Reducing Dolphin Bycatch in the Pilbara Finfish Trawl Fishery

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Nickol Bay Professional Fishers Association Inc.

Project No. 2008/048

Title: Reducing Dolphin Bycatch in the Pilbara Finfish Trawl Fishery

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Objectives:

1. Reduce the potential for interaction between dolphins and the Pilbara Fish Trawl Interim Managed Fishery through an examination of fine scale spatial, seasonal and daily data on fishing effort and dolphin interactions.

2. Reduce the chance of harm and mortality to dolphins if interactions do occur by evaluating: a) net designs and dolphin behaviour, and, b) exclusion devices, alternative net designs and the effective operation of the nets.

An additional objective was developed during the project:

3. Identify the species and genetic diversity of dolphins interacting with the fishery.

OUTCOMES ACHIEVED TO DATE

This project has involved strong communication and engagement with the Pilbara fish trawl industry, the Department of Fisheries WA and net-makers to modify and trial different net designs. Following discussion with industry about dolphin behaviour, the exclusion grids were moved forward to the start of the net extensions in June 2008. We have compared three broad categories of net designs: trawl nets with no exclusion grid or escape hatch; trawl nets with exclusion grids and bottom-opening escape hatches built in to the aft end of the net extension (just in front of the codend); and, trawl nets with exclusion grids and bottom-opening escape hatches moved forward in the net to the start of the net extension. After the introduction of exclusion grids, there was a clear (~50%) reduction in dolphin catch rates. However, the trends in skipper and observer reported catch rates are not consistent for the grid forward design, probably because of the small sample size and low observer coverage.

The modifications to net design and apparent reduction in dolphin catch resulted in renewal of the industry's 'Interim Managed Fishery' status in June 2009. In September 2009, the fishery was granted an extension on its Wildlife Trade Operation (WTO) under the Environmental Protection and Biodiversity Conservation Act until June 2010, pending adherence to and reporting on numerous conditions.

Observations of dolphins from trawlers, as well as an examination of underwater video records, suggest that dolphins are associated with trawlers >90% of the time they are within the fishery. These findings, and the information from skipper logbook and observer data which show that dolphins are generally caught throughout the fished areas, suggest that spatio-temporal controls of fishing effort (other than a reduction of effort across the whole fishery) would be unlikely to reduce dolphin catch. The research on dolphin behaviour around trawl nets provided training for an Honours student, Ms Vanessa Jaiteh, at Murdoch University and the University of Western Australia.

Research using genetic methods found that most dolphins interacting with the fishery are the larger, 'offshore' species, the common bottlenose dolphins (*Tursiops truncatus*), and not the shallow-water Indo-Pacific bottlenose dolphin (*T. aduncus*).

This project lead to a successful grant application to the Australian Marine Mammal Centre to investigate the population genetic structure and abundance of dolphins in the Pilbara region of north-western Australia. This ongoing research will provide the information necessary to assess the level of impact that interactions with this fishery have on the dolphin population/s.

i. Non-Technical Summary:

The incidental capture of cetaceans (whales, dolphins and porpoises) in fishing gear is a serious threat to populations and species worldwide. In Australia, several dolphin populations are being impacted by mortalities through interaction with fisheries, in particular, gillnets, purse-seining, long-lining and trawl fisheries. The capture of dolphins has been a conservation issue in the Pilbara Fish Trawl Interim Managed Fishery (PFTIMF) that was first assessed in 2002 by the Department of Fisheries Western Australia (DoFWA). At that time, an estimated 50 to 100 dolphins were being caught each year. A number of bycatch mitigation techniques were trialed between 2004 and 2007, including pingers (acoustic deterrents) and different exclusion grids, meeting with varying degrees of success (FRDC 2004/068). Due to ongoing dolphin bycatch, successive Ministers for Fisheries have not been prepared to move the fishery beyond 'Interim Managed' status. In late 2007, Murdoch University was asked to provide expertise on cetacean behaviour and fisheries interactions in the Pilbara trawl fishery.

