considered together, they provide an effective approach for evaluating BRDs. The charter facilitated full control over the experimental design, which resulted in statistically robust data, results and conclusions, while the fisher trials provided data and other useful information under commercial fishing conditions. Trials involving fishers usually have limited experimental control which often limits the ability to draw statistically robust conclusions, but they promote communication between researchers and fishers, and foster extension and uptake of results.

7.3.1 Research charter

The research charter was undertaken over nine nights (one night steaming and eight nights trawling) in banana prawn, tiger/endeavour prawn and redspot king prawn trawling grounds between Cape Upstart and Cairns from 23 May 2006 to 1 June 2006 (Figure 7.3.1) aboard Queensland Government's *RV Gwendoline May*. The location of the trawls was determined from an analysis of the SOCI logbook data, which identified areas where trawl fishers reported relatively high catch rates of sea snakes.

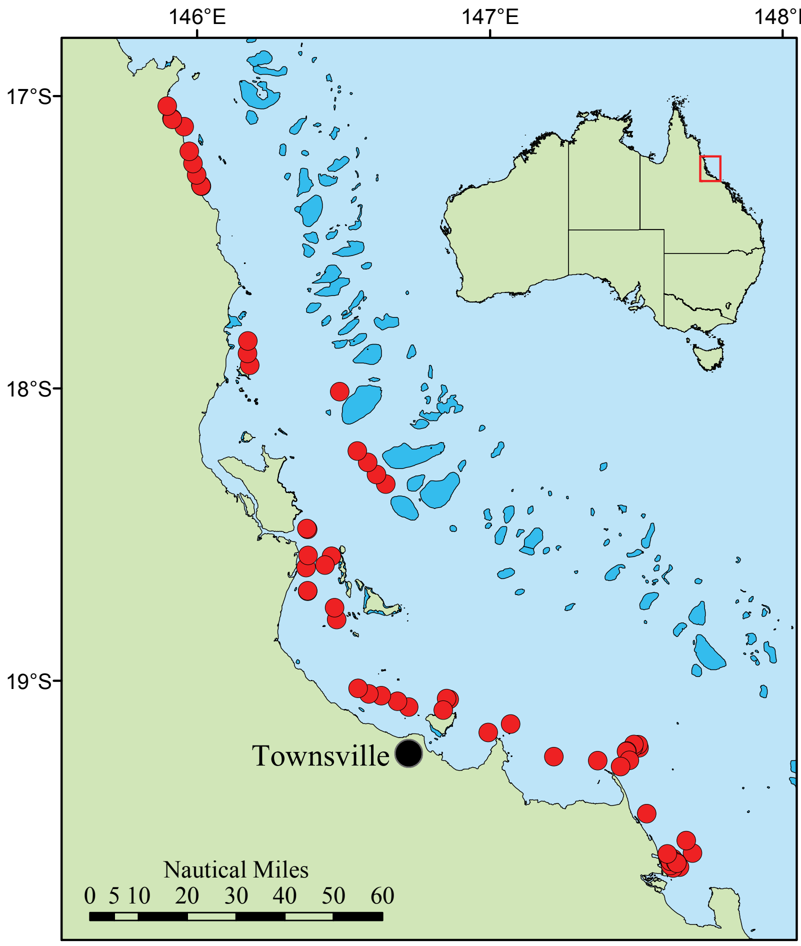

Figure 7.3.1. Location of the 83 two–nautical mile trawl sites where the effects of BRDs on sea snake catch rates were evaluated. The sites were sampled using the *RV Gwendoline May* in May–June 2006. The vessel towed quad gear (i.e. four nets) with a different BRD inserted in the codend of each net.

A total of 83 two–nautical mile trawls were carried out over eight nights towing quad gear (83 trawls x four nets), giving a total of 332 catch rate measures for sea snakes, prawns, commercially important scyllarid lobsters (*Thenus australiensis* and *T. parindicus*, commonly known as Moreton Bay bugs) and bycatch. The four treatments were:

1. standard codend with no BRD inserted, which was considered as a control treatment
2. fisheye BRD
3. square mesh codend BRD
4. square mesh panel BRD (Figure 7.3.2).

The position of the BRDs, in terms of whether they were sewn onto the outer port net, inner port net, outer starboard net or inner starboard net was changed daily according to a predetermined protocol based on a back-to-back Latin square design (Table 7.3.1) such that each BRD type was tested in each position for two nights of sampling. All of the nets were fitted with TEDs. Each two–nautical mile trawl was undertaken along a straight line, avoiding turning of the vessel, to ensure that each net swept the same size area along the bottom. The average duration of the trawls was 37.3 minutes.

Figure 7.3.2. The four BRD 'treatments' compared during the charter. From left to right the devices were the standard codend with no BRD (i.e. control net), fisheye BRD, square mesh codend BRD and square mesh panel BRD. The most forward edge of each device was 50 meshes from the drawstring.

Table 7.3.1. The sampling protocol that was applied to the codend treatments during the research charter, based on a back-to-back Latin square design. Each codend type was sampled in each net position on two nights. A total of 83 sites were trawled with the number of sites trawled each night in brackets.

	Net position			
Night	**Port inner**	**Port outer**	**Starboard inner**	**Starboard outer**
1 (9)	Square mesh panel BRD	Fisheye BRD	Square mesh codend	Standard codend (Control)
2 (10)	Square mesh codend	Standard codend (Control)	Square mesh panel BRD	Fisheye BRD
3 (12)	Standard codend (Control)	Square mesh codend	Fisheye BRD	Square mesh panel BRD
4 (12)	Fisheye BRD	Square mesh panel BRD	Standard codend (Control)	Square mesh codend
5 (11)	Fisheye BRD	Standard codend (Control)	Square mesh codend	Square mesh panel BRD
6 (10)	Square mesh codend	Square mesh panel BRD	Fisheye BRD	Standard codend (Control)
7 (8)	Standard codend (Control)	Fisheye BRD	Square mesh panel BRD	Square mesh codend
8 (11)	Square mesh panel BRD	Square mesh codend	Standard codend (Control)	Fisheye BRD

The effect of TEDs on sea snake catch rates is not well understood and so it was intended to include nets with and without TEDs as part of the range of codend treatment types to be evaluated. Permission to remove the TED from one of the treatment codends during the research charter was therefore sought from GBRMPA and DEWHA. However, neither agency was prepared to grant permission on the grounds that one or more turtles might be caught in the net that did not have a TED installed. Although we explained that the risk of capturing one turtle over the eight nights of sampling in one net without a TED was low (approximately 1 in 400), DEWHA insisted that all nets used during the research charter had a TED installed and as a result, the effect of TEDs on sea snake catch rates could not be evaluated.

The design specifications for the codend treatments that were assessed were as follows:

1. Standard codend was constructed from #60 ply, 1¾-inch Markwell blue codend material, 100 meshes round x 100 meshes long. A skirt constructed of the same material 100 meshes round x 30 meshes long was attached to the codend 30 meshes forward of the drawstring.
2. The fisheye BRD was an elliptical frame constructed from 6 mm stainless steel rod, 35 cm wide x 15 cm high, installed into a standard codend (as in 1 above) 50 meshes from the drawstring. Again, a skirt constructed of the same material 100 meshes round x 30 meshes long was attached to the codend 30 meshes forward of the drawstring.
3. The square mesh panel consisted of a panel of mesh 400 mm wide x 600 mm long, with mesh size 100 mm, installed so that it was 50 meshes from the drawstring, sewn into a standard codend, as above. The square mesh panel was constructed from 6 mm braided polyethylene twine.
4. The square mesh codend was constructed from 2.5 mm braided polyethylene codend material. Four 40 bar x 40 bar sections of material with mesh size of 50 mm were selvedged together to form the device. The square mesh section was sewn to a diamond mesh section, 100 meshes round x 55 meshes long, constructed from the same material as the standard codend. Approximately five meshes of the same material were sewn onto the aft edge of device for the attachment of the drawstrings. Belly ropes were attached to the square mesh section for additional strength and to ensure that the square meshes did not distort or stretch while being used.

After each trawl, the contents of the four nets were emptied onto the partitioned sorting tray of the vessel (Figure 7.3.3) so they could be measured separately and recorded. The following procedure was applied to the catch of each net. Large individual bycatch specimens (i.e. weighing more than about 10 kg) were identified to species level, weighed and released. All elasmobranchs were separated from the catch, identified, weighed and measured before being released. Sea snakes were identified and recorded. Some of the snakes caught during the charter were held in plastic holding containers and observed over 4–5 days as part of the post-trawl survival research reported in section 6.4.3. The prawn catch was separated into species and retained for further measuring and analysis at the Southern Fisheries Centre. All Moreton Bay bugs (*T. australiensis* and *T. parindicus*) were removed from the catch, labelled, frozen and later measured in the laboratory. The remaining bycatch was placed in plastic baskets, weighed to the nearest kilogram and returned to the sea.

Figure 7.3.3. The sorting tray on the back deck of the Queensland Government *RV Gwendoline May*, showing the sorting tray partitions and the catch from each net.

In the laboratory, the prawn catch of each net-trawl was sorted into species before the carapace length (CL) and sex of each prawn were determined. The CL was measured to 0.1 mm. Prawn lengths were then converted to weight in order to determine the weight of the prawn catch in each net trawl. Moreton Bay bugs were measured to the nearest 0.1 mm carapace width (CW) and, again, the weight of each individual estimated using length–weight relationships. The swept area of each trawl was determined using:

$$S = \frac{H \times F \times D}{10\,000}$$

where H was the headline length of the net (7.32 m), F was the net spread factor (0.70) and D was the distance trawled (two nautical miles = 3704 m). Division by 10 000 converts the area from square meters to hectares (ha). Using this formula, each net swept 1.90 ha along the bottom during each trawl. All prawn and bycatch weights were converted to grams hectare^{-1} and kilograms hectare^{-1}, respectively, by dividing the weights by the swept area.

7.3.2 Statistical analyses

As the vessel towed quad gear, all four treatments could be applied simultaneously, facilitating a complete block design (Montgomery 1997). Swapping codend treatments and sewing them back onto different nets reduced the likelihood of possible net-position effects biasing the results. GLM, using GenStat (2007) statistical software, was used to examine the effect of codend type on the catch rate of sea snakes, the remaining bycatch, marketable prawns and Moreton Bay bugs. 'Trawl site' was considered as a categorical blocking term and even though codend treatments were swapped around, net position was also considered as a factor with four levels (Table 7.3.1), thus further taking into account possible net position effects.

Analyses for each response variable were restricted to only those locations where they occurred (e.g. if sea snakes only occurred at 35 of the 83 sites then the remaining sites were omitted for the sea snake analyses). This removed sites where all four treatments resulted in zero catch rates, effectively removing observations that provide no contrast in the data. An analysis of deviance model using a Poisson distribution with a logarithm link function was fitted to the number of sea snakes (all species combined), leader prawns (*Penaeus monodon)* and Moreton Bay bugs [both legal size (i.e. ≥ 75 mm CW bugs and sub-legal (i.e. < 75 mm CW)]. Leader prawns were modelled as number caught, rather than catch weight, because they are relatively uncommon and sold as individuals for the broodstock aquaculture industry, where single large females commonly command \$100–200. This model was used to examine influential factors and to derive adjusted means (i.e. number two-nautical mile trawl^{-1}) for each codend type. An analysis of deviance developed using a gamma distribution with a logarithm link function was used to analyse bycatch weight. As there were no trawls with zero bycatch, data from all 83 sites were used. As the gamma distribution does not include zero, it is particularly appropriate for examining such bycatch data. This model was used to examine factors and derive adjusted means (i.e. bycatch weight in kilograms two–nautical mile trawl^{-1}) for each treatment type.

The prawn catch rates for a) *Melicertus latisulcatus* and *M. longistylus*, b) *Metapenaeus ensis* and *M. endeavouri* and c) *Penaeus esculentus* and *P. semisulcatus* were grouped to their market categories—king, endeavour and tiger prawns, respectively. Three models were used to analyse the marketable (i.e. ≥ 20 mm CL) prawn categories. The response variable was prawn catch rate, expressed as grams hectare^{-1}. All models were an analysis of variance with a normal distribution. Only the link function (i.e. identity, square root or logarithm) was altered and the most appropriate model chosen based on the distribution of the residuals. The same models were used to analyse the sub-optimal (i.e. < 20 mm CL) marketable prawns (i.e. pooled small king, endeavour and tiger prawns) and the small low-value prawn species (i.e. *Metapenaeopsis* spp., *Trachypenaeus* spp., *Parapenaeopsis* spp. and *Metapenaeus* spp., excluding the endeavour prawns).

7.3.3 Commercial fisher trials of BRDs

As a result of the research charter in May and June 2006, and preliminary analysis of the charter data, project staff developed a better understanding of the types of BRDs that were more likely to reduce sea snake catch rates, how they worked, and which devices were likely to adversely affect prawn catch rates. With this information we were in a much more informed position to recruit commercial fishers to trial BRDs. Trawler operators in the port of Townsville were targeted because both the SOCI data and the project's CMP data indicated that the highest catch rates of sea snakes occur in this region. Because the charter had shown that the fisheye BRD was the most effective of the three devices trialled at excluding sea snakes, the primary objective was to encourage fishers to trial this device and record their catch rate data for sea snakes, prawns and bycatch.

Fishers were asked to install the device at a distance of no more than 50 meshes from the drawstring because that was where the research charter had assessed the device and because the effectiveness of BRDS generally declines with increasing distance from the drawstring (Broadhurst et al. 2002; Raudzens 2007). However, persuading fishers to trial highly effective BRDs is difficult and most of the fishermen were adamant that other devices—such as the devices they already had installed in their nets—were just as effective or better than what the research charter had identified. Thus, the commercial fisher trials were not undertaken under the most preferred or experimentally robust conditions, but this is common when relying upon fishers working during their normal fishing activities. It also highlights the importance of undertaking experimental trials under controlled conditions that can only be achieved via dedicated research charters.

To encourage involvement in the trials, the details and objectives of the project were explained to fishers, including the positive research results on the fisheye BRD. Fishers were provided with waterproof paper, pencils and project staff contact details and then asked to trial the fisheye BRD. To further encourage participation, fishers were offered \$25 night^{-1} of data recording. Over a typical commercial trip of 15 nights, fishers were paid \$375 for recording details on their prawn, sea snake and bycatch rates from each of two nets compared simultaneously during each trawl. Weighing bycatch at sea can be difficult and demanding. The reality is that fishers would not voluntarily do this and it was considered unfruitful to ask them. Therefore, we asked participants to provide an estimate of the weight of their bycatch. As the prawn and sea snake catch rates could be readily and accurately quantified, it was only the remaining bycatch weight that was estimated.

The trials required fishers to ‘sew up’ or close off the BRD in one net while keeping the BRD in the second net open and functioning normally on the other side of the vessel. Hence, each trawl gave a paired comparison of the effect of the BRD on prawn, sea snake and bycatch rates. Over a typical 15-night trip this produced 70–100 paired comparisons. Project staff informed the local Queensland Boating and Fisheries Patrol of these trials so the participating fishers were not breached for closing off one of their BRDs.

Analyses of variance and deviance, using GenStat software (GenStat 2007), were undertaken on the response variables:

1. sea snake number caught trawl^{-1}
2. marketable prawn catch weight trawl^{-1}
3. bycatch weight trawl^{-1}.

Fishers were asked to periodically swap their BRD treatments from one net to another, but this was not carried and so all treatment BRD measures were obtained from the one net and, conversely, all control non-BRD measures were obtained from only one net. This lack of experimental control complicates making any definitive statement about the effects of the BRDs that the fishers were using, due to possible net-type effects (i.e. inherent differences between nets) and net position effects (variation due to the position of the net on the vessel). Therefore, the results should be considered as preliminary and interpreted with caution. The sea snake count data were analysed using a Poisson distribution with logarithm link function, while the prawn catch rates were modelled using a normal distribution with identity link function and the bycatch rates with a gamma distribution and logarithm link function.

7.4 RESULTS

7.4.1 Research charter results

A total of 70 sea snakes were caught during the charter; 65 spine-bellied sea snakes, (*Lapemis curtus*) were caught in 31 of the 83 sites and five elegant sea snakes, (*Hydrophis elegans*) from five sites. The analysis of deviance indicated that BRD type had a highly significant effect on the number of sea snakes caught trawl^{-1} (DR = 4.03, d.f. = 3, $P < 0.001$). Pairwise t-tests of the adjusted means showed that the fisheye and square mesh codend caught significantly fewer snakes ($P < 0.001$) than the standard codend (Table 7.4.2)—63% and 60% fewer snakes, respectively, compared to the standard net. There was no significant difference between the square mesh codend and the fisheye. Trawl site, net position, and the net position-BRD type interaction were not significant, hence both site and net position were dropped from the model.

Analysis of deviance indicated that site, BRD type, net position and the BRD type–net position interaction all significantly affected the catch rate of total bycatch (excluding snakes), although the interaction term was weak (DR = 3.19, d.f. = 9, $P = 0.001$). For clarity of presentation, and because BRD type explained most of the variation (DR = 47.94, d.f. = 3, $P < 0.001$), the adjusted means for the BRD type main effect only are provided in Table 7.4.2, ignoring the interaction term. Paired t-tests showed that the adjusted mean for each BRD type was significantly less than the standard codend ($P < 0.001$). Reductions of 33%, 31% and 24% were obtained for the fisheye, square mesh codend and square mesh panel respectively, compared to the standard codend.

A total of 692 Moreton Bay bugs were caught. Of these, 228 were of legal size (≥ 75 mm CW) and 464 were sub-legal (< 75 mm CW). Bugs were caught in 69 of the 83 sites, with legal-size bugs occurring in 49 sites and sub-legal bugs occurring in 57. Analysis of deviance revealed that site had a significant effect (DR = 4.73, d.f. = 48, $P < 0.001$) on the number of legal bugs caught trawl^{-1}. The influence of BRD type was marginal (DR = 2.12, d.f. = 3, $P = 0.095$, Table 7.4.2). There were no significant effects due to net position or the BRD type–net position interaction and therefore net position was dropped from the model.

Site (DR = 9.75, d.f. = 56 $P < 0.001$) and net position (DR = 3.31, d.f. = 3, $P < 0.05$) had a significant effect on sub-legal bug catch rates. Neither BRD type nor the BRD type–net position interaction had a significant effect on sub-legal bug catch rates.