Two companies were active in the fishery in 2007, completing between 5-6,000 trawls per year, at a fishing effort equivalent to 4.3 full-time vessels. In that year, bycatch levels reported by independent observers remained as high as ~40 dolphins per year. Since the commencement of this project in May 2008, our aims were to: coordinate a directed program of research that maintained communication and collaboration between industry, resource managers and research; assess factors affecting dolphin bycatch using skipper logbook and observer data from late 2003 onward; trial modified exclusion grids and escape hatches in an attempt to further reduce dolphin bycatch; assess the extent and nature of interactions between dolphins and trawl nets; and assess the efficacy of different exclusion grids in allowing dolphins and other megafauna to escape from the trawl nets.

Spatial and temporal extent of dolphin-fishery interactions: Data from both skipper logbooks and independent observers indicate that dolphins are caught throughout the fishery and that dolphin bycatch rates: (a) Varied between the four vessels that conduct most fishing activity; (b) Did not vary spatially (management area and water depth) or seasonally (wet vs dry), but were significantly lower during the early morning period (00:00 to 05:59) than other times of day; (c) Decreased significantly (by ~50%) when exclusion grids and bottom-opening escape hatches were built into trawl nets; and (d) May have been further reduced when the grids and escape hatches were moved forward to the beginning of the net extension in June 2008. These data, however, include information only on those dolphins that are landed on the decks of the trawl vessels. We do not know how many dolphins are caught and then fall from the bottom-opening escape hatch prior to being landed on deck. Further work using video deployments is needed to determine whether the declines in dolphin catches observed by skippers and observers equates to less dolphins being injured and killed during all trawling operations.

Grid designs and subsurface dolphin behaviour: Using the nets with the grid placed forward, dolphin behaviour was studied by reviewing video footage collected from within actively fishing trawl nets as part of an Honours thesis by Ms. Vanessa Jaiteh (co-supervised by Murdoch University and the University of Western Australia). Analyses of the footage collected from 36 trawls revealed high interaction rates: (a) Dolphins were recorded inside trawl nets during 29 trawls and for up to 98% of the total trawl duration, and outside trawl nets in 34 trawls for up to 99% of the trawl time; (b) The behaviours displayed by dolphins inside and outside the net differed, with dolphins inside the net engaging predominantly in foraging activity, while those outside the net exhibited mostly travelling behaviours. Some socialising also took place both inside and outside the nets. These results indicate that dolphins are motivated by numerous factors to interact with trawl nets; (c) Furthermore, despite this subset of 36 trawls being taken across a broad extent of the fishery, only 29 dolphins were individually identified foraging inside the nets. Since these individuals were

seen repeatedly both within and between trawls and fishing trips, it is likely that they are a small community of dolphins within the population in the fishery that are behaviourally specialising in foraging inside trawl nets. This has implications for the level of impact that bycatch has on the dolphin community or population as a whole, since there may be just a small proportion of the population subject to unnatural mortality through bycatch.

A further net design modification was made to two nets (one per fishing company) in March 2009. These nets were fitted with top-opening escape hatches. However, observers have not collected data on the use of these nets, except for one trip in which fish catch rate was higher than average and no dolphins were caught. Adequate observer coverage and net-mounted underwater video camera deployment (perhaps up to 2000 trawls; which would take around six months of fishing) will be required to monitor nets with top-opening escape hatches in the future.

Analysis of wildlife interactions with exclusion grids: The efficacy of two different grid designs (both placed at the forward-end of the extension) in allowing wildlife to escape was assessed by reviewing footage of 22 trawls with a larger, older grid in place, as well as 22 trawls with a new grid installed in a more upright position. Overall, this indicated that the diversity and abundance of bycatch is high in the PFTIMF, and that the two grids differed in their function: (a) The 44 trawls resulted in the incidental capture of at least 86 individuals from 19 species including dolphins, sharks, rays, turtles, sea snakes and pipefish; (b) Three dolphins interacted with the grids, resulting in the apparent death of all three. Two of these three fell out of the bottom-opening escape hatch prior to the net being hauled up and, as a consequence, were not reported by the skippers or observers, i.e. only one dolphin catch was recorded in the logbooks and observer reports. Dolphin and other bycaught species are therefore under-reported whilst the current net designs remain in use; (c) Results from the analysis of 22 trawls each with an old and new grid design showed that 50% and 24% of captured wildlife escaped from the hatches, respectively. Large sharks and rays typically escaped or fell from the bottom-opening hatch and the older grid model was more effective at excluding bycatch than the newer grid model. This seems likely to have been due to a combination of 1) the lower angle at which the old grid was placed in the net, which meant that bycatch was guided toward the escape hatch, and 2) the older grid featured a horizontal bar across the middle section, which prevented large animals from swimming through gaps between the vertical bars into the codend.

Further instances of dolphins, sea snakes, sharks and a turtle swimming upward upon interacting with the grid were observed, indicating that a top-opening escape hatch would be the logical next step in reducing the bycatch of megafauna. Since bycaught wildlife remains in the cod-end for the duration of the trawl, then spends time on deck before being expelled overboard where scavenging sharks and dolphins occur, post-capture and post-discard mortality of bycaught wildlife is high. This highlights the need for further improvements in the design and positioning of exclusion grids and escape hatches. We recommend that trials be carried out with an exclusion grid featuring a top-opening escape hatch. This is likely to require a trial period of six months with observer coverage and video camera deployments to confirm the fishing efficiency and non-target wildlife excluding efficiency of these nets.

Independent observer coverage: Independent observer coverage has yielded dolphin capture rates that are typically 1.6 to 3.7 times higher than those reported in skippers' logbooks. The DoFWA established that observer coverage at a minimum of 22% of total fishing effort was required in order to provide robust estimates of dolphin and other bycatch levels from 2006-2007 onward. This level has never been attained and has subsequently fallen each financial year (17% in 2006-2007, 13% in 2007-2008, 13% in 2008-2009 and 8% to the present). This low coverage, combined with the relatively infrequent incidence of dolphin capture, means that the comparisons of dolphin catch rates between the different net designs have low power.

Identification of the dolphins: We used small biopsy samples from dolphins caught in trawls and samples taken from free-ranging dolphins over an east-west distance of 160 nm to assess the species identity and the genetic diversity of dolphins interacting with the fishery. The results of this research showed that: (a) Most dolphins interacting with the fishery are common bottlenose dolphins (*Tursiops truncatus*); (b) One bycaught individual shared a closer genetic affinity to the Indo-Pacific bottlenose dolphin (*T. aduncus*); (c) Four individuals appear more closely related to the Fraser's dolphins (*Lagenodelphis hosei*); and, (d) Population genetic diversity appears comparable to other dolphin populations, with 16 haplotypes identified across 43 sampled individuals. Further research is needed to assess the size of the dolphin population(s) that are impacted and the levels of gene flow and connectivity between the impacted population(s) and those in adjacent regions.

Recommendations: This research indicates that bycatch in the PFTIMF still includes protected dolphins (at 20 to 50 dolphins per year based on logbook and observer figures, respectively, from 2008-2009), sharks and rays, critically endangered sawfish and various other wildlife species. It also demonstrates that the current exclusion grid and escape hatch design leads to the under-reporting of injury and mortality of bycatch by both skippers and observers.

1. Further investigation into the efficacy of exclusion grids with top-opening escape hatches is needed to inform management action in the PFTIMF. Research based on footage obtained with trawl net-mounted video cameras will allow a more accurate estimates of actual (i.e. landed and non-landed) dolphin and other species bycatch to be made;
2. Differences between logbook and observer reported bycatch levels indicate that greater observer coverage is needed. A period of intensive observer coverage and video camera deployments (i.e. 6 months or approx. 2000 shots) will be necessary to evaluate upward opening escape hatches;
3. The spatial and temporal extent of interactions between dolphins and the fishery make it difficult for fishery management measures to reduce the level of interaction without reducing fishing effort across the fishery. Results suggest that catch rates are higher in one vessel and lower in the early morning, but do not vary spatially or seasonally;
4. In order to quantify the level of threat that ongoing bycatch poses, a population study (including assessment of abundance and gene flow) of the dolphins inhabiting the fishing grounds and adjacent regions is required. Knowledge of a maximum allowable mortality rate will provide direction for future bycatch mitigation efforts and allow the fishery to better demonstrate the outcomes of such efforts;
5. A more detailed study quantifying the composition and biomass of landed bycatch would also provide direction for bycatch mitigation efforts. An electronic observer system could be trialled in addition to an intensive period of observer coverage;
6. Dolphin mortality events currently lead to immediate discarding of carcasses. This is a waste of invaluable sources of information and dolphins that are landed dead in future should be accurately measured and have samples taken by observers.