A total of 15 983 prawns of primary commercial interest were caught. A summary of the marketable species is presented in Table 7.4.1. Given that the charter was primarily designed to test the effects of BRDs on sea snake catch rates, most of the sampling effort was concentrated in shallow inshore areas where the snakes were more abundant. Hence, a relatively high number of red-tailed endeavour prawns (*M. ensis*), banana prawns (*F. merguiensis*), brown tiger prawns (*P. esculentus*) and grooved tiger prawns (*P. semisulcatus*) were caught while the number of western king prawns (*M. latisulcatus*), redspot king prawns (*P. longistylus*) and blue-tailed endeavour prawns (*M. endeavouri*) were relatively low. *Melicertus longistylus* is a coral reef–associated species; juveniles of this species use reef lagoons as nursery areas and migrate from these areas into deeper waters where they are targeted by the fleet.

Table 7.4.1. Number of marketable prawns caught during the research charter.

Species	Number of individuals	Number of sites each species was recorded from (out of a total of 83 sites)
Metapenaeus endeavouri	488	27
Metapenaeus ensis	6443	62
Penaeus esculentus	1273	52
Melicertus latisulcatus	412	36
Melicertus longistylus	723	9
Fenneropenaeus merguiensis	3788	44
Penaeus monodon	208	33
Penaeus semisulcatus	2648	64

Banana prawns were present at 44 of the 83 sites and ranged in size from 14 mm to 49 mm CL. Analysis of variance indicated that site (variance ratio, VR = 74.79, d.f. = 44, $P < 0.001$) and BRD type (VR = 10.67, d.f. = 3, $P < 0.001$) significantly affected the catch rate of marketable (≥ 20 mm CL) banana prawns. Paired t-tests of the adjusted means revealed that the square mesh codend had significantly ($P < 0.001$) higher catch rates than the other three treatments (Table 7.4.2). Catch rates from the square mesh panel and fisheye did not differ significantly from the standard codend. Neither net position nor its interaction with BRD type were significant, hence net position was omitted from the model.

Tiger prawns (*P. semisulcatus* and *P. esculentus*) were caught at 69 of the 83 sites and ranged in size from 12 mm to 49 mm CL. Analysis of variance indicated that site (VR = 74.08, d.f. = 68, $P < 0.001$), net position (VR = 7.92, d.f. = 3, $P < 0.001$) and the BRD type–net position interaction (VR = 3.76, d.f. = 9, $P < 0.001$) had a significant effect on marketable tiger prawn catch rates. The BRD type main effect was marginal (VR = 2.18, d.f. = 3, $P < 0.092$). For clarity of presentation, only the BRD type main effect adjusted means are provided in Table 7.4.2.

King prawns (*M. latisulcatus* and *M. longistylus*) were present at 33 of the 83 sites and ranged from 15 mm to 54 mm CL. Site (VR = 12.89, d.f. = 32, $P < 0.001$), net position (VR = 18.55, d.f. = 3, $P < 0.001$) and BRD type (VR = 6.33, d.f. = 3, $P < 0.001$) had a significant effect on the catch rate of marketable king prawns. The BRD type–net position interaction was not significant and therefore dropped from the model. Paired t-tests of the adjusted means indicated that the square mesh codend catch rate was significantly less than the standard codend and the fisheye. There was no significant difference between standard codend, the square mesh panel and the fisheye (Table 7.4.2).

A total of 6931 endeavour prawns (*M. ensis* and *M. endeavouri*) were caught at 74 of the 83 sites, ranging in size from 12 mm to 49 mm CL. The endeavour prawns were the most abundant marketable species with 6443 *M. ensis* caught during the charter. Site (VR = 45.33, d.f. = 73, $P < 0.001$), net position (VR = 2.82, d.f. = 3, $P = 0.04$), BRD type (VR = 4.48, d.f. = 3, $P = 0.005$) and the BRD type–net position interaction (VR = 2.79, d.f. = 9, $P = 0.004$) were all significant. For clarity of presentation, and because the interaction term explained relatively little variation, the adjusted means from the BRD type main effect only are provided in Table 7.4.2. Paired t-tests of the adjusted means indicated that endeavour prawn catch rates were significantly lower in the square mesh codend, while catch rates from the fisheye and square mesh panel did not differ significantly from the standard codend.

A total of 208 black tiger prawns (*P. monodon*) were caught at 33 of the 83 sites, ranging in size from 27 mm to 69 mm CL. Site had a significant effect on black tiger prawn catch rates (DR = 8.31, d.f. = 32, $P < 0.001$). Net position, BRD type and the BRD type–net position interaction had no significant effect on catch rates (Table 7.4.2).

Site (DR = 32.03, d.f. = 71, $P < 0.001$) and net position (DR = 4.46, d.f. = 3, $P = 0.05$) had a significant effect on the catch rate of marketable prawns (i.e. marketable species ≥ 20 mm CL). BRD type had no significant effect, nor was the BRD type–net position interaction significant, and therefore this term was dropped from the model. Adjusted mean catch rates for each BRD type are provided in Table 7.4.2 and indicate that about 0.5 kg of marketable prawns were caught in each net at each site.

Site (DR = 14.58, d.f. = 70, $P < 0.001$), net position (DR = 6.12, d.f. = 3, $P < 0.001$) and BRD type (DR = 32.03, d.f. = 3, $P < 0.001$) each had a significant effect on the catch rate of marketable prawn species that were smaller than 20 mm CL. These small sizes are not retained by most fishers. Paired t-tests of the adjusted means indicated that the net with the square mesh codend reduced the catch rate by 52% ($P < 0.001$) compared to the standard net. There was no significant difference between the fisheye, square mesh panel and the standard codend. The BRD type–net position interaction term was not significant and was therefore dropped from the model.

The final catch component that was examined was the low-value prawn species, which was composed of *Metapenaeopsis* spp., *Trachypenaeus* spp., *Parapenaeopsis* spp. and *Metapenaeus* spp., collectively grouped into the category ‘small, low-value prawn species’ (Table 7.4.2). Site (DR = 42.95, d.f. = 69, $P < 0.001$), net position (DR = 125.10, d.f. = 3, $P < 0.001$) and BRD type (DR = 51.94, d.f. = 3, $P < 0.001$) each had a significant effect on the catch rate of these low-value prawns. The BRD type–net position interaction term was not significant and therefore dropped from the model. Paired t-tests of the adjusted means indicated that catch rates from the square mesh panel and the square mesh codend were significantly less than the standard net ($P < 0.001$). Catch rates from the square mesh codend were significantly less than all other codends and 65% lower than the standard net.

Table 7.4.2. Effect of BRD type on catch rates. Significant differences due to BRD type are bolded and identified by different alphabetic characters (A, B and C). The king prawns (*M. latisulcatus* and *M. longistylus)*, endeavour prawns (*M. ensis* and *M. endeavouri*) and tiger prawns (*P. esculentus* and *P. semisulcatus*) were grouped to their market categories. Small, low-value prawn species are comprised of *Metapenaeopsis* spp., *Trachypenaeus* spp., *Parapenaeopsis* spp. and *Metapenaeus* spp. (excluding *M. ensis* and *M. endeavouri*) and are generally not retained by fishers.

Catch component	Model distribution type and link function	Response variable	Adjusted mean catch rate (s.e.)			
			Standard codend	Square mesh panel	Fisheye	Square mesh codend
Sea snakes	**Poisson (Log)**	**No. trawl^{-1}**	**0.77 (0.15) A**	**0.63 (0.13) A**	**0.29 (0.09) B**	**0.31 (0.09) B**
Total bycatch	**Gamma (Log)**	**kilograms hectare^{-1}**	**15.74 (0.47) A**	**12.03 (0.36) B**	**10.58 (0.32) C**	**10.79 (0.32) C**
Legal bugs	Poisson (Log)	No. trawl^{-1}	0.94 (0.14)	1.43 (0.17)	1.27 (0.16)	1.02 (0.14)
Sub-legal bugs	Poisson (Log)	No. trawl^{-1}	1.77 (0.18)	2.25 (0.20)	2.12 (0.20)	1.99 (0.19)
Banana prawns (*F. merguiensis*)	**Normal (Sqrt)**	**grams hectare^{-1}**	**254.7 (10.32) A**	**242.9 (10.19) A**	**244.0 (10.44) A**	**312.2 (10.82) B**
Tiger prawns (*P. esculentus* & *P. semisulcatus*)	Normal (Sqrt)	grams hectare^{-1}	216.6 (36.26)	192.4 (30.11)	216.0 (35.26)	185.3 (27.28)
King prawns (*M. latisulcatus* & *M. longistylus*)	**Normal (Sqrt)**	**grams hectare^{-1}**	**188.8 (20.91) A**	**144.1 (28.91) AB**	**153.7 (18.03) A**	**117.9 (13.05) B**
Endeavour prawns (*M. ensis* & *M. endeavouri*)	**Normal (Sqrt)**	**grams hectare^{-1}**	**136.6 (6.14) A**	**119.5 (5.82) AB**	**120.4 (6.24) AB**	**110.7 (5.85) B**
Black tiger prawn (*P. monodon*)	Poisson (Log)	No. trawl^{-1}	1.7 (0.23)	1.6 (0.22)	1.6 (0.22)	1.5 (0.21)
All marketable prawn species ≥ 20 mm CL	Gamma (Log)	grams hectare^{-1}	546.6 (17.90)	571.0 (18.75)	547.5 (17.93)	536.8 (17.56)
All marketable prawn species < 20 mm CL	**Normal (Sqrt)**	**grams hectare^{-1}**	**20.47 (1.27) A**	**21.59 (1.31) A**	**21.29 (1.23) A**	**9.85 (0.96) B**
Small, low-value prawn species	**Normal (Sqrt)**	**grams hectare^{-1}**	**118.87 (6.02) A**	**76.58 (4.74) B**	**114.36 (5.96) A**	**41.73 (3.13) C**

7.4.2 Commercial fisher BRD trial results

Three commercial fishers participated in the trials during a total of four fishing trips. To prevent disclosure of their catch details and maintain privacy, the identities of the fishers and their vessels are not provided, but rather referred to only as fisher A, fisher B and fisher C, all based in Townsville. None of the fishers wanted to remove their BRDs and install the fisheye BRD that had been tested during the charter, nor did they want to install a device at 50 meshes from the drawstring. Instead, they preferred to assess the devices they already had installed in their nets and at the distances from the drawstring that they were already sewn in, which were generally much greater than 50 meshes. Photographs of the devices that fisher A had installed and that were subsequently assessed are provided in Figure 7.4.1. Fisher B had a similar device installed in his nets.

Figure 7.4.1. The BRDs installed on fisher A's vessel that were evaluated as part of the commercial fisher trials. The device on the left was constructed from steel cable, while the device on the right was constructed from stainless steel. Both devices had an escape opening sewn into the net with a flap of loose netting partly covering the opening. The flaps probably reduce or inhibit bycatch escapement. Note the close position of the BRDs to the TED frame, particularly in the right photograph, showing that the devices were positioned relatively far forward in the codend (i.e. around 90 meshes in front of the drawstring), which reduces their effectiveness at excluding bycatch. It is debatable whether these devices conform to the technical specifications required of BRDs listed in the Queensland Trawl Fishery Management Plan, but it is our experience that similar such BRD designs, and the positions that they are installed at, are common throughout the fishery.

Fisher C had two BRDs installed in each of his nets, in addition to TEDs. The first was a V-cut BRD installed about 10 meshes behind the TED and the second was a bigeye BRD installed in front of the TED (Figure 7.4.2). That some fishers voluntarily install two BRDs in each net, when they are only legally required to install one, reflects their awareness and commitment to reducing bycatch. The three participating fishermen recorded their catches of sea snakes, prawns and bycatch from a total of 323 comparative trawls (Table 7.5.1). The BRDs used on vessel A and vessel C significantly reduced the catch rate of sea snakes. For example, vessel A demonstrated a 40% reduction in sea snake catches (i.e. 1.18 snakes shot^{-1} with no BRD compared to 0.71 snakes shot^{-1} with BRD), while vessel C demonstrated a 38% reduction (i.e. 0.94 snakes shot^{-1} with no BRD compared to 0.58 snakes shot^{-1} with BRD). None of the BRDs used by the fishermen had a significant effect on their prawn catch rates (Table 7.5.1). Significant reductions in the catch rate of bycatch were detected in two of the four commercial vessel trips. Vessel B (Trip 2) demonstrated a 5% reduction in bycatch (i.e. 93.12 kg bycatch shot^{-1} in the net with no BRD compared to 88.07 kg bycatch shot^{-1} in the net with BRD) and vessel C demonstrated a 14% reduction (i.e. 65.95 kg bycatch shot^{-1} in the net with no BRD compared to 56.50 kg bycatch shot^{-1} in the net with BRD).

Figure 7.4.2. The BRDs that were evaluated aboard fisher C's vessel. The left photograph shows the V-cut BRD installed just behind the TED and the right photograph shows the bigeye BRD installed in front of the TED.

7.5 Discussion

The fact that two of the commercial fisher trips showed significant reductions in sea snake catch rates of 38–40% due to BRDs is promising (Table 7.5.1). However, data from two of the four trips suggested that the devices being used by some fishers are having little or no effect on sea snakes and the remaining bycatch (Vessel B, Table 7.5.1). Results from the commercial fisher trials should be interpreted with caution due to the lack of experimental control. For example, some of the results may be due to net position effects, or because one of the vessel's nets fished 'better' than the other. Results from the research charter are more robust and suggest that larger reductions in bycatch and sea snake catch rates can be achieved.

Results from the research charter suggest that sea snake bycatch in the Queensland trawl fishery can be significantly reduced by using properly designed and installed BRDs, with no significant reduction in targeted prawn catch rates. The fisheye BRD was the most effective device at excluding snakes—63% reduction compared to the standard codend, with no significant effect on the catch rate of marketable (≥ 20 mm CL) prawns (Table 7.4.2). Importantly, the fisheye BRD was also the most effective device for excluding bycatch—a 33% reduction in bycatch rate compared to the standard net. The square mesh codend was also highly effective at excluding both sea snakes and bycatch, with reductions of 60% and 31% respectively, compared to the standard net.

Table 7.5.1. The effects of BRDs on sea snake, prawn and bycatch rates as determined by commercial fishermen during their normal fishing activities. Significance tests were determined using GLM. Adjusted mean catch rates and their standard errors (brackets) are provided. The results should be interpreted with caution due to a lack of experimental control. NS, not significant; *, $P < 0.05$; **, $P < 0.01$; ***, $P < 0.001$.

Vessel	Number of trawls	Net with no BRD	Net with BRD installed	Chi or F probability
Vessel A	66	1.18 (0.13) snakes shot^{-1}	0.71 (0.10) snakes shot^{-1}	0.005 (**)
		14.63 (0.91) kg prawns shot^{-1}	14.97 (0.91) kg prawns shot^{-1}	0.794 (NS)
		No bycatch weight estimates recorded	No bycatch weight estimates recorded	–
Vessel B (Trip 1)	37	1.27 (0.19) snakes shot^{-1}	1.57 (0.21) snakes shot^{-1}	0.283 (NS)
		7.65 (0.99) kg prawns shot^{-1}	7.97 (0.99) kg prawns shot^{-1}	0.817 (NS)
		111.27 (3.43) kg bycatch shot^{-1}	111.16 (3.42) kg bycatch shot^{-1}	0.982 (NS)
Vessel B (Trip 2)	83	2.54 (0.18) snakes shot^{-1}	2.57 (0.18) snakes shot^{-1}	0.923 (NS)
		3.65 (0.29) kg prawns shot^{-1}	3.57 (0.29) kg prawns shot^{-1}	0.838 (NS)
		93.13 (1.37) kg bycatch shot^{-1}	88.07 (1.30) kg bycatch shot^{-1}	0.008 (**)
Vessel C	137	0.94 (0.8) snakes shot^{-1}	0.58 (0.07) snakes shot^{-1}	<0.001 (***)
		11.46 (1.09) kg prawns shot^{-1}	11.53 (1.09) kg prawns shot^{-1}	0.962 (NS)
		65.95 (3.59) kg bycatch shot^{-1}	56.95 (3.59) kg bycatch shot^{-1}	0.045 (*)

There was no significant difference between the fisheye and the square mesh codend BRDs, in terms of their effects on sea snake, bycatch and marketable (≥ 20 mm CL) prawn catch rates (Table 7.4.2). However, we suspect that the fisheye BRD would eventually prove to be more effective at excluding snakes because the 50 mm meshes in the square mesh codend are too small for large snakes to escape from. For example, it seems highly unlikely that snakes with diameters ≥ ~60 mm could escape through square meshes of 25 mm bar length x 25 mm bar length. Larger square meshes could be considered to increase sea snake escapement, but this would likely result in a reduction in marketable (≥ 20 mm CL) prawn catch rates, which would probably be economically unacceptable to fishers. The square mesh codend BRD trialled here greatly reduced the catch rate of sub-optimal size (< 20 mm CL) marketable prawn species, as well as the other small, low-value species, by 52% and 65% respectively, compared to the standard net (Table 7.4.2). For this reason alone, it should be considered as a highly effective management measure for reducing incidental fishing capture and mortality on small prawns, as well as for significantly reducing sea snake and bycatch rates. However, it is important to note that the square mesh codend did have a detrimental effect on the catch rate of marketable endeavour and king prawns (Table 7.4.2) and so any further increase in the square mesh size would likely exacerbate this. The escape opening of the fisheye BRD was 350 mm wide x 150 mm high, as specified in the Queensland Trawl Fishery Management Plan, and as such is likely to facilitate escapement of even the largest sea snakes encountered on the Queensland east coast.

Tests undertaken on the Popeye fishbox BRD conducted by the Australian Fisheries Management Authority in the NPF in the GOC reported an 87% reduction in the catch rate of sea snakes when the device was installed 70 meshes from the drawstring, with no significant effect on prawn catch rates (Raudzens 2007). Repositioning the device to 100 meshes from the drawstring lowered the bycatch exclusion rate. While the Popeye fishbox results are very promising, the results have not been published in the primary literature, and therefore need to be considered with caution.

Heales et al. (2008) examined the effect of the Yarrow fisheye BRD on tiger prawn, small fish, invertebrate and sea snake catch rates on a trawler undertaking normal commercial fishing activities in the NPF in 2004 and 2005. This device is very similar to the fisheye BRD (Figure 7.3.2) trialled herein, except that it has two strengthening bars wielded into its design. While the bars give the device greater strength, they split the escape opening down the centre, halving the dimensions through which the bycatch escapes. This modification probably reduces the likelihood of larger species escaping. Heales et al. (2008) concluded that the Yarrow fisheye BRD reduced the weight of small fish bycatch and sea snakes by a mean of 22% and 43.3%, respectively, with no loss of tiger prawn catch.