KEYWORDS: **Bottlenose dolphin, fish trawling, protected species, bycatch**

ii. Acknowledgements

The Fisheries Research & Development Corporation's Tactical Research Fund, the DoFWA through the Development of Better Industry Fund and the Nickol Bay Professional Fishers Association Inc. (NBPFA) funded this research. We thank Westmore Seafoods, Shine Fisheries and MG Kailis for in-kind support and gratefully acknowledge the logistic support provided by skippers (especially Paul Harrison, Russell Greary and Dave Waite) and crews of the Pilbara Fish Trawl Interim Managed Fishery. Dr John Henstridge of Data Analysis Australia provided statistical advice. The project would not have been possible without the support of the Steering Committee (Dr. Lindsay Joll and Shane O'Donoghue of DoFWA, and Graeme Stewart of the NBPA) and the thorough efforts of fishery observer Gavin Kewan.

iii. Background

The Pilbara Fish Trawl Interim Managed Fishery (PFTIMF), within the broader Pilbara Demersal Scalefish Fishery (including trap and line fisheries), is bound by longitudes of 116º to the west and 120º to the east, and by an approximation of the 50m-depth contour inshore and the 100m-depth contour as an offshore limit. Since being gazetted in 1998, only Management Areas 1, 2, 4 and 5 within Zone 2 are open to trawl fishing operations (Fig. 1.1).

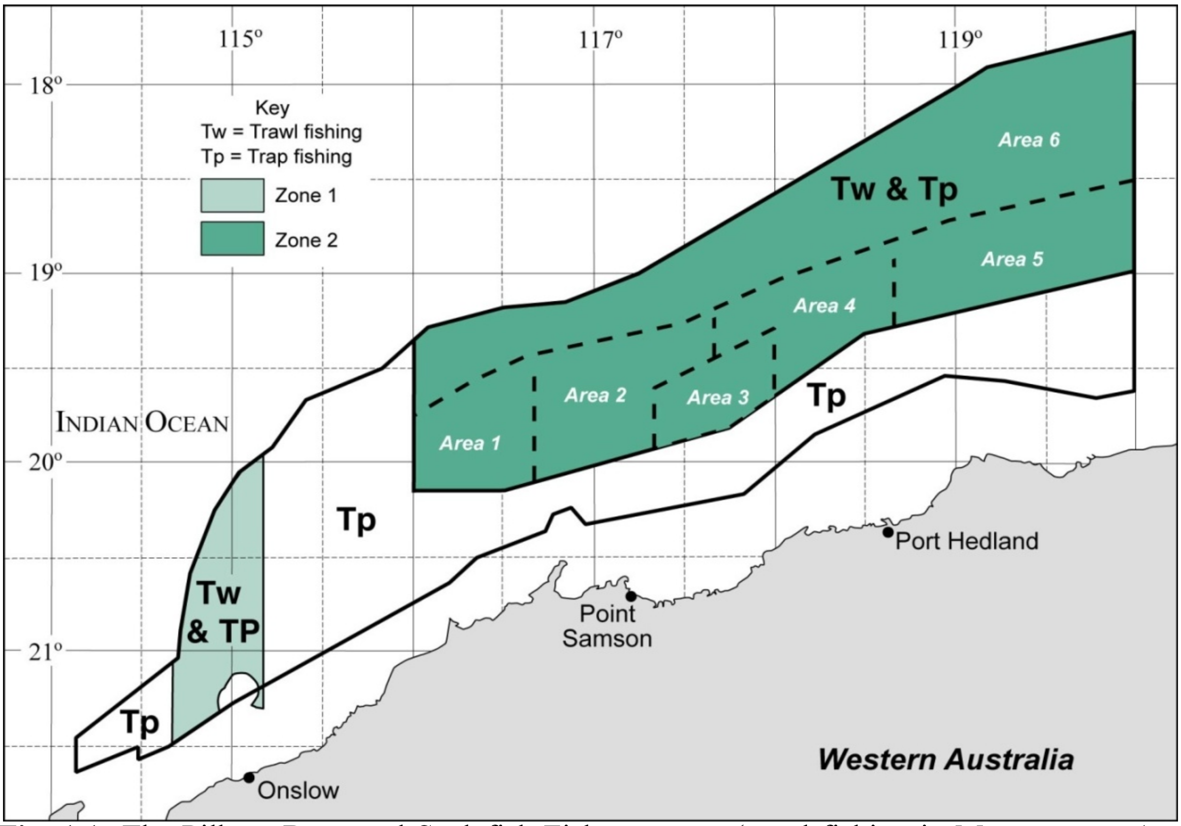

Fig. 1.1: The Pilbara Demersal Scalefish Fishery zones (trawl fishing in Management Areas 1, 2, 4 and 5). This equates to a trawled area of approximately 13,000 km^2 (7,000 nm^2).

The PFTIMF is the most productive scale-fish fishery in Western Australia (WA), with recent annual catches of 2-3,000 tons, currently all for consumption within Australia and making up some 75% of the scale-fish on the Western Australian market. There are currently four vessels that conduct 5-6000 trawl 'shots' per annum. It is a year-round, demersal, single otter-trawling operation with reduced effort from December to March when cyclones are more frequent. Trawls generally last between half an hour and five hours (median and modal time ~ three hours) and vessels generally stay at sea for between five and twelve days at a time.

Bycatch of protected and listed species was first highlighted as problematic in 2002 and remains a serious issue, with up to 10 species (including dolphins, sea snakes, turtles, seahorses, sea dragons, pipefish and sawfish) caught in the PFTIMF. Some trials assessing mitigation strategies for reducing the incidence of dolphin capture have been carried out between 2004 and 2007. Pingers, exclusion grids and escape hatches have met with varying degrees of success in reducing bycatch.

iv. Need

The bycatch of dolphins and other protected and listed species in the PFTIMF was recognised as being unacceptably high by the WA Minister of Fisheries. In 2005, the then Minister wrote to industry participants expressing his concern for the "…real or perceived lack of adequate action being undertaken to address this serious bycatch issue…". He indicated that he was prepared to close the fishery to protect the industry's reputation should progress not be made. Semi-flexible exclusion grids reduced the dolphin catch rate by almost 50% in 2006, but the Minister stated that further reductions were necessary if the fishery was to be granted permission to continue operations or gain 'Managed Fishery' status.

In 2007, the need for a renewed approach to resolving the PFTIMF bycatch issues were further highlighted by the Draft Bycatch Action Plan and reports from the Department of Fisheries WA (DoFWA) to the Commonwealth Department of Environment, Water, Heritage and the Arts. There are both ecological and political needs for ongoing efforts to further reduce bycatch. Common themes to successful implementation of bycatch reduction measures include: Collaborations between industry, scientists and resource managers; Pre- and post-implementation monitoring; and, compliance via enforcement and incentives. This project was designed to conform to the first two of these three themes.

v. Benefits

Reductions in bycatch benefit wild stocks/populations of animals. This benefits the industry (and the public that it supplies) by increasing the likelihood of the WA Minister of Fisheries allowing the fishery to continue operating whilst further bycatch mitigation measures are trialed. The benefits thus encompass progression toward a sustainable fishery at the same time as maintaining viable populations of protected and listed species. Meeting the requirements of the EPBC Act and maintaining a WTO and the right to export are included.