Importantly, their trials were undertaken with the device installed 70 meshes forward of the drawstring. They noted that most NPF fishers are unwilling to install BRDs this close to the catch and that the wide-spread practice of installing devices 110 meshes from the drawstring has ‘been ineffective in reducing bycatch in this fishery’ (Brewer et al. 2006). Similarly, in the Queensland otter trawl fishery, fishers are reluctant to install BRDs close to the drawstring. Photographs of the gear used by the commercial fishers who participated in the trials above (Figure 7.4.1 and Figure 7.4.2) indicate that the devices were installed at least 90 meshes from the drawstring. During the research charter, all three devices were tested at 50 meshes from the drawstring.

The location of the BRD in the codend significantly affects its ability to exclude bycatch. Even if the most effective BRD is implemented, its performance will be greatly compromised unless an appropriate maximum distance from the drawstring is also specified. If the Queensland Government fishery managers decide to mandate use of fisheye BRDs to reduce sea snake bycatch, then such a measure should include a maximum distance from the drawstring. Since a) our research was conducted with the fisheye BRD installed at 50 meshes from the drawstring, b) the fisheye was highly effective at excluding both sea snakes and bycatch with no significant reduction in the catch rate of marketable prawns, and c) greater reductions in sea snake catch rates were achieved than the NPF trials where the Yarrow fisheye was 70 meshes from the drawstring, our recommendation is to install the fisheye BRD at a maximum distance of 50 meshes from the drawstring. This recommendation should apply to those areas or sectors where sea snake mortality rates are high, particularly (but not necessarily limited to) the redspot king prawn sector.

8 References

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9 Benefits and adoption

The research addressed a formal recommendation from the Commonwealth DEWHA to the Queensland Government 'that research into the impact of trawling on sea snakes be promoted, and that all reasonable steps should be undertaken to reduce interactions between protected species and the Queensland trawl fishery'. The project not only undertook research that quantified sea snake bycatch, but it also identified, developed and tested practical and inexpensive technologies (i.e. fisheye BRD) that can be used to significantly reduce sea snake catch and mortality. To this end, the project has also addressed mitigation. Beneficiaries of the research are Queensland trawler operators and the Fisheries Queensland managers, who are now in a much more informed position to understand the magnitude of the problem and how to mitigate it.

Under the *Australian Environment Protection and Biodiversity Conservation Act 1999*, DEWHA has the authority to withdraw export permission for Queensland seafood, if they conclude that fishing practices are 'not sustainable'. If recommendations from the project are implemented, Queensland trawler operators, seafood processors and exporters will benefit because the impact of trawling on sea snake populations will be reduced; therefore, the likelihood that DEWHA will continue to permit export will be increased. The project has brought about greater security-of-supply to international export markets for Queensland seafood producers. It is difficult to quantify these benefits in terms of revenue. However, the Queensland trawl fishery lands about $100 million of seafood annually, of which about 20–30% is exported; therefore, the benefit to fishers, processors, exporters and the national deficit could be in the order of several million dollars annually.

All Australian state and federal agencies that have a role in the conservation and management of sea snakes, including the Queensland Department of Environment and Resource Management (DERM), DEWHA and GBRMPA, will benefit from being able to access the data, results, conclusions and recommendations in the report, because their management decisions will be based on more factual and quantitative information. Monitoring programs for sea snakes, and other species of conservation value interacting with Queensland commercial and recreational fisheries (i.e. the Fisheries Queensland SOCI logbook), should improve as a result of the study. Finally, researchers, conservation agencies and herpetologists with an interest in the biology and conservation of sea snakes will benefit from the information contained in the report.

10 Further development

The effects of TEDs on sea snake escapement in the Queensland, and other Australian, prawn trawl fisheries remains unclear. It may well be that the TEDs used by Queensland trawler operators already exclude a high proportion of snakes. If this is the case then the catch rate estimates herein (Table 6.4.4 and Table 6.4.7) probably underestimate the relative abundance of sea snakes. The project sought to quantify TED effects during the research charter (Section 7) but DEWHA would not grant permission to remove one of the TEDs as part of the experimental design (because of a very small risk of a turtle capture).

To thoroughly assess the impact of trawling on sea snake populations, risk assessments should take into account the proportion of snakes that are being excluded by BRDs, and this has to include possible TED effects. For this reason, future research on the impacts of trawling on sea snakes and other bycatch species should include quantifying TED effects. TED designs (i.e. grid size and shape, inclination, escape opening shape and size, and escape hole flaps) are changing in Australia. TEDs can significantly affect the performance of the secondary BRD, and therefore the effects of TEDs on bycatch—other than turtles—needs to be quantified, even in situations where there may be a small risk of turtle capture.

Although it was not a requirement of the study, the project developed a risk assessment (Appendix 5. Risk assessment) for sea snakes with modeling and advice provided by CSIRO's Elliot Dovers and Roland Pitcher. No funding was allocated for this task. The appropriateness of the logistic regressions for predicting the distribution of sea snakes (Appendix 4. CSIRO sea snake maps) has received little scrutiny and it's possible that some of the predictions differ significantly from reality. For example, the beaked sea snake *E. schistosa* was relatively uncommon in the crew member samples (Table 6.4.2) and largely restricted to shallow inshore sectors (Figure 6.4.2), and yet the logistic model predicted that it was common, widely distributed and also found in deep waters. This may be due to a lack of predictors and covariates for this species, as noted in Appendix 4. Overestimating the distribution of the snakes will result in an underestimate of the true risk. Further scrutiny of the logistic regression models and the subsequent mapped distributions of the snakes are required.

Estimates of the instantaneous rates of natural mortality M used in the risk assessment may also require attention. All estimates of M used here were borrowed from Milton et al. (2008) and based on sea snakes sampled from the NPF. It's likely that there are significant differences in the snake growth rates and water temperatures between northern Australia and the Queensland east coast, which affect the estimates of M. It would therefore be preferable to derive estimates of M directly from Queensland snakes and use these in the risk assessment.

Furthermore, there may be inherent problems applying Pauly's (1980) empirical estimate of M to sea snakes from trawl bycatch. This method relies upon being able to sample large/old snakes from unexploited populations. Such large/old individuals can significantly affect the estimates of L_∞ and K that are used to derive M. On the Queensland east coast, it may be difficult to locate and sample unexploited sea snake populations. The L_∞ values that are likely to be obtained from Queensland trawl caught snakes would probably be smaller than the true values, and therefore the estimates of M and the subsequent risk assessment reference point C/M would also be erroneous. Perhaps this could be addressed by using stochastic methods that consider a broad range of values for L_∞ to estimate of M, such that the derived L_∞ is considered as the 'lower limit', with simulations undertaken that consider larger values.

11 Planned outcomes

The planned outcomes as specified in the project agreement are as follows:

1) Identification of sea snake species and populations in the Queensland East Coast

Trawl Fishery that may be threatened by trawling.

Stakeholders, including Fisheries Queensland, Queensland trawler operators, the GBRMPA, DERM and DEWHA, now have a much clearer understanding of the impacts of trawling sea snake populations in Queensland. The outcome is an improved ability to manage sea snakes and the impact of trawling on them.

2) Identification of areas where sea snake populations may be threatened by trawling.

The project collected information on sea snake catch rates and within-trawl mortality from 8289 trawls. Additional information on post-trawl mortality rates was obtained for 206 snakes that were held in water-filled containers for a minimum of 96 hours after they were trawled. About 105 210 snakes are caught annually by the fishery, with 25.9% dying as a result. The redspot king prawn fishery, which is mainly located in North Queensland off Townsville, is responsible for about 58.9% of all sea snake catches and 84.5% of mortalities.

Stakeholders now know the spatial locations where high sea snake catches and mortalities are occurring. One possible outcome may be to close these areas to trawling. However, given the controversy and high compensation costs associated with closing areas in the GBRMP in 2004 under the Representative Areas Program, we suspect that spatial closures are an unlikely first choice for mitigation management by Fisheries Queensland. (Closures would be a more likely option if, and when, the adoption of highly effective BRDs was not successful).

3) Adoption of more effective bycatch reduction devices by the trawl fishing industry, particularly devices that facilitate the effective escape of sea snakes.

In Queensland, all otter trawl vessels must have both a TED and BRD installed in each net. In general, the BRDs that are being used by fishers only reduce bycatch rates by an average of 8% (Courtney et al. 2007). This low reduction rate is due to the range of BRDs types that can be used and the highly variable positions in which they can be installed. The research charter (Section 7) demonstrated that sea snake catch rates can be reduced by an average 63% with the fisheye BRD installed 50 meshes from the codend drawstring, with no reduction in marketable prawn catch rates. As the redspot king prawn fishery accounts for the majority of sea snake catches and mortalities in Queensland, a major outcome of the project would be for those fishers operating in this sector to install the fisheye BRD in their nets.

Uptake of the fisheye BRD specifically for excluding sea snakes from trawl nets, and other highly effective BRDs, including square mesh codends (which were demonstrated in FRDC 2000/170) are currently being promoted by Fisheries Queensland and FRDC via the extension project FRDC 2008/101 *Extension of fisheries research and development funded research results on improved bycatch reduction devices to the Queensland East Coast Otter Trawl Fishery*.

In 2009 a draft copy of the project final report was forwarded to the Fisheries Queensland trawl manger (Mr Eddie Jebreen) and Mr Jim Higgs of DERM. Shortly thereafter, DERM provided $250 000 to Fisheries Queensland for the extension and uptake of fisheye BRDs. While we are pleased with the quick response and acknowledge that the initiative will promote extension and uptake of the device, we note that it does not mandate the use of fisheye BRDs as recommended in this report. It is our understanding that Fisheries Queensland will implement the program over the following months (i.e. 2010 to 2011).

4) The provision of advice on the sustainability of sea snake populations to DEWHA, for the purposes of securing accreditation under the EPBC Act and permission to export.

The project addressed a formal recommendation from DEWHA to the Queensland Government concerning the impact of trawling on sea snake populations and identified mitigation measures that significantly reduce these impacts. If Fisheries Queensland managers and the trawl industry adopt these recommendations then a major outcome from the project will be the reduced risk of depletion to sea snake populations. This is likely to assure DEWHA that Fisheries Queensland is managing the trawl fishery sustainably, which, in turn, should result in greater resource security and profitability to those fishers and processors who export seafood in Queensland. Thus, while we cannot guarantee that Fisheries Queensland implement the project's recommendations, if they choose to do so then a significant outcome of the project will be enhanced access to export markets.

5) The ultimate outcome will be a significant reduction in the number of sea snakes that are caught and die as a result of the Queensland trawl fishery.

Information about the project, including results showing the effectiveness of the fisheye BRD, was disseminated during the project via discussions with fishers, extension and trialling of BRDs with fishers (Section 7), project steering committee meetings and via published articles, newsletters, presentations and websites. However, at present we suspect that very few fishers have changed their behaviour or modified their fishing gears to reduce their sea snake catches. Fisheries Queensland is currently running an extension project (FRDC 2008/101) to promote the uptake of highly effective TEDs and BRDs, and we also note recent additional funding provided by DERM to Fisheries Queensland (i.e. $250 000) to promote the uptake of fisheye BRDs, specifically for sea snake bycatch mitigation. However, it remains to be seen what proportion of the fleet adopt fisheye BRDs, particularly in the redspot king prawn fishery, before this outcome can be truly evaluated. We suspect use of the fisheye BRD will have to be made mandatory in order for a significant and large reduction in sea snake catches to occur.

12 Conclusion

All of the project's objectives were achieved. The project exceeded what was required, specifically going beyond the objectives to develop the first semi-quantitative risk assessment for sea snakes impacted by trawling on the Queensland east coast (i.e. Appendix 5. Risk assessment).

Objective 1. *Collate and review existing data and literature on sea snake distribution and abundance on the Queensland east coast. This will enhance the detail and precision of the recently introduced CFISH logbook data program on species of conservation interest (SOCI).*

This objective has been achieved. The literature and available data were reviewed and collated in Section 5. Additional, relevant literature and data sources were cited throughout the report. Prior to the project, there was very little available data on the sea snake catch, composition or mortality for the Queensland trawl fishery. The SOCI data was reviewed, and from the results in Section 6, it is apparent that there are major limitations with the SOCI logbook which grossly under represents the number of sea snakes that are caught and killed in Queensland annually.

Objective 2. *Implement a crew-based data collection program to quantify information on sea snake catch rates, species composition and distribution. Where possible, consider areas that are closed and open to trawling (contingent upon GBRMPA approval to sample closed areas).*

This objective has been achieved. From July 2005 to October 2007, approximately 67 commercial crews provided detailed information on their trawl gear, location and duration of trawls, and incidental sea snake catches from 6429 trawls. Some fishers volunteered to provide data from multiple trips. Information was also collected from an additional 1860 research and survey trawls, and fishery observer data.

From these data and the logbook effort data it was estimated that 105 210 s.e. 18 288 sea snakes are caught by the Queensland trawl fishery annually (Table 6.4.16) and that about 25.9% of these snakes die in the nets when caught and in the hours and days after trawling. Only the commercial fishing data were used to derive the total annual catch. No samples were obtained from areas closed to commercial trawling in the GBRMP. This was partly because most of the data were obtained from commercial fishers who operate in open fishing grounds and partly because there were very limited project funds for chartering vessels and directing them where to sample.

Permission from the GBRMPA to sample in closed areas was not sought or obtained because, from experience, we know that the GBRMPA would not grant such permission for research trawling. The permits required for the project were extensive and limited the project to areas open to trawling. Permits were obtained from GBRMPA, DEWHA and DERM, as well as animal ethics approval through the Department of Employment, Economic Development and Innovation (DEEDI). As neither DEWHA nor GBRMPA would permit the research charter to be undertaken without a TED installed in all nets, we were unable to quantify the effects of TEDs on sea snake catch rates. The limited available data on the effects of TEDs on sea snake catch rates gives mixed results. Unfortunately, due to the permit restrictions, we were unable to further investigate these effects.

Information on sea snake distributions inside closed green zone protected areas was estimated from the CSIRO logistic regression models (Appendix 4. CSIRO sea snake maps)—hence, no sampling inside closed areas was undertaken. These models used the sea snake catch rate data that were produced by the project and abiotic data, to predict sea snake distributions in both closed and open areas. The project also deployed GLM to examine the effects of several factors on sea snake catch and mortality rates. The redspot king prawn fishery, which is a coral reef-associated prawn, accounted for 58.9% of all sea snake catches in the trawl fishery and 84.5% of all incidental fishing mortality. The high catches of snakes in this sector appear to be due to the habitat of adult redspot king prawns overlapping with the habitats of reef-associated sea snakes, particularly, the olive sea snake (*A. laevis*), the reef shallow's or Dubois's sea snake (*A. duboisii*) and the horned sea snake (*Acalyptophis peronii*). We suspect the high incidental mortality of snakes in the redspot king prawn fishery is due to the bulky, spiny, spiky and venomous composition of bycatch in this sector crushing and injuring the snakes.

Objective 3. *Quantify post-trawling mortality rates of sea snakes by undertaking survival experiments at sea on commercial vessels*.

This objective has been achieved. A total of 206 trawl-caught sea snakes were held in plastic holding containers and monitored every few hours for a minimum of 96 hours. 79% of these snakes were obtained from five commercial fishing trawlers while the remaining 21% were obtained aboard the *RV Gwendoline May* during the BRD research charter.

The adjusted mean post-trawl mortality rate was 0.2050 s.e. 0.02962—in other words, of those snakes that are still alive after the net comes to the surface, about 20% die in the following hours and days after trawling. (Note: the adjusted mean post-trawl rate of 0.2050 should not be added directly to the adjusted within-trawl mortality rate of 0.0710 reported in section 6.4.2 to derive a total mortality rate because the post-trawl mortality only applies to those snakes that are still alive when the nets are brought to the surface).

Most deaths occur in the first 24 hours after trawling. It is unclear whether the snakes were dying as a result of being trawled, or because of the containers imposing some level of mortality. We attempted to address this by gently hand-catching a sample of sea snakes and holding them in the containers, but this was not successful. We suspect that the containers did not impose any mortality over the relatively short period that the snakes were held and that the mortalities can be attributed to trawling.

The redspot king prawn fishery had the highest post-trawl mortality rate of 0.2829 s.e. 0.063. The North Queensland tiger/endeavour prawn fishery produced a post-trawl mortality rate of 0.2535 s.e. 0.09195—almost as high as the red spot fishery. The length of the snakes also affected their post-trawl survival rates; mortality increased with snake length (Figure 6.4.6). Post-trawl mortality rates varied significantly between species, but this should be considered with caution due to small sample sizes.

Objective 4. *Test effectiveness of BRDs, including square mesh panels, on sea snake catch rates and promote the uptake of effective devices by industry*.

This objective has been achieved. The effects of three BRDs on the catch rates of sea snakes, prawns, bycatch and Moreton Bay bugs were evaluated during a dedicated nine-day research charter that deployed the *RV Gwendoline May* in 2006. A square mesh panel, fisheye and a square mesh codend were compared against a standard codend with no BRD inserted. All nets had TEDs inserted. The catch rates of sea snakes were significantly reduced in nets with the fisheye and square mesh codend BRDs, by 63% and 60%, respectively, compared to the standard net. No significant reduction was found in the catch rates of marketable ($\geq$ 20 mm CL) prawns.

These devices also significantly reduced the catch rates of the remaining bycatch. If the Queensland Government intends to reduce the incidental catch and mortality of sea snakes in the fishery, we recommend that the fisheye BRD be made mandatory in those sectors with relatively high mortalities. This is an inexpensive and simple device that can be readily constructed and installed. Much research is now showing the importance of effectively positioning the BRDs in trawl nets. Fishers tend to insert the devices too far forward, to avoid prawn loss. We recommend that the fisheye BRD be inserted no more than 50 meshes forward of the codend drawstring.

Uptake of the device was promoted by approaching commercial fishers and asking them to trial the fisheye BRD, but fishers were reluctant to change from the devices that they were already using. Data collected from fishers showed that some of the devices they are using reduce bycatch and sea snake catches. Conversely, some of the devices used by fishers had little or no effect. We have observed a very broad range of 'interpretations' for what constitutes a BRD by fishers. Many devices used by fishers appear unlikely to meet the technical specifications for BRDs listed in the Queensland Trawl Fishery Management Plan. To our knowledge, there has never been a prosecution in Queensland against a fisher for an improperly installed or ineffective BRD (excluding TEDs)—there have only been prosecutions for the complete absence of devices. Further initiatives are required to ensure that fishers use only highly effective BRDs that are installed correctly.

We further promoted uptake of the fisheye BRD for reducing sea snake bycatch through the following publications, presentations and web pages. Video footage of the research charter in 2006 has also been shown during several presentations.

1. Courtney, AJ, Schemel, B and Wallace, R 2006, 'The impact of trawling on sea snakes', *Queensland Fisherman* 24 (12): pp. 21–22.