vi. Further development

There are three key areas in which this applied research requires further development in the near future:

(1). We strongly recommend that further trials of modified exclusion grids with top-opening escape hatches be conducted over a minimum period of six months or approximately 2000 shots;

(2). Observer coverage combined with deployment of net-mounted video cameras in underwater housings for these trials are required to confirm fishing efficiency of nets with top-shooting escape hatches and to validate that further reduced numbers of dolphins being landed on deck equates to less dolphins being injured or killed; and,

(3). An electronic observer system could be trialled in conjunction with the intensive period of observer coverage in order to obtain more accurate assessments of the quantity and composition of bycatch.

vii. Conclusion

This research indicates that, despite considerable effort from a variety of stakeholders, bycatch in the PFTIMF still includes protected dolphins (at around 20 to 50 dolphins per year based on logbook and observer figures from 2008-2009), sharks and rays, critically endangered sawfish and various other wildlife species. It also demonstrates that the current exclusion grid and escape hatch design leads to the under-reporting of bycatch by both skippers and observers. Whether or not current levels of bycatch of several species are sustainable remains impossible to determine without further knowledge of the impacted populations.

1. Further investigation into the efficacy of exclusion grids with top-opening escape hatches is needed to inform management action in the PFTIMF. Research based on footage obtained with trawl net-mounted video cameras will allow for a more accurate estimate of actual (i.e. landed and non-landed) dolphin and other species bycatch;

2. Differences between logbook and observer reported bycatch levels indicate that greater observer coverage is needed. A period of intensive observer coverage and video camera deployments (i.e. 6 months or approx. 2000 shots) will be necessary;

3. Results suggest that catch rates are higher in one vessel and lower for the fleet in the early morning, but do not vary spatially or seasonally. The spatial and temporal extent of interactions between dolphins and the fishery will make it difficult for fishery management measures to reduce the level of interaction without reducing fishing effort across the fishery;

4. In order to quantify the level of threat that ongoing bycatch poses, a basic population study (including assessment of abundance and gene flow) of the dolphins inhabiting the fishing grounds and adjacent regions is required. Knowledge of a maximum allowable mortality rate will provide direction for future bycatch mitigation efforts and allow the fishery to better demonstrate the outcomes of such efforts;

5. A more detailed study quantifying the composition and biomass of landed bycatch would also provide direction for management of bycatch mitigation. This could be coupled with trialling an electronic observer system;

6. Dolphin mortality events currently lead to immediate discarding of carcasses. This is a waste of invaluable sources of information and dolphins that are landed dead should have a variety of measurements and samples taken by observers in future.

2. Chapter Two: Genetic status of dolphins interacting with the Pilbara Fish Trawl Interim Managed Fishery of north-western Australia

Authors: Simon Allen, Neil Loneragan and Michael Krützen (University of Zurich)

Abstract
The incidental capture of small cetaceans in fisheries often requires species- and fishery-specific approaches to mitigation. We used biopsy samples taken from dolphins caught in nets (n=6) and free-swimming dolphins near trawlers (n=45) in the Pilbara Fish Trawl Interim Managed Fishery, Western Australia, to assess the species status and genetic diversity of these dolphins. Microsatellite data indicated that a total of 43 individuals were sampled, i.e. 8 duplicate samples were taken. The majority of individuals (n=38) aligned more closely with the common bottlenose dolphin (*Tursiops truncatus*) than other species, but one individual fell within the Indo-Pacific bottlenose dolphin (*T. aduncus*) clade, and four individuals showed greater affinities to two Fraser's dolphin (*Lagenodelphis hosei*) haplotypes found on *Genebank*. The mitochondrial DNA diversity of the individuals was similar to that of other *Tursiops* populations in Australia (n=16 haplotypes in 43 individuals across the *ca.* 160 nm stretch of sampling effort). Genetic sexing of individuals indicated an unequivocal bias toward males being biopsy sampled around the stern of actively fishing trawlers, suggesting that adult males dominate the primary positions for exploiting fish discarded shortly after retrieving the trawl net. In contrast, both males and females were biopsy sampled from the bow of trawlers. These results show the importance of matching morphological data with genetic data from the impacted dolphin population to: (a) resolve taxonomic uncertainties (i.e. how many dolphin species are interacting with the fishery?), and (b) better inform protected species bycatch mitigation efforts (i.e. to determine how many, and which, dolphin species should be the focus for bycatch mitigation efforts?).

2.1 Introduction
Negative outcomes for cetacean populations through interactions with coastal and offshore fishing operations are intensifying as both the human population and our demand for seafood increases (DeMaster et al. 2001; Read et al. 2003, 2008). The combination of direct and indirect impacts of fishing activities has resulted in declines in cetacean populations in locations such as the Mediterranean Sea, the Gulf of Mexico and around New Zealand (Northridge & Pilleri 1986; Dawson et al. 2001; Reeves et al. 2003; Jaramillo-Legorreta et al. 2007; Bearzi et al. 2008). Bycatch in gillnets, purse-seining and trawling operations are implicated as resulting in the greatest proportion of fisheries-related cetacean mortalities (Northridge 1991, Read et al. 2006). Some fishery-impacted stocks/populations, for example the spinner (*Stenella longirostris*) and spotted dolphin (*S. attenuata*) populations of the Eastern Tropical Pacific, are not recovering despite considerable reductions in bycatch in recent decades (Cramer et al. 2008).

The extremely variable nature of cetacean-fisheries interactions requires a necessarily cetacean species-, fishery type- and sometimes even local condition-specific approach to bycatch mitigation efforts (Bache 2003; Cox et al. 2004, 2007). Numerous delphinid species suffer fisheries-related mortality throughout Southeast Asian and Australian waters (Shaughnessy et al. 2003; Hamer et al. 2008; Yousuf et al. 2008; Jaaman et al. 2009). Bottlenose dolphins (*Tursiops* spp.) have a global temperate and tropical distribution and, being behaviourally plastic and highly adaptable to exploiting various types of fisheries in order to procure resources (Shane et al. 1986; Fertl & Leatherwood 1997), are well known for associating with prawn- and fish-trawling operations around Australia (Corkeron et al. 1990; Hill & Wassenberg 1990; Svane, 2005; Allen et al. 2007).

As a first step toward informing bycatch mitigation efforts, we used biopsies from both incidentally caught and free-ranging dolphins to assess the species identity and genetic diversity of dolphins interacting with the Pilbara trawl fishery. Specifically, we aimed to determine whether the individuals in this population show greater genetic affinities to the common bottlenose dolphin (*Tursiops truncatus*) or the Indo-Pacific bottlenose dolphin (*Tursiops aduncus*).

2.2 Methods and Materials

Biopsy sample collection

A total of 51 biopsy samples were used for DNA extraction and genetic sex determination. Four samples from incidentally caught dolphins (two from 2005 and two from 2006) were added to those collected here. Two more individuals were caught and 45 biopsies were collected from free-ranging dolphins during trawling operations in October and November 2008): Six were obtained using the Paxarms biopsy rifle (see Krützen et al. 2002) and a further 39 were obtained using a biopsy pole (see Bilgmann et al. 2007) for sampling individuals close to the bow or stern of trawlers. Dolphins at the stern were foraging on discards shortly after winch-up, while dolphins at the bow were bow-riding on the pressure wave in front of the trawlers. All biopsy samples were collected over an east-west distance of about 160 nm across the fishery.

DNA extraction and gender determination

DNA extraction from biopsy samples was performed using the Gentra (Quiagen) tissue kit following the manufacturer's instructions. The extracted genomic DNA was resuspended in TE buffer (10mM Tris, 1mM EDTA, pH 8) and concentration was adjusted to 20ng/ul. Gender determination was carried out by amplification of parts of two genes located on the X- and the Y-chromosome - ZFX and SRY, respectively (Gilson et al. 1998).