2. Courtney, AJ, Schemel, B and Wallace, R 2007, 'The impact of trawling on sea snakes', *Ausmarine* 29 (4): pp. 16–17.

3. Courtney, AJ, Schemel, B, Wallace, R and Ballam, D 2007, 'The impact of trawling on sea snakes', *Bycatch Communication Network Newsletter*, Issue 4, February 2007.

4. Courtney, AJ, Schemel, BL, Wallace, RM, Campbell, MJ and Mayer, DJ 2008, 'Quantifying and reducing the incidental catch and fishing mortality of sea snakes in the Queensland (Australia) trawl fishery', in *Proceedings of the 5th World Fisheries Congress,* 20–24 October 2008, Yokohama, Japan. (A copy of this presentation and a summary of this conference is provided in Appendix 6.)

5. Courtney, AJ and Milton, D 2008, 'Scientists step in to separate snakes and deckands', FRDC *FISH* magazine, Vol. 16, March, pp. 18–19.

6. Courtney, AJ, Presentation of the project research results to the QPI&F Fisheries Business Group in 13 November 2008, Primary Industries Building, 80 Ann St, Brisbane.

7. Courtney, AJ, Presentation of the project research results to the GBRMPA Fisheries Reef Advisory Committee (FRAC), Townsville, 27 March, 2009.

8. Courtney, AJ, Presentation of project research results to the International Union for the Conservation of Nature (IUCN) Sea Snake Red List Assessment Workshop, 11–14 February 2009, Mt Cootha Botanical Gardens, Brisbane.

9. The project web pages:
http://www.dpi.qld.gov.au/cps/rde/dpi/hs.xsl/28_5193_ENA_HTML.htm
http://www.dpi.qld.gov.au/cps/rde/dpi/hs.xsl/28_5197_ENA_HTML.htm

13 Acknowledgements

The project was funded by the Australian Fisheries Research and Development Corporation (FRDC Project No. 2005/053) and DEEDI, Queensland. Dr Malcolm Dunning from Fisheries Queensland was instrumental in securing additional funding for the project.

We thank the 67 crews from the Queensland beam trawl and otter trawl fisheries who volunteered to record details of their catches, provide photographs of sea snakes, participate in the commercial vessel BRD trials and allow project staff on board their vessels to record the post-trawl mortality data. Mr Dennis Ballam from SeaNet extension services helped distribute the sea snake kits to fishers in North Queensland.

Fisheries Queensland Observer Program staff Mr Sam McCulloch, Mr Gavin Leese and Mr Brian Watson generously provided their time and advice in clarifying catch data from the observer program. The support from Fisheries Queensland staff Mr Jason Stapley, Ms Nadia Engstrom and Ms Kate Yeomans is also greatly appreciated in relation to providing SOCI, observer and logbook data. Dr Roland Pitcher, Dr Elliot Dovers and Dr Ross Darnell from CSIRO provided their time and advice to produce the sea snake distribution maps (Appendix 4) and the risk assessment (Appendix 5). We thank the crew of the *RV Gwendoline May*, Mr Barry Ehrke (skipper) and Mr Rod Hansen (deckhand) for their support during the BRD research charter and Mr Peter Kyne from The University of Queensland for helping to process the charter samples and identify the elasmobranch bycatch. The support provided by Ms Jessica Gorring from the University of the Sunshine Coast for checking the sea snake CMP data and the post-trawl mortality data was very much appreciated. Dr James Haddy (University of Tasmania) provided advice and supervision of Mr Brendon Young.

Guidance and advice for the project were provided by members of a joint steering committee of the two FRDC-funded sea snake bycatch projects (FRDC 2004/051 *Risk assessment and mitigation for sea snakes caught in the Northern Prawn Fishery* and FRDC 2004/053 *Reducing the impact of Queensland's trawl fisheries on protected sea snakes*). Members of the steering committee were:

- Dr David Milton, Dr Shiji Zhou, Mr Gary Fry and Mr Quentin Dell (CSIRO)
- Mr Wade Whitelaw (Australian Fisheries Management Authority)
- Ms Dorothea Huber and Mr Randall Owens (GBRMPA)
- Mr Mike O'Brien (Raptis/NPF by teleconference), Jim Yarrow (NPF fisher)

- Mr Greg Radley (Queensland commercial fisherman)
- Mr James McLellan (North Queensland Conservation Council)
- Dr Malcolm Dunning, Mr Shane Gaddes, Dr Tony Courtney, Mr Ben Schemel, Mr Rohan Wallace, Mr Brad Zeller and Dr Ross Quinn (DEEDI),
- Mr Dennis Ballam (SeaNet)
- DEWHA were invited to participate in the committee but declined. FRDC were also invited but did not attend.

Dr Malcolm Dunning and Mr Andrew Prosser critically reviewed early drafts of the report. We also thank the DEEDI Southern Fisheries Centre staff Mr Tony White, Mrs. Kelly Breddin, Ms Melissa Whitford, Mr Bob Cooper and Mr Ben Bassingthwaighte for administrative and accounting assistance associated with the project.

This research was undertaken under the GBRMPA Permit G05/14443.1, Queensland Primary Industries Animal Ethics Approval Reference Number Bribie 58/05/05, Queensland Parks and Wildlife Environmental Protection Agency Permit Number WISP03205105 and the Commonwealth DEWHA Permit E2005-60221.

14 Intellectual property

No intellectual property has arisen from the research.

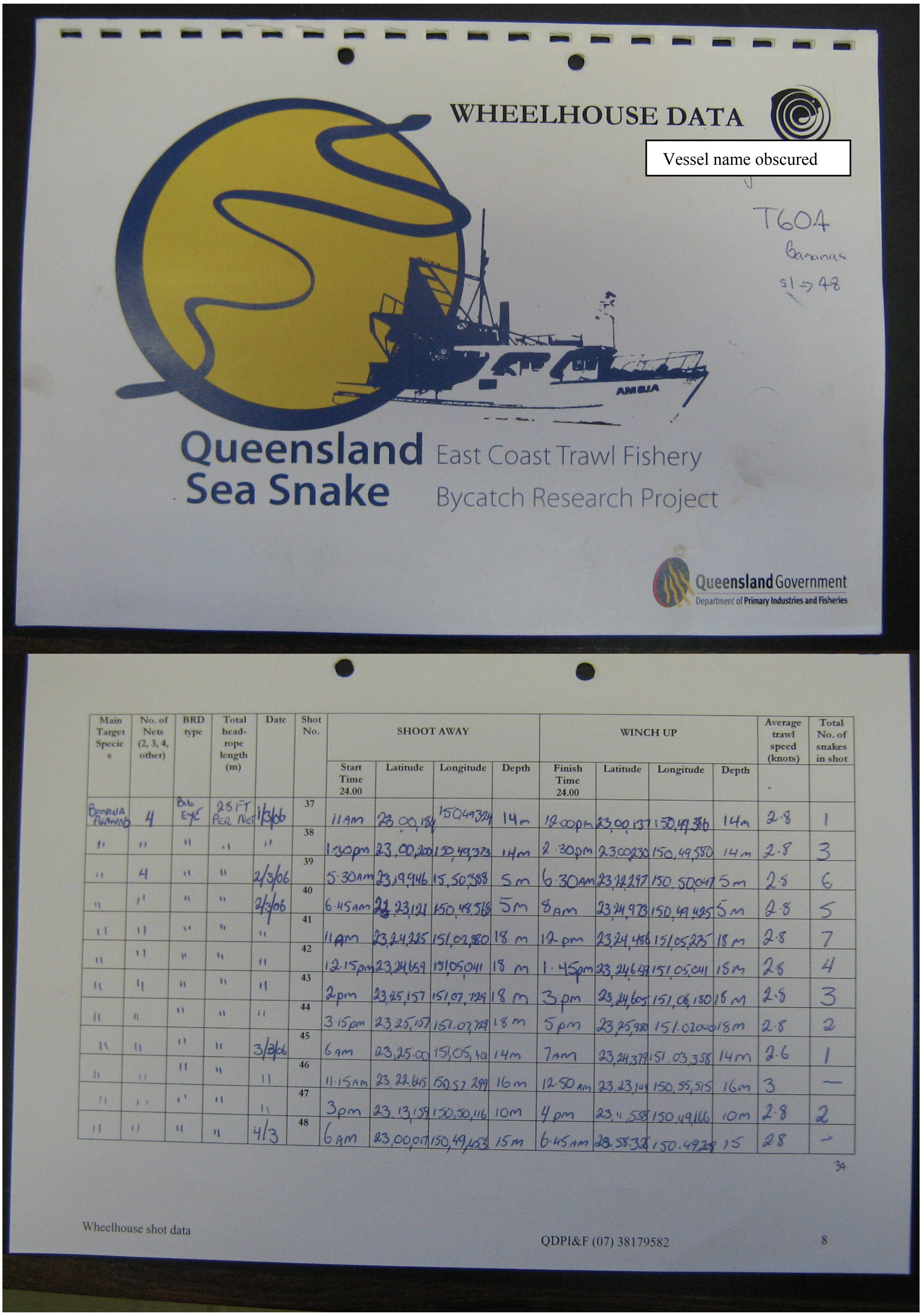
15 Staff

- Dr Tony Courtney, Agri-Science Queensland, Principal Fisheries Biologist (Principal Investigator)
- Mr Ben Schemel, Agri-Science Queensland, Fisheries Biologist
- Mr Rohan Wallace, Agri-Science Queensland, Fisheries Technician
- Mr Matthew Campbell, Agri-Science Queensland, Senior Fisheries Biologist
- Dr David Mayer, Agri-Science Queensland, Principal Scientist (Biometry)

Mr Brendon Young was not a staff member but provided input to the project through his Honours research based at the Australian Maritime College (now part of the University of Tasmania), Tasmania, which focused on the growth and diet of Queensland sea snakes.

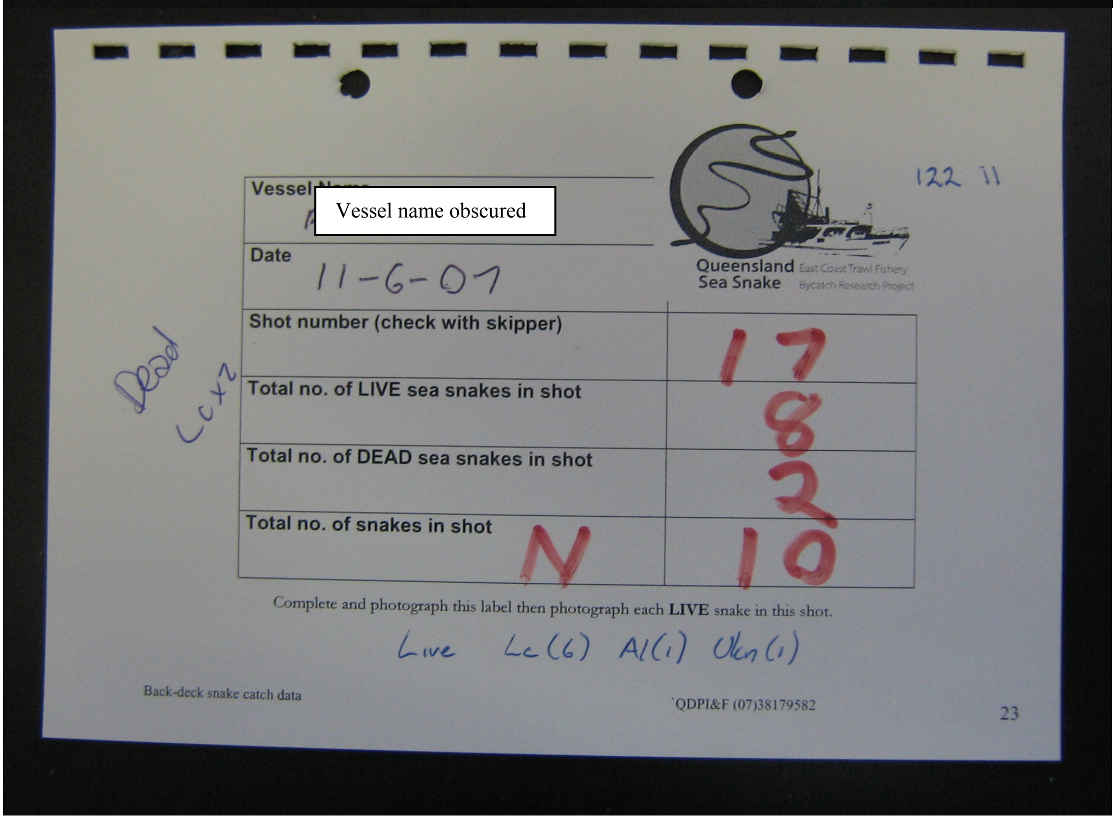
Appendix 1. Wheelhouse data booklet

Photographs of the wheelhouse data booklet front cover and a typical data page from the booklet.



Appendix 2. Back deck data booklet

Photographs of the back deck data booklet front cover and a typical data recording page from the booklet. Precise details of trawl number 17 (i.e. location, date, time, headrope length, BRD, depth, etc) which caught 10 snakes (i.e. 8 alive and 2 dead) could be obtained from the wheelhouse data booklet.



Appendix 3. Back deck data booklet with olive sea snake

Photograph of a live olive sea snake (*Aipysurus laevis*) and the back deck data booklet showing which trawl it was caught in. Detailed information on the location, duration, time, date, gear type, etc of this trawl could be obtained from the wheelhouse data booklet. Note this trawl recorded one live snake and one dead snake. Dead snakes were not photographed but rather labelled, frozen, stowed on board and provided to research staff for further analysis. In this way, data on both live and dead snakes from each trawl were collected. All live snakes were released back into the water by crews.

Appendix 4. CSIRO sea snake maps

CSIRO

Predicting the presence of sea snake species in the Great Barrier Reef

Elliot Dovers (CMIS, Cleveland)
30 January 2009

www.csiro.au

Objectives

To create predictive models of the presence of individual species of sea snake in the Great Barrier Reef (GBR) based on a range of spatial and physical variables. In addition, to use these models to obtain presence probability maps for each species over the GBR grid.

Data

There were 12 species of sea snake: *Acalyptophis peronii* (Ap), *Aipysurus duboisii* (Ad), *Aipysurus eydouxii* (Ae), *Aipysurus laevis* (Al), *Astrotia stokesii* (As), *Disteira kingii* (Dk), *Disteira major* (Dm), *Enhydrina schistosa* (Es), *Hydrophis elegans* (He), *Hydrophis mcdowelli* (Hm), *Hydrophis ornatus* (Ho) and *Lapemis curtus* (Lc). For each species, information on the number of individuals caught in 8291 trawls was available. Table 1 displays the numbers of observed counts for each species.

Table 1 The number of trawls in which counts of each species were recorded. There were a total of 8291 trawls.

Species	Count					
	0	1	2	3	4	5+
Ap	8143	88	30	16	6	8
Ad	8040	152	42	27	14	15
Ae	8209	73	6	2	1	0
Al	7998	179	58	25	22	9
As	8267	19	4	1	0	0
Dk	8266	20	5	0	0	0
Dm	8242	43	6	0	0	0
Es	8240	34	8	4	2	2
He	8131	142	13	2	3	0
Hm	8221	38	12	5	5	9
Ho	8221	55	11	3	0	1
Lc	7874	224	76	55	20	42

Due to the small number of recorded counts greater than zero it was deemed more prudent to examine the presence/absence of each species rather than exact numbers caught. Counts were converted into a binary factor indicating the presence or absence in each trawl. Other information recorded for each trawl included the average latitude and longitude and the variables outlined in Table 2.

Table 2.Trawl site-specific variables – termed covariates

Variable	Description (units where applicable)
Area	Area swept by trawl (m2)
Rope	Head rope length (m)
Net	Net spread factor
Hours	Hours trawled

The date and some categorical variables (such as trip number, vessel and fishery) were also recorded; however these were not deemed appropriate for subsequent analysis with respect to the current objective. The latitudes and longitudes were used to match the trawl data to existing GBR gridded physical variables outlined in Table 3.

Table 3. GBR gridded physical variables – termed predictors

Variable	Description (units where applicable)
GBR_BATHY	Bathymetry
GBR_ASPECT	Polar direction
GBR_SLOPE	Benthic slope
M_BSTRESS	Benthic stress measure
GA_CRBNT	Carbonate sediment (%)
GA_GRAVEL	Gravel sediment grainsize fraction (%)
GA_SAND	Sand sediment grainsize fraction (%)
GA_MUD	Mud sediment grainsize fraction (%)
CRS_NO3_AV	Annual average Nitrate concentration (uM)
CRS_O2_AV	Annual average Oxygen concentration (ml l-1)
CRS_PO4_AV	Annual average Phosphate concentration (uM)
CRS_SI_AV	Annual average Silicon concentration (uM)
CRS_S_AV	Annual average salinity (psu)
CRS_T_AV	Annual average temperature (degrees C)
SW_CHLA_AV	Annual average Chlorophyll A concentration (mg m-3)
SW_K490_AV	Diffuse attenuation coefficient at wavelength 490nm m-1
SW_K_B_IRR	Relative benthic irradiance (based on K490, latitude and depth
TRWL_EFF_I	Weighted annual average of commercial trawl fishery effort, local to the sampling site

The longitude and latitude data were then transformed into spatial variables representing in relative terms the distance between shoreline and outer reef, and between the northern-most and southern-most points of the GBR (labelled across and along respectively). For all species other than *Aipysurus duboisii*, information on 4794 trawls (samples) were available once 62 missing longitude and latitude values were deleted, as well as those trawl sites that were outside of the GBR (to within 0.2°)—as shown in Figure 1. *Aipysurus duboisii* had a missing count observation, thus reducing the number of samples by 1. Trawl sites are shown in Figure 1 which also reveal that some of the recorded longitudes and latitudes must have been erroneous as these occur over land and in areas extremely far removed from the GBR.

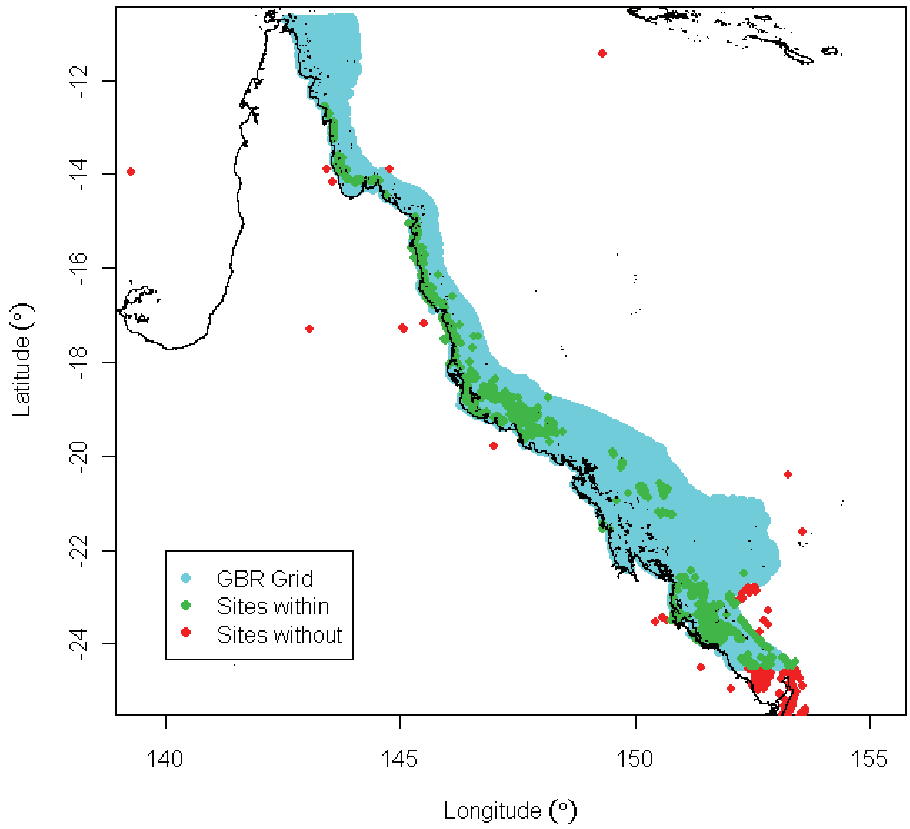


Figure 1 Displays the location of trawl sites. Some erroneous recordings were evident.

Method

Logistic regression was used to model the presence/absence (binary) response against the extensive list of variables outlined in the previous section. All analyses were performed in R. A range of models were examined for each species, which differed according to their utilisation of predictors/covariates. The 'minimum' model examined was the null (no predictor/covariates); while the 'maximum'model involved all main effects, quadratic terms and first order interactions. The most parsimonious model for each species was selected using BIC—through the use of an appropriately configured stepAIC function within the MASS library. BIC was implemented over AIC due to the greater penalty it gives to complex models (in terms of retention of predictors/covariates). Each variable was fitted via a numeric vector—that is, each was considered a quantitative continuous variable; however, a natural log transformation was performed on Area to reduce its range of variation.
Each final model was assessed based on both the area-under-the-curve (AUC) statistic and the ratio of 'explained' to null deviance (Deviance Ratio). These measure the model's ability to discern true positives and negatives from false positives and negatives in the binary response. The AUC statistic was calculated via implementation of the ROCR package. A reported AUC value of 0.5 implies that the prediction is no better than flipping an unbiased coin and hence, in the current context, a value of 0.8 or greater was considered sufficient. In an effort to improve

reporting of this statistic, predictions used in its calculation were based on a 10-fold cross validation as apposed to use of the linear predictor. Other common model diagnostics are less appropriate when implementing a logistic regression.

To achieve the current objective, extrapolation over the GBR grid was required; however, only information for the variables outlined in Table 1. (termed predictors) were available for the entire grid. Hence the trawl specific variables (Area, Speed, Net and Hours), termed covariates, had to be imputed to perform extrapolated predictions. The specific value imputed for each of the covariates was that which maximised the probability of presence, termed optimal values, the idea being that the species is still present at a site for other values; however, it may be less likely to be caught. These optimal values were obtained by predicting over a grid spanning the range of the some of the covariates. Computational capacity can become an issue here, and so 50 evenly spaced values over the range of Rope, Hours and Speed were used. Once the optimal value of the potential 50 was found, the most similar observed value was imputed for prediction. Net and Area were excluded since for Net only 3 values were observed (hence it could be treated as a 3 level-ordered factor); while for Area, a standard value of 1 Ha for each prediction was used.

Results

Figures 2 to 13 display the predicted probability of each sea snake species' presence in the GBR grid. The figures also detail key model assessment statistics as outlined in the previous section, as well as predictors/covariates retained in the final model.

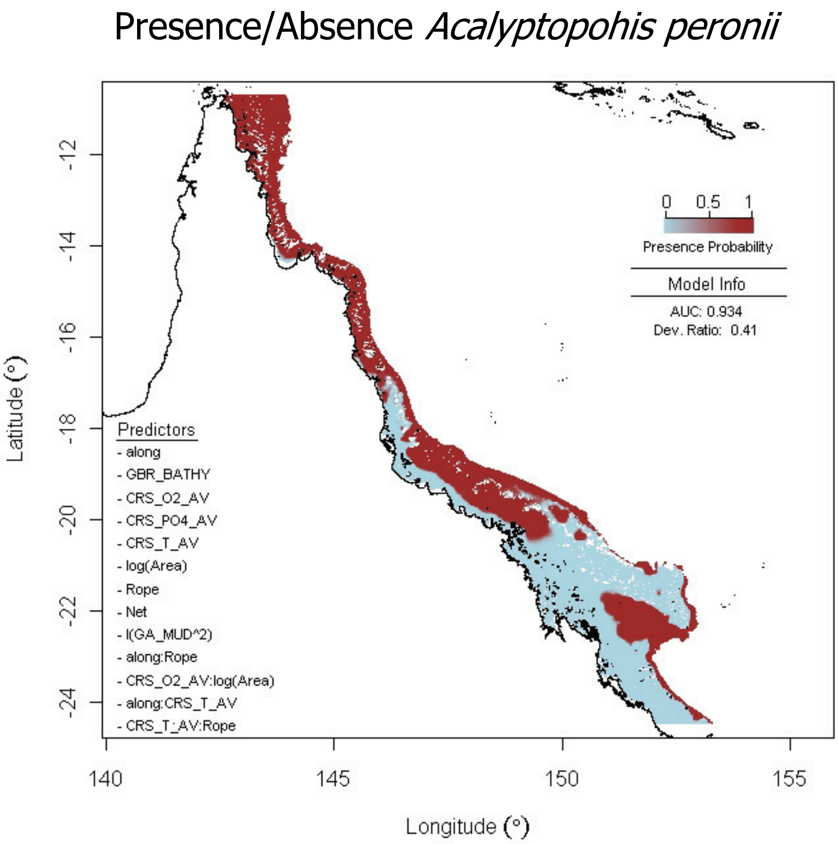


Figure 2 Results for *Acalyptophis peronii*

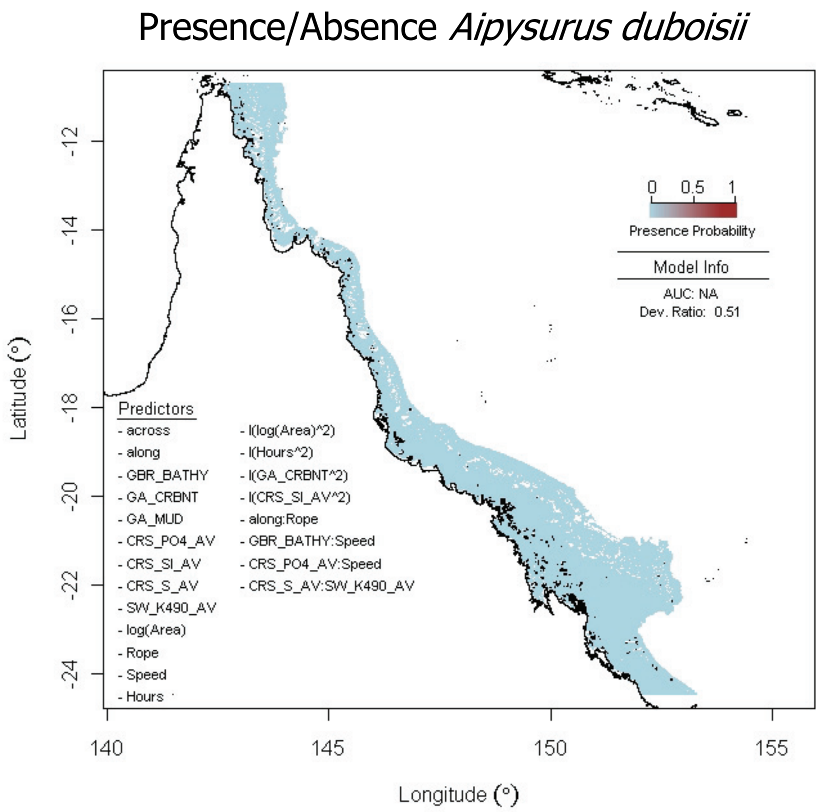


Figure 3 Results for *Aipysurus duboisii*

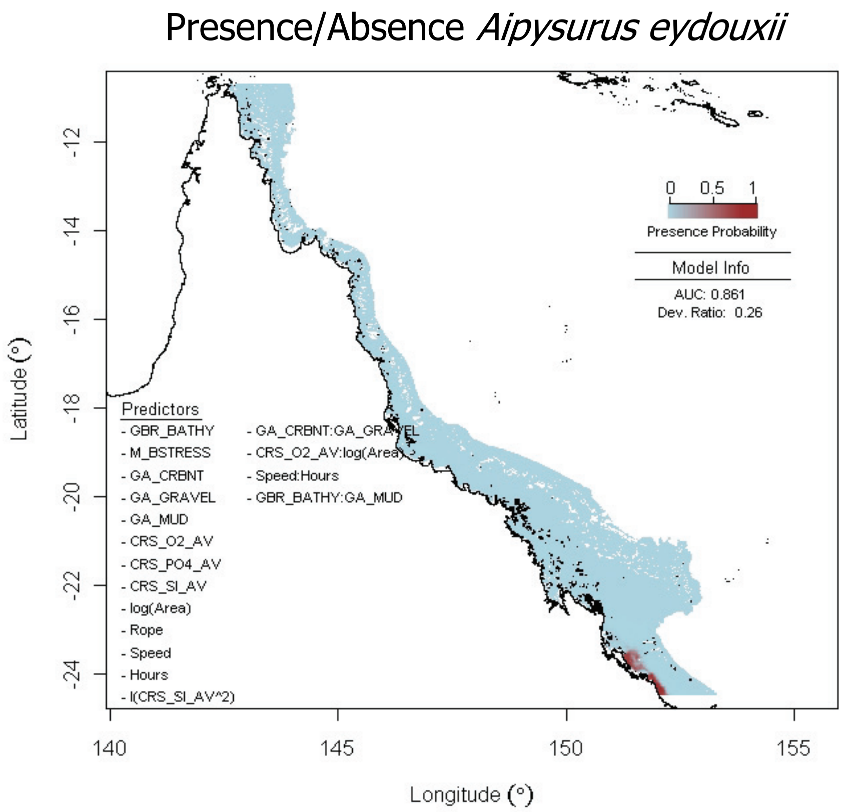


Figure 4 Results for *Aipysurus eydouxii*

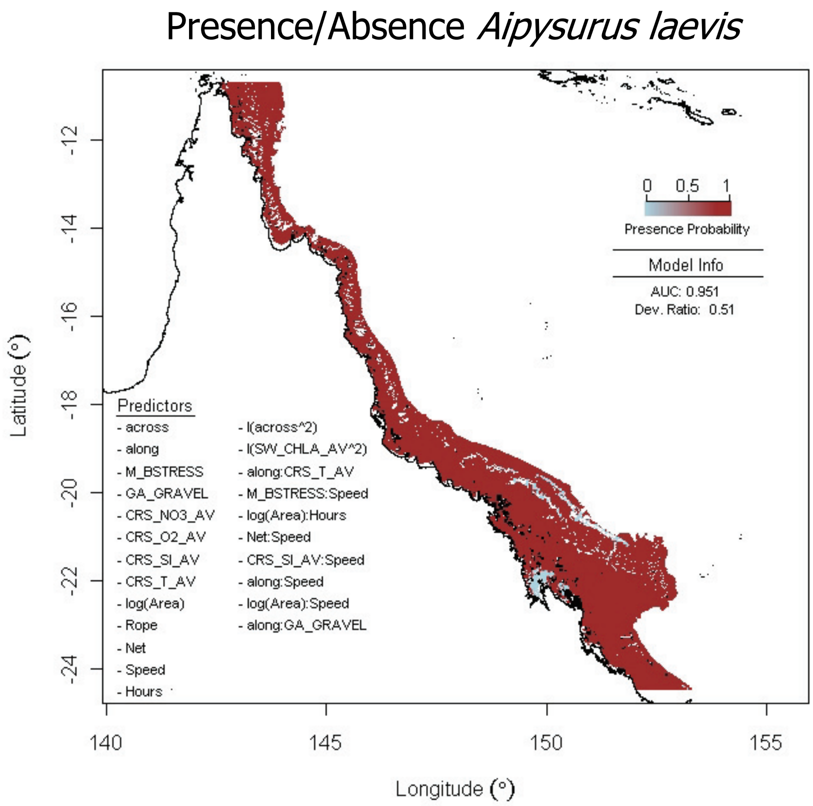


Figure 5 Results for *Aipysurus laevis*

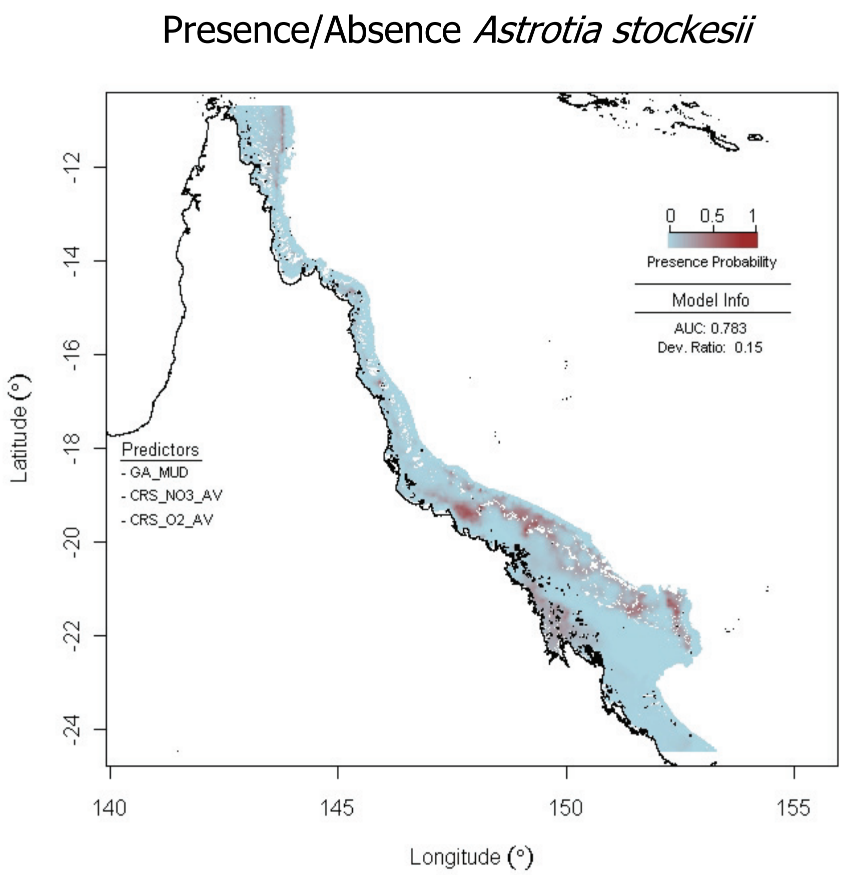


Figure 6 Results for *Astrotia stokesii*

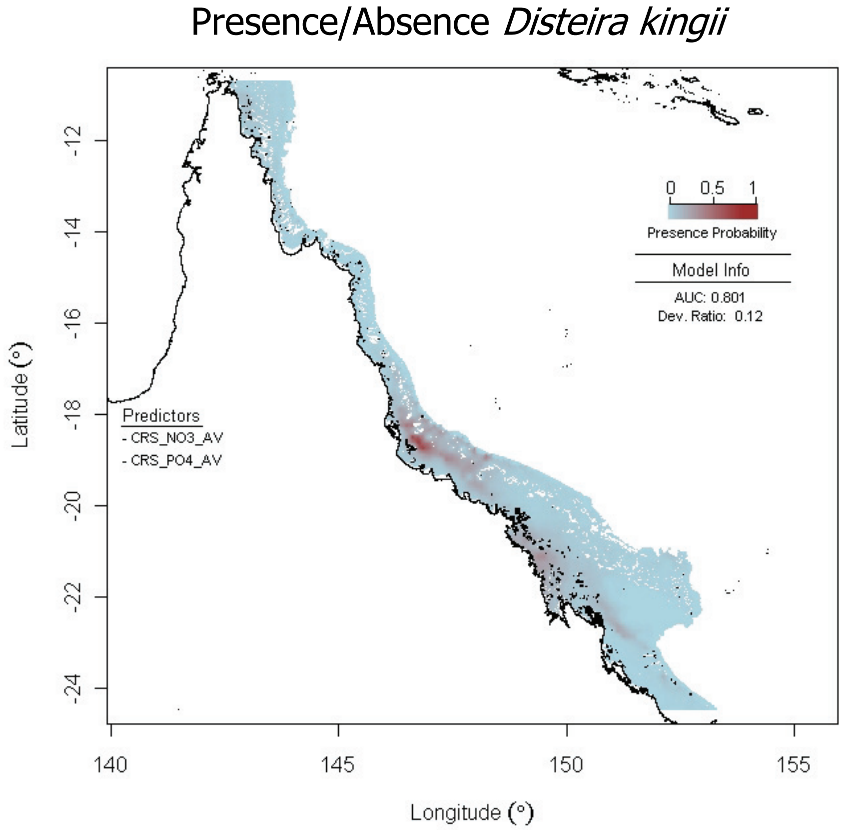


Figure 7 Results for *Disteira kingii*

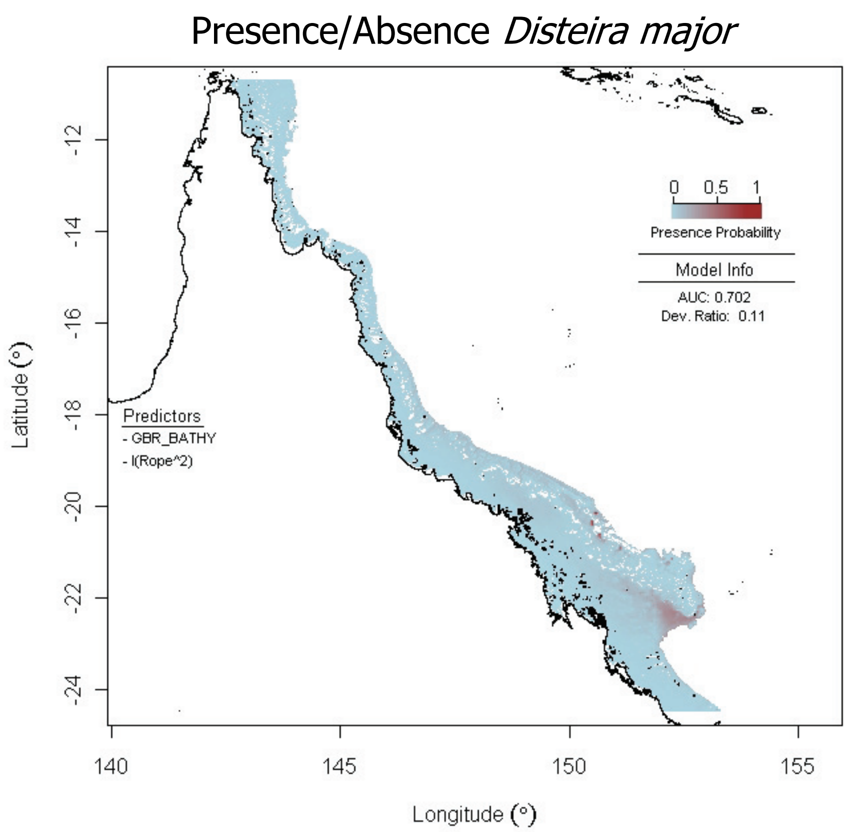


Figure 8 Results for *Disteira major*

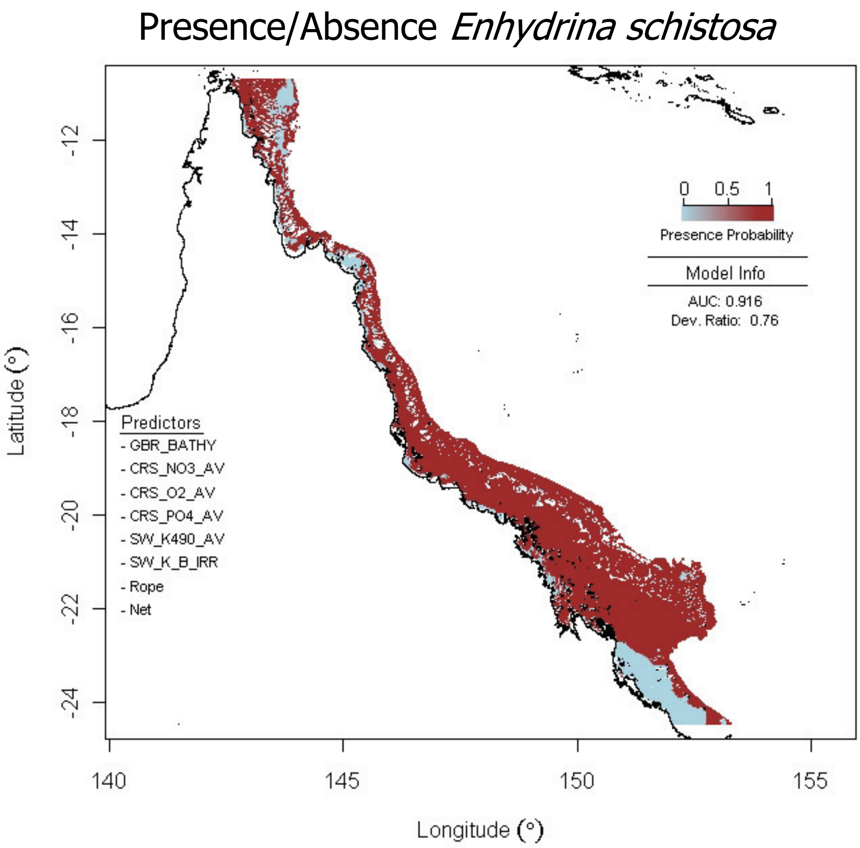


Figure 9 Results for *Enhydrina schistosa*

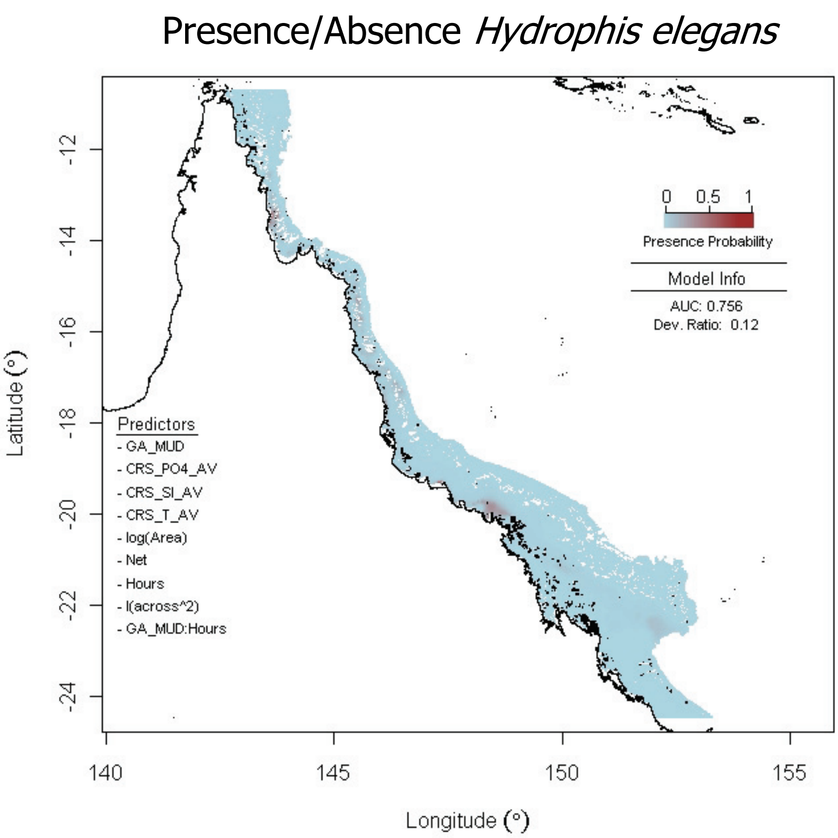


Figure 10 Results for *Hydrophis elegans*

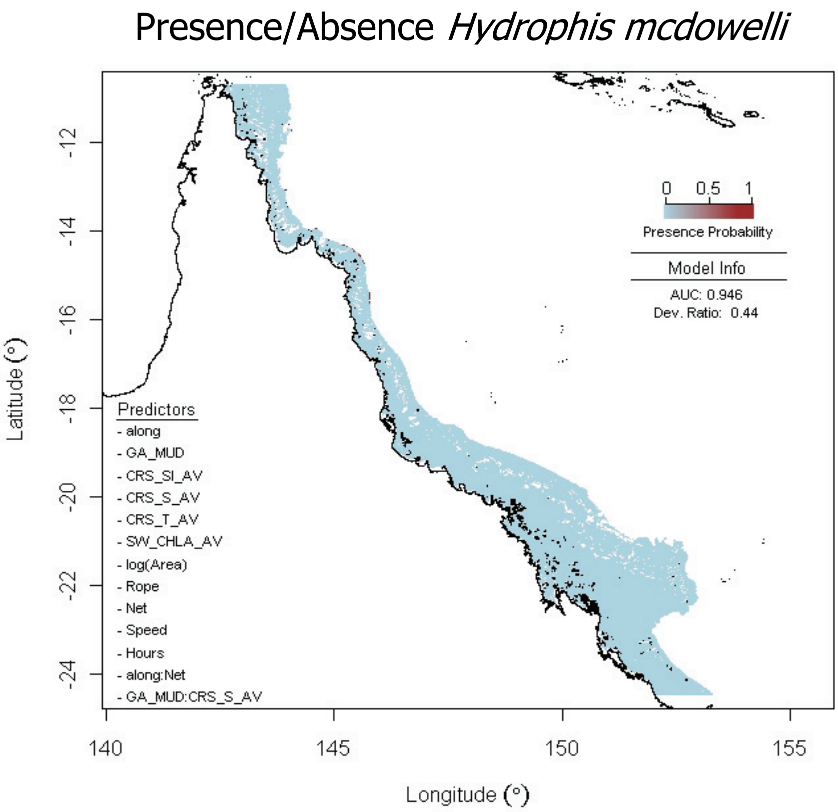


Figure 11 Results for *Hydrophis mcdowelli*

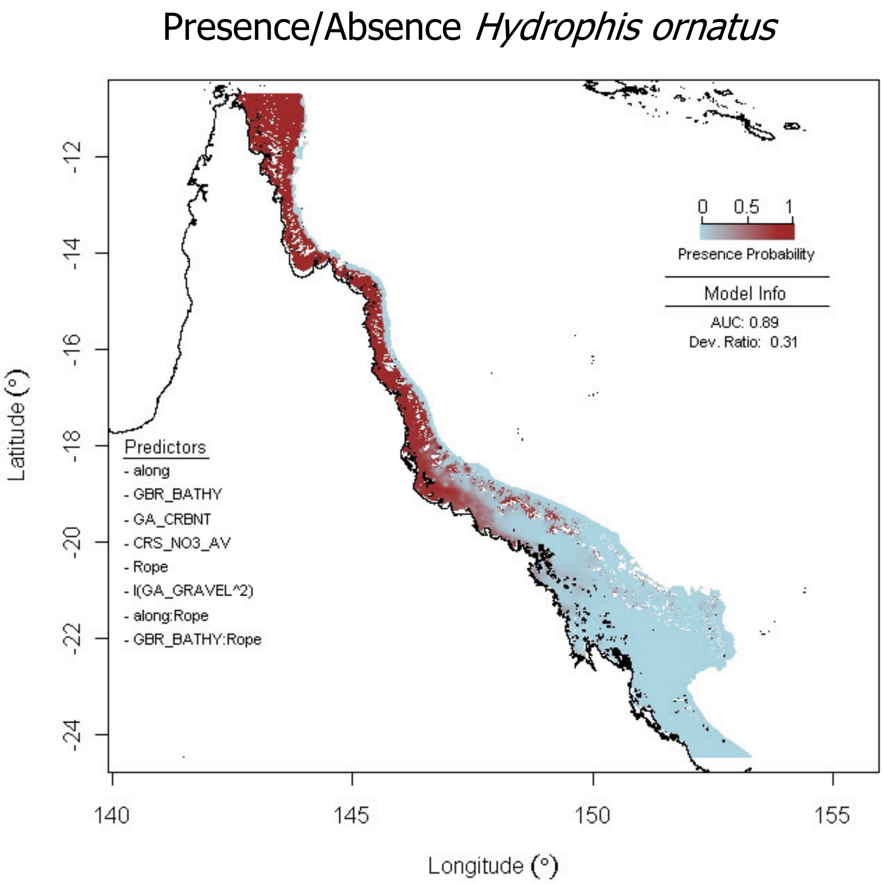


Figure 12 Results for *Hydrophis ornatus*

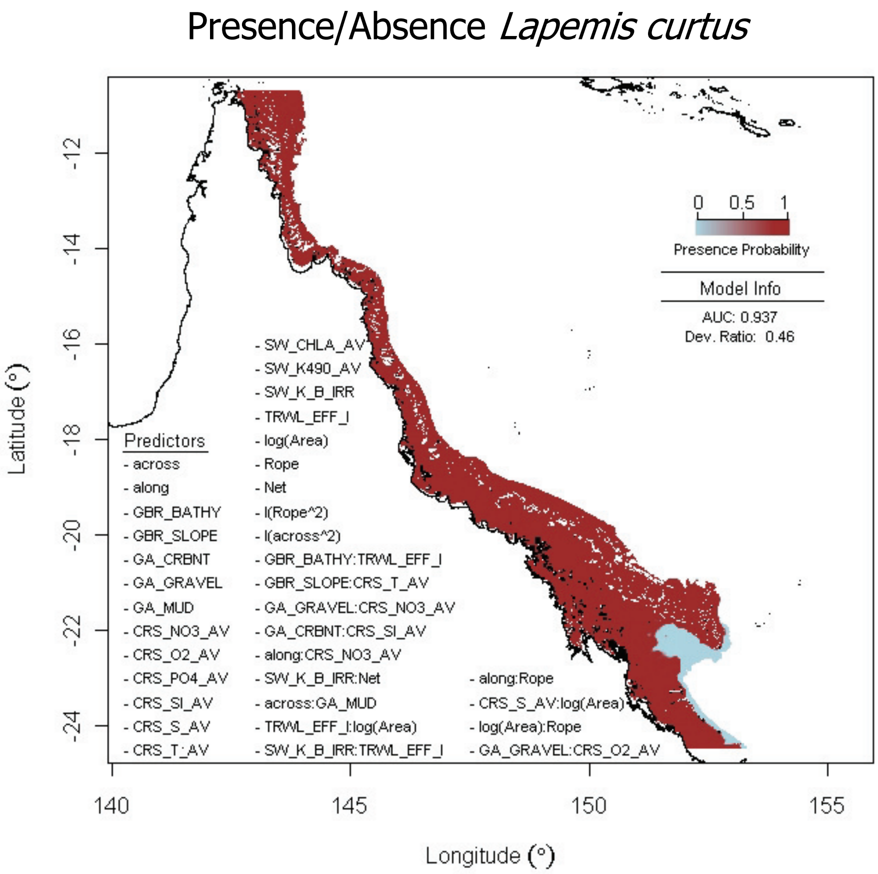


Figure 13 Results for *Lapemis curtus*

Comments
No predictors or covariates were identified as significant in explaining the presence or absence of *Enhydrina schistosa*. In turn the following general comments exclude them.

With the exceptions of the *Disteira major, Hydrophis elegans* and *Astrotia stokesii* models (AUC of 0.66, 0.77, 0.78 respectively), the models appear successful in accurately predicting the presence each species, as indicated by AUC values greater than 0.8. The Deviance Ratios ranged from approx. 0.54 (reasonable) to 0.09 (very poor), suggesting that for most species there is much deviance in presence probability unaccounted for by the predictors and covariates.

Some spatially extensive, very high predicted probabilities could be of concern since sampling generally found absence of species much more prevalent than presence. This could be attributed to the imputation of optimal covariate values—perhaps variation in the spatial and physical predictors has little effect on presence-probabilities dominated by the imputed covariates.

Appendix 5. Risk assessment

Assessing the risk of incidental fishing mortality from trawling on Queensland sea snake populations

Introduction
The following attempts to assess the risk to sea snake populations in Queensland due to incidental capture and death attributed to trawling. The assessment was not included in the project objectives, nor was any funding sought or obtained from FRDC to undertake it. In this respect it should be considered as an additional component of the project which enhances the project's value. It was undertaken because once information on the sea snake distributions, catches and mortalities were obtained, it is reasonable to conclude that the next logical step for resource management is to assess the risk to the snakes. Risk assessments also help identify critical knowledge gaps in the population dynamics of the species being considered. If additional funding is provided in the future then perhaps some of these knowledge gaps could be addressed. As there is still a great deal that is unknown about the population dynamics of sea snakes along the Queensland coast, and the impacts of trawling on them, the risk assessment should be considered as preliminary.

Methods
The methods used to assess risk were based on the approach and spreadsheet models developed by Pitcher et al. (2007) in the Great Barrier Reef Marine Park (GBRMP) seabed biodiversity mapping project. The methods used here differed slightly as they were based on the proportion of each sea snake species' spatial distribution, in terms of numerical abundance that was exposed to trawling, whereas the Pitcher et al. method estimated the proportion of each species' biomass that was subjected to exposure. The difference is due to the current project's CMP recording snake catches in number rather than weight. The risk assessment was limited to the GBRMP as the spreadsheet model was designed to estimate the size of the areas that were open or closed to trawling within the park, and the intensity of trawling in open areas. About 70% of all trawl fishing effort and catch in Queensland occur in the GBRMP. However, the present study has determined that 90-95% of all sea snake bycatch in the fishery occurs within the park and so although the risk assessment does not consider the entire fishery, assessing impacts in the park will closely reflect that of the whole fishery.

A brief description of the general approach and some key population parameters used in the spreadsheet model are provided here. A more detailed description of the methods can be found in section 2-75 of Pitcher et al. (2007). The risk assessment required modelling the distribution of each sea snake species in the GBRMP and estimating the proportion of the species' distribution that was exposed to trawling, based on its mapped distribution. Mapped distributions were estimated from logistic regression models that considered several abiotic factors and covariates to predict the presence/absence of sea snakes. The regressions included all sea snake catch data from the current project, including all of the CMP data. Details of the regressions, key abiotic predictors for each sea snake species and the subsequent modelled distribution maps for each species were provided by Elliot Dovers (Appendix 4. CSIRO sea snake maps). The spatial resolution of the maps was 0.01 degree. The proportion of each species distribution that was exposed to trawling was estimated based on Vessel Monitoring System data for 2005 (Gribble et al. 2007). It was assumed that 100% of snakes immediately in front of the trawl gear entered the net, which is reflected in the Rel Catch or 'catchability' column value 1 in the risk assessment table below. The assessment also considered the likely effect of TEDs and BRDs on sea snake catch rates. While the precise effect of the TEDs and BRDs being used by fishers in Queensland on sea snake catch rates is unknown, the devices are known to reduce total bycatch rates by 8% (Courtney et al. 2007) and therefore this level of reduction was assumed to apply to snakes. Hence, the table's BRD column has a value of 0.92. The risk assessment considered the proportion of snakes that died as a result of trawling in the Trawl Mort column. The maximum fishing mortality rate experienced by snakes occurred in the redspot king prawn fishery (Table 6.4.16), where the combined within-trawl and post-trawl mortalities was approximately 40%. Hence, the 0.4 value in the Trawl Mort column, which was applied to all 12 sea snakes should be considered as relatively high, thus making the assessment conservative. The assessment also considered the instantaneous rate of natural mortality (M, year^{-1}) for the sea snakes. In general, species with low rates of natural mortality are more prone to overfishing than species with high rates. There is scant information in the peer-reviewed literature on natural mortality rate estimates for sea snakes, as noted in the literature review of Section 5. Therefore, the estimates used here were taken from Milton et al. (2008) who used Pauly's (1980) empirical method for estimating M. This method requires estimates of the von Bertalanffy growth parameters L_∞ and K for the snakes and the mean annual water temperature in which they occur. These parameters (i.e. L_∞, K and water temperature) will almost certainly differ for populations of sea snakes located in the NPF, where Milton et al. (2008) obtained their data, and the Queensland east coast. Hence, the estimates of M may also differ between the regions.

Finally, the risk was quantitatively assessed by determining whether the reference point C/M exceeded a value of 0.5, where C is the proportion of the population that is caught and killed. In this instance, C is analogous to the exploitation rate $E=F/(F+M)$ (Sparre and Venema 1992) and harvest rate H (Haddon 2001), where F is the instantaneous rate of fishing mortality. Exploitation rate is also sometimes referred to as U. Key to use of the C/M reference point is the assumption that when the exploitation rate is low, F is approximately equal to exploitation E. This assumption is verified and can be checked using the equation $H = 1 - e^{-F}$ (Haddon 2001). Based on the Schaffer surplus production model maximum sustainable yield (MSY) is achieved when $F=M$ (F/M=1.0). In their sea snake risk assessment Milton et al. (2008) applied a more conservative approach and put forward two reference points; F_{msm} such that the 'maximum sustainable fishing mortality' should not exceed 0.5M (F/M=0.5). They assumed that snake populations would decline markedly if $F=M$ (or F/M=1.0) and referred to this as F_{crash}. The current risk assessment reference point substitutes F for exploitation rate E in the equation where F/M=0.5, such that C/M=0.5. Hence, values of C/M in the table that exceed 0.5 indicate that the populations are not being maintained and values that exceed 1.0 are indicative of populations that have declined markedly.

Table 1. Assessing the risk of incidental overfishing to sea snake populations in the Queensland trawl fishery. Parameters provided include the proportion of each species distribution within the GBRMP that is available to trawling (pAvailable), effects of BRDs, relative catchability (Rel Catch), the proportion of the population caught (pCaught) and the instantaneous rate of natural mortality M year^{-1}. Species with a risk indicator reference point $C/M > 0.5$ are bolded and indicate that the population is not being maintained.

Genus	Species	Pres	Total area	pAvailable	Not trawled	Trawled	pExposed	pEffortExp	Rel Catch	BRD	pCaught	Trawl Mort	*M*	C/*M*
Acalyptophis	*peronii*	215	88824	37	70695	18129	20	23	1	0.92	21	0.4	0.356	0.23
Aipysurus	*duboisii*	0	0	16	0	0	0	0	1	0.92	0	0.4	0.393	0.00
Aipysurus	*eydouxii*	0	1757	84	937	820	47	18	1	0.92	17	0.4	0.517	0.13
Aipysurus	*laevis*	297	166693	45	126162	40531	24	20	1	0.92	18	0.4	0.193	0.38
Astrotia	*stokesii*	2	1368	35	1086	282	21	12	1	0.92	11	0.4	0.28	0.15
Disteira	*kingii*	1	863	56	566	297	34	26	1	0.92	24	0.4	0.373	0.26
Disteira	*major*	8	7345	32	6420	925	13	7	1	0.92	7	0.4	0.434	0.06
Enhydrina	*schistosa*	231	140741	41	111123	29618	21	17	1	0.92	16	0.4	0.434	0.15
Hydrophis	***elegans***	**0**	**131**	**49**	**93**	**38**	**29**	**35**	**1**	**0.92**	**32**	**0.4**	**0.219**	**0.59**
Hydrophis	*mcdowelli*	11	189	0	189	0	0	0	1	0.92	0	0.4	0.373	0.00
Hydrophis	*ornatus*	126	51960	50	35949	16010	31	38	1	0.92	35	0.4	0.445	0.32
Lapemis	*curtus*	323	161846	44	122267	39579	24	20	1	0.92	18	0.4	0.374	0.19

Risk assessment summary and conclusions

Modelling the spatial distribution of snakes indicated that a high proportion of the distribution for *A. eydouxii* occurred in areas that were open and available for trawling (i.e. pAvailable = 84%). However, trawling does not occur in all areas that are open and the actual proportion trawled was much lower at 47%. In addition, the amount of effort applied in these areas was quite low (i.e. pEffortExp = 18%). When these parameter values were considered with the relatively high value of *M* for *A. eydouxii*, the resulting risk assessment reference point *C/M* was quite low at 0.13—well below the 0.5 (F_{msm}) put forward by Milton et al. (2008).

Hydrophis elegans was found to have the highest risk (*C/M* = 0.59). This is not necessarily because trawling occurred throughout its distribution (i.e. 29% was exposed to trawling), but rather because it had the lowest value of *M* (i.e. 0.219) which increased the reference point *C/M* value. This low value of *M* is probably attributed to the large size (i.e. length), that *H. elegans* attains (Ward 2000 and Table 6.4.13) which affects the von Bertalanffy growth parameter estimates L_∞ and *K* that were used to derive *M*. L_∞ and *K* are negatively correlated (Sparre and Venema 1998), hence the large value for L_∞ generally results in a low value of *K*, which subsequently results in the low estimate of *M*. The low *M* value for *H. elegans* obtained by Milton et al. (2008) should not be considered as incorrect, nor should the subsequent elevated risk for this species be discarded. In fact the post-trawl mortality analysis (Table 6.4.14, Figure 6.4.6) indicated that mortality increased with snake size, and therefore the risk to the larger species, such as *H. elegans,* may be higher. The *C/M* value of 0.59, which exceeds the 0.5 (F_{msm}) reference point, indicates that the level of incidental fishing mortality is above that associated with maximum sustainable yield and therefore, that recruitment for *H. elegans* is being reduced by trawling. It should not be interpreted as a high risk of extinction from the Queensland east coast.

This is the first risk assessment of the impact of trawling on sea snake populations in Queensland coastal waters. In general, the risk of incidental mortality approaching levels that are associated with recruitment failure appears low for all species, while the risk of localised (i.e. with the GBRMP) extinction due to trawling is highly unlikely. The results are heavily dependent on the accuracy of the predicted snake distributions in Appendix 4. At the time of writing, the models used to generate the maps had received little scrutiny and it's possible that some of the predicted distributions from the models are poor. For example, *Enhydrina schistosa* was relatively uncommon in the CMP data and largely limited to the shallow inshore beam trawl and black tiger prawn broodstock collection fisheries (Table 6.4.2 and Figure 6.4.2) and yet the predicted distribution for this species strongly indicated that it was widespread, common and also found in relatively deep, off-shore waters. This is likely due to a lack of predictors and covariates for this species, as noted in Appendix 4. Overestimating the distribution will generally result in underestimating the risk. It would also be prudent to re-calculate the natural mortality rate *M* for each species using data from the Queensland east coast, including water temperature data. Water temperatures from the east coast are generally lower than those from the GOC that were used by Milton et al. (2008) to derive the estimates of *M*. Using Pauly's (1980) method, the lower Queensland temperatures would probably result in lower values of *M*, which in turn, would probably result in higher risk values. For these reasons, the current risk assessment should be considered as preliminary.

Appendix 6. Trip report

Attendance by Dr Tony Courtney at the 5th World Fisheries Congress 20-24 October, 2008, Yokohama, Japan.

The purpose of the trip was to a) learn from, and make contacts with, attendees of the 5th World Fisheries Congress, b) represent Queensland Primary Industries and Fisheries (QPI&F) at a global fisheries research forum, c) present recent FRDC and QPI&F funded research results on bycatch in Queensland, and d) enhance QPI&F knowledge, skills and networks in fisheries science.

Outcomes of the trip include:

- An enhanced network of professional fishery scientists, managers and academics, with global experience, that QPI&F can now 'tap into' for advice and collaboration. This network is also available to other fishery stakeholders in Queensland, including fishers, students and management advisory committee members.
- The profile of QPI&F as an effective fisheries research agency was raised. Research undertaken by QPI&F, on sea snake bycatch rates, incidental fishing mortality and mitigation, was presented to a global audience. The research has now been published in the Congress Proceedings (see below) and disseminated to the 1600 participants from approximately 75 countries.
- By attending the Congress, QPI&F obtained a better understanding of the status of the world's fisheries and trends in fisheries' management and research.

The 5th World Fisheries Congress (WFC) was hosted by Japan in the port city of Yokohama. The Congress was organised by World Council of Fisheries Societies (WCFS), The Japanese Society of Fisheries Science (JSFS), Science Council of Japan Fisheries Research Agency (FRA) and supported by the Food and Agriculture Organization of the United Nations (FAO). The Congress is held every four years, in the same year of the Olympics. Brisbane hosted the 2nd WFC in 1996. This global conference was attended by approximately 1600 participants from about 75 countries. There were about 600 presentations and about 200 posters. Topics covered included stock assessment methods, fishing technology, aquaculture, genetics, aquatic animal nutrition, bycatch, disease, ecosystem and habitat impacts, population dynamics, human health and nutrition, biodiversity, fisheries trade, economics and womens' roles. Dr Courtney presented research on the bycatch of sea snakes, which are protected species in Australia, in Queensland's trawl fishery. The Japanese did an outstanding job as host, and at organising this very large conference. A highlight of the Congress was a personal presentation by Japan's Royal Highness, Emperor Akihito, who has qualifications and publications in fisheries science. The next WFC will be held in Edinburgh, Scotland in 2012.

A copy of the presentation Abstract, the two-page project summary and the Powerpoint presentation are attached. Proceedings from the Conference are now published and available, entitled 'Proceedings of the 5th World Fisheries Congress', 20-24 October, 2008, Yokohama, Japan.

5th WFC 2008. Presentation Abstract

Quantifying and reducing the incidental catch and fishing mortality of sea snakes in the Queensland (Australia) trawl fishery

Anthony J Courtney, Benjamin L Schemel, Rohan M Wallace, Matthew J Campbell and David G Mayer

Queensland Department of Primary Industries and Fisheries
Southern Fisheries Centre
PO Box 76
Deception Bay
Queensland 4508
AUSTRALIA

The Queensland trawl fishery lands 8-10 000 tonnes of seafood annually, mainly penaeid prawns and saucer scallops. Past bycatch research on the fishery focused on reducing the incidental capture of sea turtles, which was largely achieved through the implementation of turtle excluder devices (TEDs). Sea snakes are air-breathing reptiles and protected under Australian law. A research project funded by the Australian Fisheries Research and Development Corporation and the Queensland Department of Primary Industries and Fisheries commenced in 2005 to quantify and reduce sea snake bycatch in the fishery. Results from the project indicate that approximately 100 000 snakes, comprised of about 12 species, are caught annually. The most commonly caught species are the spine-bellied sea snake *Lapemis curtus* and the olive sea snake *Aipysurus laevis*. Measures of the incidental fishing mortality vary from zero to about 45%, depending on the fishing sector/type of trawling. Mortality rates also vary between snake species. It is unknown whether the sea snake populations can sustain these levels of fishing mortality. The project tested bycatch reduction devices (BRDs) on sea snake, prawn and bycatch rates, and demonstrated that one device, the Fisheye BRD, reduces sea snake catch rates by 65% with no reduction in prawn catch rates.

5th WFC 2008. Two-page project summary

Quantifying and reducing the incidental catch and fishing mortality of sea snakes in the Queensland (Australia) trawl fishery

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Southern Fisheries Centre,
PO Box 76, Deception Bay 4508,
Queensland
AUSTRALIA

Introduction

The 'true' sea snakes (Family: Hydrophiidae) are the only marine reptiles to spend their entire lives in water. They are found only in the Indian and Pacific oceans and mostly in warm, shallow, inshore waters. Of the 54 known species, 37 occur in Australian waters—11 of which occur nowhere else (Heatwole 1999). Australia's sea snakes, therefore, represent a diverse and unique faunal group and as such are protected under the *Australian Environment Protection and Biodiversity Conservation Act 1999*. Queensland has the largest benthic trawl fleet in Australia, with approximately 450 licensed otter trawlers and 150 licensed beam trawlers in 2007. The fleet mainly targets penaeid prawns (*Penaeus* spp., *Melicertus* spp. and *Metapenaeus* spp.) and saucer scallops (*Amusium balloti*), but fishers can also retain several other incidentally-caught species as byproduct. Between 2000 and 2002, the fishery's managers mandated the use of turtle excluder devices (TEDs) and bycatch reduction devices (BRDs). While these devices have had positive effects reducing bycatch, particularly for large bycatch such as turtles, sharks, rays and sponges, the impact of the fishery on sea snakes remains largely unknown. The following recent research results show that although the fishery continues to impose significant incidental catch and mortality on sea snakes, some BRDs show potential for excluding a high proportion of snakes from trawl nets.

Crew member observer program

Information on sea snake catch rates, species composition and within-trawl mortality rates were obtained from a purposely-designed voluntary crew-member observer program. Crews were provided with research logs and digital cameras and the program was stratified across all sectors of the trawl fishery. Over a two-year period, about 67 crews participated in the program recording information on about 7400 trawls. A total of 3910 sea snakes were caught, with the majority identified to species level (Fig. 1)—a catch rate of about one sea snake for every two trawls.

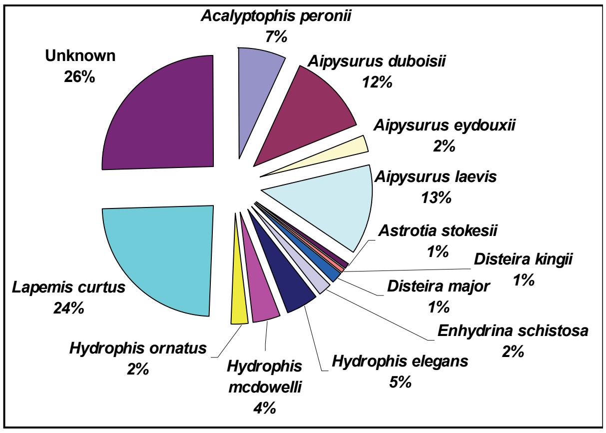


Figure 1. Breakdown of sea snake species caught incidentally in the Queensland trawl fishery.

The spine-bellied sea snake *Lapemis curtus* was the most common snake in the bycatch. Catch rates varied across sectors from 0.05 to 15.0 snakes per boat-day. Data provided by the program indicated that when species were pooled, about 9% of snakes were dead in the nets when brought to the surface. The small headed sea snake *Hydrophis mcdowelli* experienced the highest within-trawl mortality rate of 33%.

Figure 2 Snakes were held in 140 L drums for 96 hours to quantify post-trawl mortality rates.

Measuring post-trawl survival rates
The project also included quantifying the post-trawl mortality rates of sea snakes in the hours and days after being caught in trawl nets. This was undertaken by research staff on board trawlers during their normal fishing activities. A total of 211 trawl-caught sea snakes were held in drums on board vessels for a minimum of 96 hours. The overall mean observed post-trawl mortality rate was 24%. Most mortalities occurred in the first 24 hours after trawling and differed significantly between sectors—4.2% in the banana prawn (*Fenerropenaeus merguiensis*) sector, 31.6% in the broodstock (*Penaeus monodon*) collection fishery, 37.2% in the redspot king prawn (*Melicertus longistylus*) fishery and 15.7% in the tiger/endeavour prawn sector (*Penaeus esculentus, P. semisulcatus, Metapenaeus endeavouri* and *M. ensis*). The difference between sectors appears largely due to differences in the a) duration of the trawls and b) the weight and composition of the bycatch which can crush and injure the snakes.

Extrapolating total annual sea snake catch and mortality
When the sea snake catch and mortality rates (i.e. number caught or number that die per boat-day) for each sector are multiplied by the average annual effort in each sector (in boat-days) an estimate of the total number of snakes caught and killed annually can be derived. For all sectors pooled, the estimated mean annual number of sea snakes caught by the fishery from 2003–07 was 105 210 (s.e. 18 288). Of these, about 8939 snakes were dead in nets when brought to the surface and a further 18 334 snakes died in the following hours and days after trawling. The redspot king prawn sector was responsible for the majority of sea snake bycatch and mortality.

Testing bycatch reduction devices
While the estimates of total annual catch and mortality are considerable, the project also tested different BRDs during a dedicated research charter in areas associated with high sea snake catch rates and found that two BRDs, the Fisheye and the square mesh codend, significantly reduced the catch rate of sea snakes by 63% and 59%, respectively, compared to a standard net with no BRD (Table 1). These devices also significantly reduced the catch rate of the remaining bycatch and had no significant effect on the targeted prawn catch rates. Such highly effective devices may become mandatory in some sectors if the impacts of the fishery are concluded to be unsustainable.

Table 2. Effect of three different bycatch reduction devices (BRDs) on the catch rate of sea snakes. Standard errors in brackets.

Type of BRD	Adjusted mean sea snake catch rate per trawl
Fisheye BRD	0.2857 (0.0885)
Square mesh codend BRD	0.3143 (0.0928)
Square mesh panel BRD	0.6286 (0.1316)
Standard codend (no BRD)	0.7714 (0.1458)

Acknowledgements
This research was funded by the Australian Fisheries Research and Development Corporation (FRDC) and the Queensland Department of Primary Industries and Fisheries (QPI&F).

5th WFC 2008. Powerpoint Presentation

Quantifying and reducing the incidental catch and fishing mortality of sea snakes in the Queensland (Australia) trawl fishery

Anthony J. Courtney, Benjamin L. Schemel,
Rohan M. Wallace, Matthew J. Campbell
and David G. Mayer

Funded by
Australian Fisheries Research and Development Corporation
and
Queensland Department of Primary Industries and Fisheries

Sustainable Fisheries Program

Queensland Government
Department of Primary Industries and Fisheries

Australian Government
Fisheries Research and Development Corporation

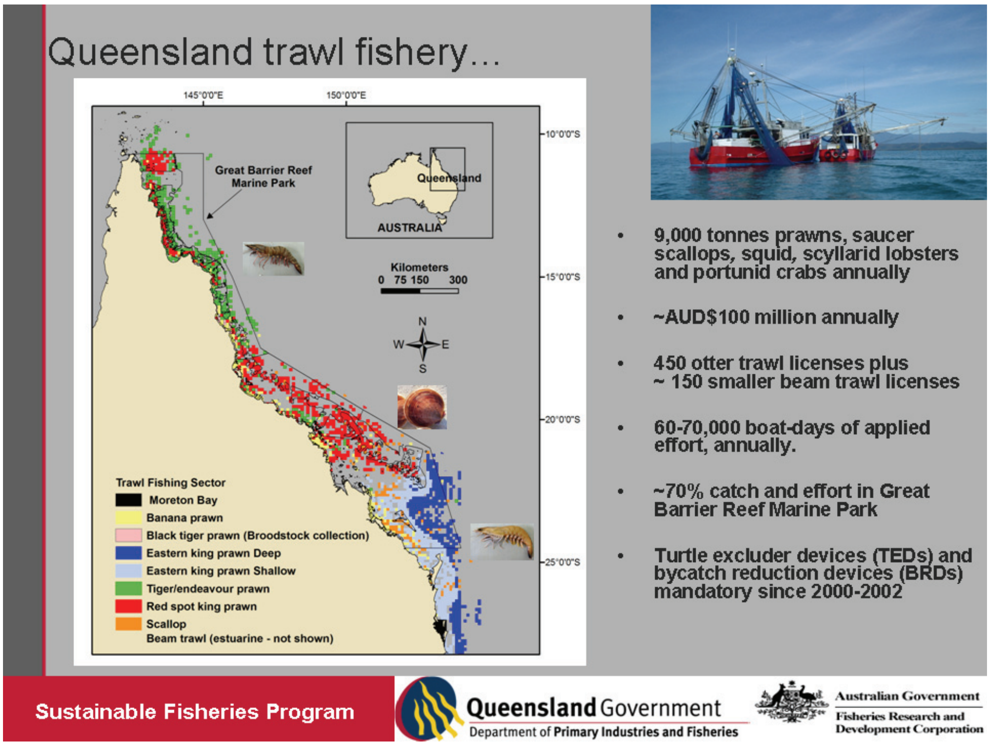
Background and justification

- 54 known sea snake species. 37 in Australian waters – 11 nowhere else. Unique and diverse faunal group.
- Protected in Australia under
  - *Australian Environment Protection and Biodiversity Conservation Act 1999*
  - *Queensland State Marine Parks Act*
  - *Great Barrier Reef Marine Park Act.*
- Commercial trawler operators legally obliged to minimise interactions with protected species.
- Australian Federal Government can withdraw export permission of trawl-caught seafood if impacts are unsustainable.
- How many sea snakes are caught and die from trawling? Sustainable?

Sustainable Fisheries Program

Queensland Government
Department of Primary Industries and Fisheries

Australian Government
Fisheries Research and Development Corporation


Queensland trawl fishery…
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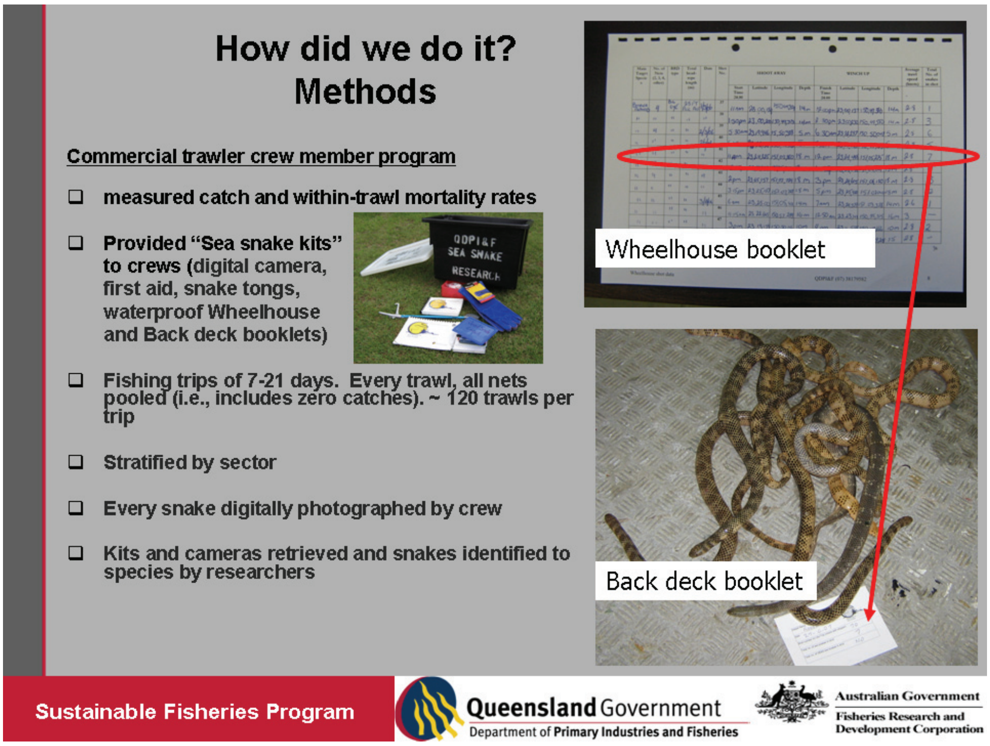
Queensland
AUSTRALIA
Kilometers
0 75 150 300
N
W
E
S
Trawl Fishing Sector
Moreton Bay
Banana prawn
Black tiger prawn (Broodstock collection)
Eastern king prawn Deep
Eastern king prawn Shallow
Tiger/endeavour prawn
Red spot king prawn
Scallop
Beam trawl (estuarine - not shown)
• 9,000 tonnes prawns, saucer scallops, squid, scyllarid lobsters and portunid crabs annually
• ~AUD$100 million annually
• 450 otter trawl licenses plus ~ 150 smaller beam trawl licenses
• 60-70,000 boat-days of applied effort, annually.
• ~70% catch and effort in Great Barrier Reef Marine Park
• Turtle excluder devices (TEDs) and bycatch reduction devices (BRDs) mandatory since 2000-2002
Sustainable Fisheries Program
Queensland Government
Department of Primary Industries and Fisheries
Australian Government
Fisheries Research and Development Corporation


What did we do?
Project objectives
1. Measured catch rates and species composition of sea snake bycatch over two years (2005-2007).
2. Quantified mortality rates of the snakes
• “within-trawl” mortality - immediate, and
• “post-trawl” mortality - held snakes for 4-5 days after being trawled
3. Tested bycatch reduction devices (BRDs) on sea snake, prawn and other bycatch rates.
Sustainable Fisheries Program
Queensland Government
Department of Primary Industries and Fisheries
Australian Government
Fisheries Research and Development Corporation


How did we do it?
Methods
Commercial trawler crew member program
measured catch and within-trawl mortality rates
Provided "Sea snake kits" to crews (digital camera, first aid, snake tongs, waterproof Wheelhouse and Back deck booklets)
QDPI&F
SEA SNAKE
RESEARCH
Fishing trips of 7-21 days. Every trawl, all nets pooled (i.e., includes zero catches). ~ 120 trawls per trip
Stratified by sector
Every snake digitally photographed by crew
Kits and cameras retrieved and snakes identified to species by researchers
Wheelhouse booklet
Back deck booklet
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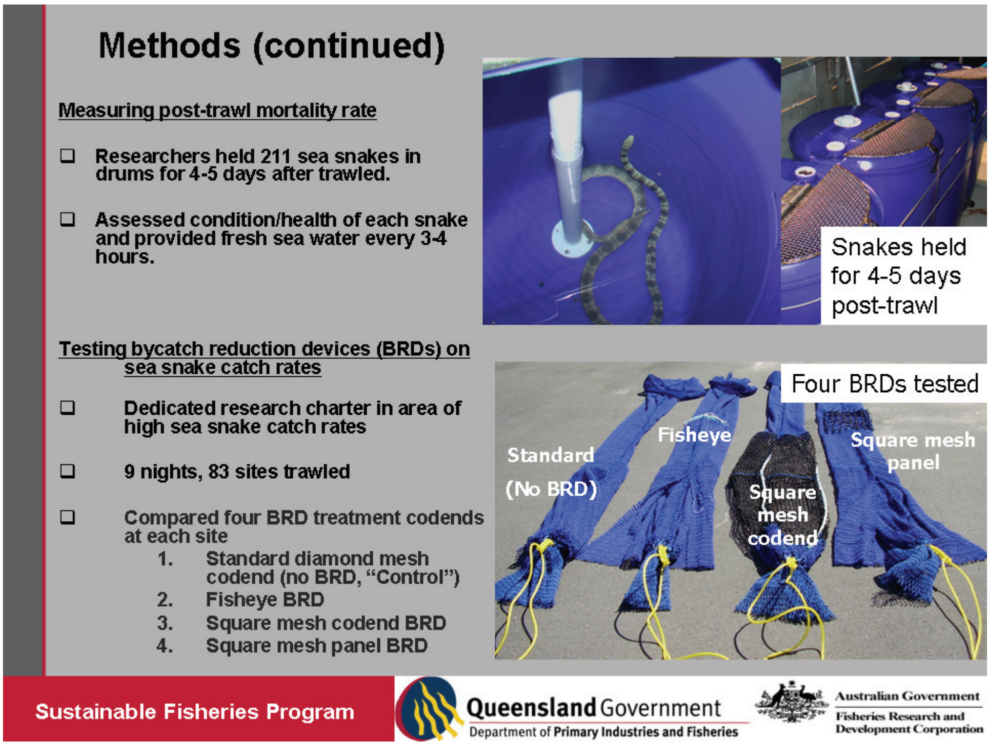
Methods (continued)
Measuring post-trawl mortality rate
Researchers held 211 sea snakes in drums for 4-5 days after trawled.
Assessed condition/health of each snake and provided fresh sea water every 3-4 hours.
Snakes held for 4-5 days post-trawl
Testing bycatch reduction devices (BRDs) on sea snake catch rates
Dedicated research charter in area of high sea snake catch rates
9 nights, 83 sites trawled
Compared four BRD treatment codends at each site
1. Standard diamond mesh codend (no BRD, "Control")
2. Fisheye BRD
3. Square mesh codend BRD
4. Square mesh panel BRD
Four BRDs tested
Standard (No BRD)
Fisheye
Square mesh codend
Square mesh panel
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Methods (continued)

Statistical methods

- Generalized Linear Models (GLMs) deployed
- Catch rates modelled using binomial/gamma conditional two-part model
- Mortality rates modelled using a binomial distribution.
- Total annual catch and mortality = product of GLM adjusted means and annual fishing effort in each sector….
  e.g., 2 snakes per boat-day x 100 boat-days = 200 snakes

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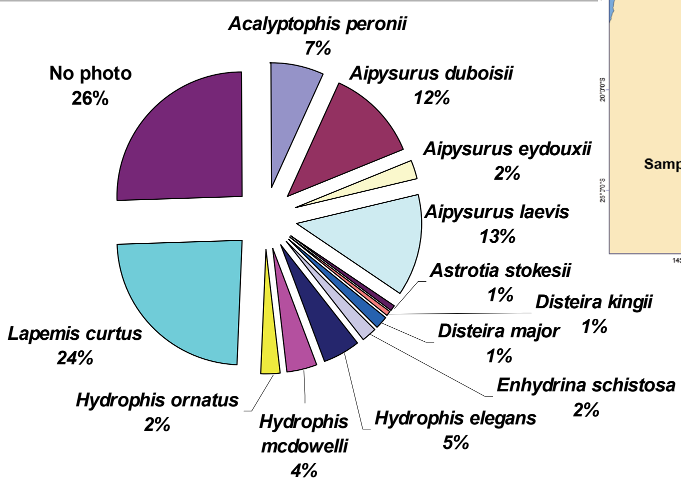
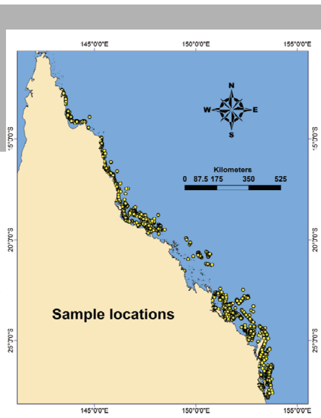
Sea snake bycatch species composition





- ~7400 trawls
- 67 commercial otter and beam trawl operators
- 3910 sea snakes sampled
- 12 species

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Estimated annual sea snake catch

Sector	Adjusted mean sea snake catch rate (boat-day^{-1})	Observed mean annual fishing effort (boat-days)	Mean number of snakes caught annually
Banana prawn	9.6	1606	15,362
Beam trawl	1.7	6830	11,577
Black tiger prawn (broodstock collection)	15.5	301	4653
Tiger/endeavour prawn	0.3	15,321	4550
Red-spot king prawn	10.2	6055	61,941
Scallop	0.05	6084	298
Moreton Bay	0.04	6490	240
Shallow water eastern king prawn	0.55	11895	6483
Deepwater eastern king prawn	0.01	5862	70
Stout whiting	0.14	262	36
Total			105,209 (se 18,288)

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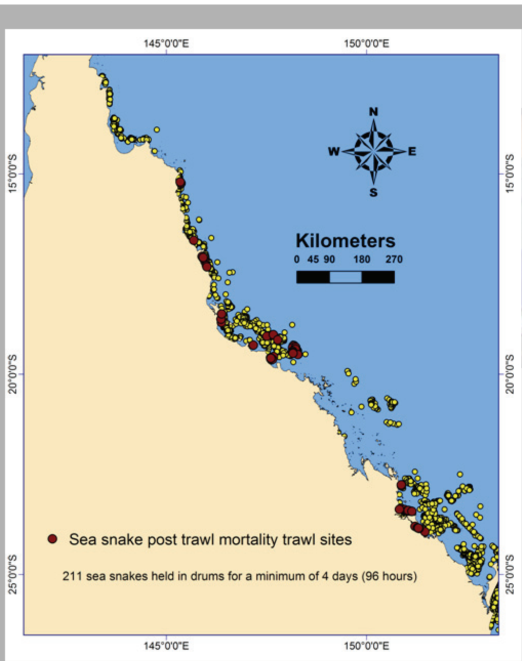

Snakes held for 4-5 days post-trawl. Checked every 3-4 hours and provided with fresh sea water.

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Estimated annual sea snake catch / Estimated annual sea snake mortality

Sector	Adjusted mean sea snake catch rate (boat-day^{-1})	Observed mean annual fishing effort (boat-days)	Mean number of snakes caught annually	Adjusted mean within-trawl mortality rate (boat-day^{-1})	Number dead in nets when brought to the surface	Adjusted mean post-trawl mortality rate (boat-day^{-1})	Number that die after being trawled
Banana prawn	9.6	1606	15,362	5%	747	0	0
Beam trawl	1.7	6830	11,577	0	0	-	-
Black tiger prawn (broodstock collection)	15.5	301	4653	1%	14	11.6%	538
Tiger/endeavour prawn	0.3	15,321	4550	6%	261	25.3%	1086
Red-spot king prawn	10.2	6055	61,941	12.5%	7718	28.3%	15,340
Scallop	0.05	6084	298	30.5%	91	20.5%*	43
Moreton Bay	0.04	6490	240	0	0	-	-
Shallow water eastern king prawn	0.55	11895	6483	1%	84	20.5%*	1312
Deepwater eastern king prawn	0.01	5862	70	35.5%	25	20.5%*	9
Stout whiting	0.14	262	36	16.7%	6	20.5%*	6
Total			105,209 (se 18,288)		8938 (se 2357)		18,334 (se 6430)

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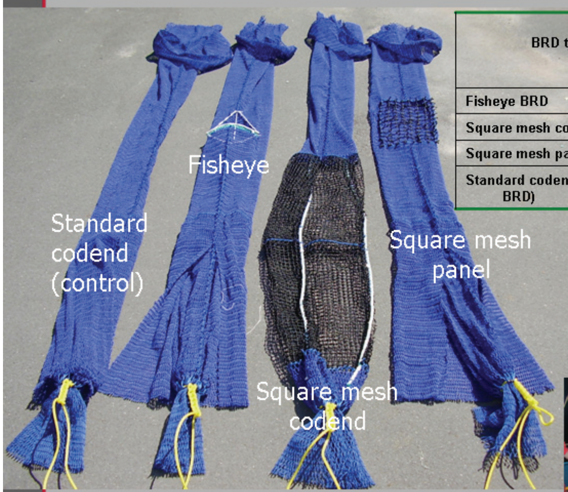
BRD effects on sea snake catch rates



GLM adjusted mean catch rates from research charter (P<0.05)

BRD type	Adjusted mean sea snake catch rate (number snakes caught 2-nautical mile trawl^{-1})	Standard error
Fisheye BRD	0.29	0.09
Square mesh codend BRD	0.31	0.09
Square mesh panel BRD	0.63	0.13
Standard codend (i.e., no BRD)	0.77	0.15

Fisheye and Square mesh codend excluded 63% and 59% of sea snakes, respectively, with no reduction in prawn catch rate

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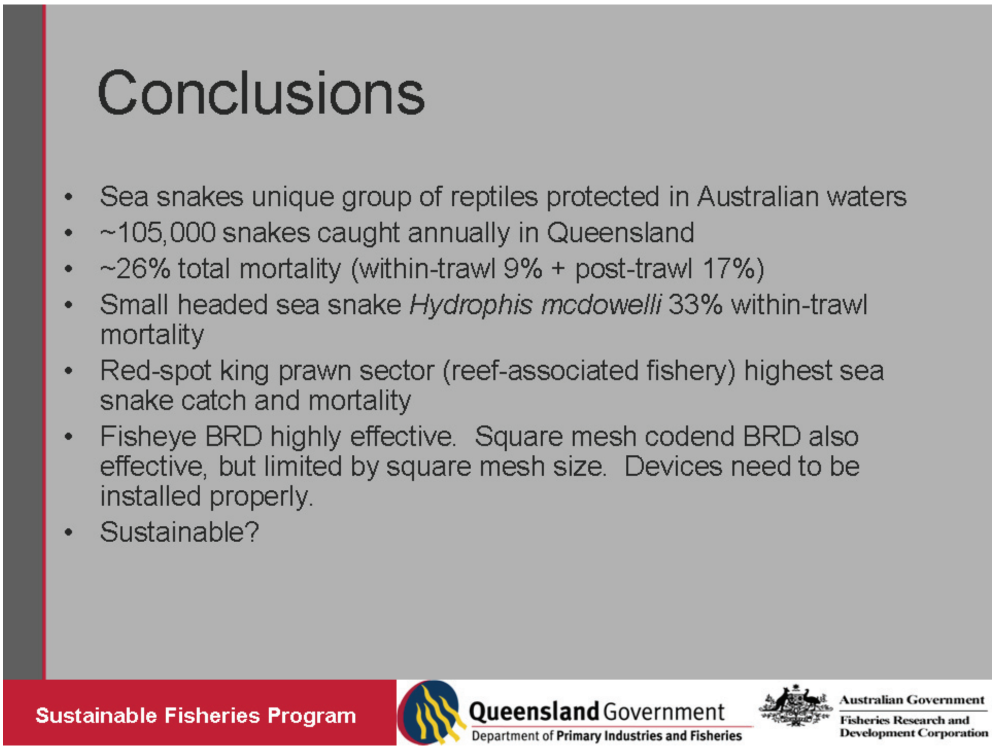
Conclusions
• Sea snakes unique group of reptiles protected in Australian waters
• ~105,000 snakes caught annually in Queensland
• ~26% total mortality (within-trawl 9% + post-trawl 17%)
• Small headed sea snake *Hydrophis mcdowelli* 33% within-trawl mortality
• Red-spot king prawn sector (reef-associated fishery) highest sea snake catch and mortality
• Fisheye BRD highly effective. Square mesh codend BRD also effective, but limited by square mesh size. Devices need to be installed properly.
• Sustainable?
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ありがとう。
Thank you
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