Mitochondrial DNA (mtDNA) markers

A 426 bp fragment of the hyper-variable region I of the mitochondrial control region (d-Loop) was amplified using primers dlp1.5 and dlp5 (Baker et al. 1993). PCR products were cleaned up using silica membrane spin columns (GeneEluteTM by Sigma-Aldrich). Cycle Sequencing was carried out using the Cycle Sequencing Ready Reaction kit (Applied Biosystems) according to manufacturer's instructions. Sequencing products were cleaned using a MgSO4 precipitation method. The software Sequencing Analysis 5.2 and BioEdit 7.0.5.3 was used to quality control, edit and align the sequences.

Microsatellites

Microsatellite genotypes were used to identify individuals sampled on more than one occasion. For the microsatellite analysis, 16 microsatellite loci were amplified using two different multiplex PCR set ups (Kopps 2007). Diluted PCR products were denaturised in 10ul HiDi formamid containing 0.686ul of the size standard (GeneScanTM500LIZTM, Applied Biosystems). The length of the DNA fragments were analysed on an ABI 3730 DNA Sequencer (Applied Biosystems) using GeneMapper4.0 software.

Phylogenetic analyses

The HVR1 alignment was trimmed to the shortest sequence, sequences containing ambiguous positions were removed, identical haplotypes were collapsed using DAMBE v5.0.72 (Xia and Xie 2001) and collapsed haplotypes were named A-P. A suitable model of sequence evolution for phylogenetic analyses of the HVR1 alignment was inferred using MrModeltest v2.3 (Posada & Crandall 1998; Nylander 2004). After calculating model fits in PAUP* v4.0b10

(Swofford 2002), the HKY+G model was selected following the Akaike information criterion (AIC). This model assumes unequal transition and transversion rates, varying base frequencies and substitution rate heterogeneity within the alignment. A Bayesian tree-building algorithm (MrBayes v3.1.2) was used to construct a phylogenetic tree based on distances according to the HKY+G model with a gamma shape parameter of 0.5. The tree was rooted with an Atlantic white-sided dolphin (*Lagenorhynchus acutus*) sequence as an 'outgroup'. Further parameters were: Four heated chains running for 10,000,000 generations, with a sampling frequency of 1,000 and a burn in of 2,500 data points. Consensus trees from both analyses were displayed and printed using FigTree v1.1.2 (http://tree.bio.ed.ac.uk/).

Sex bias in sampling location
After DNA extraction, gender determination and microsatellite work was carried out, repeat samples were removed from further analyses and a Fisher's Exact test was used to test for bias in the proportion of male and female dolphins biopsy sampled using the pole method from the bow and stern of trawlers.

2.3 Results

A total of 51 biopsy samples were sampled and analysed. Microsatellite data indicated that four individuals were sampled twice and two were sampled three times. These repeat samples were removed from all further analysis. In total, there were data on 43 different individuals available for phylogenetic reconstruction, with 16 haplotypes identified among the 43 individuals. Nine haplotypes were found in multiple individuals (totaling 36 individuals: two individuals expressed haplotype A; 12 with B; four with C; two with D, three with E; two with F; two with G; seven with H; and two with I) and seven haplotypes were present in only one individual each (Fig. 2.1).

While the tree of phylogenetic relationships (Fig. 2.1) lacks the overall resolution necessary to resolve the relationships among all the included delphinid species from *Genebank*, there are strong signals in the dataset. Firstly, most Pilbara samples group with individuals that have previously been identified as the common bottlenose dolphin (*T. truncatus*), suggesting that most animals occurring in this region belong to this species. Secondly, one individual (14671) shows closer affinity to the Indo-Pacific bottlenose dolphin (*T. aduncus*), a clade with very high support. Thirdly, four individuals show distinctly close affinities to the Fraser's dolphin (*Lagenodelphis hosei*).

The distribution of haplotypes between both sampling areas is heterogeneous (Fig. 2.2). Most haplotypes are not restricted to a specific area, suggesting a lack of population structure within the PFTIMF. However, assessing population structure is not the scope of this chapter and additional sampling and further statistical analyses need to be carried out in order to reject the existence of population structure within the PFTIMF.

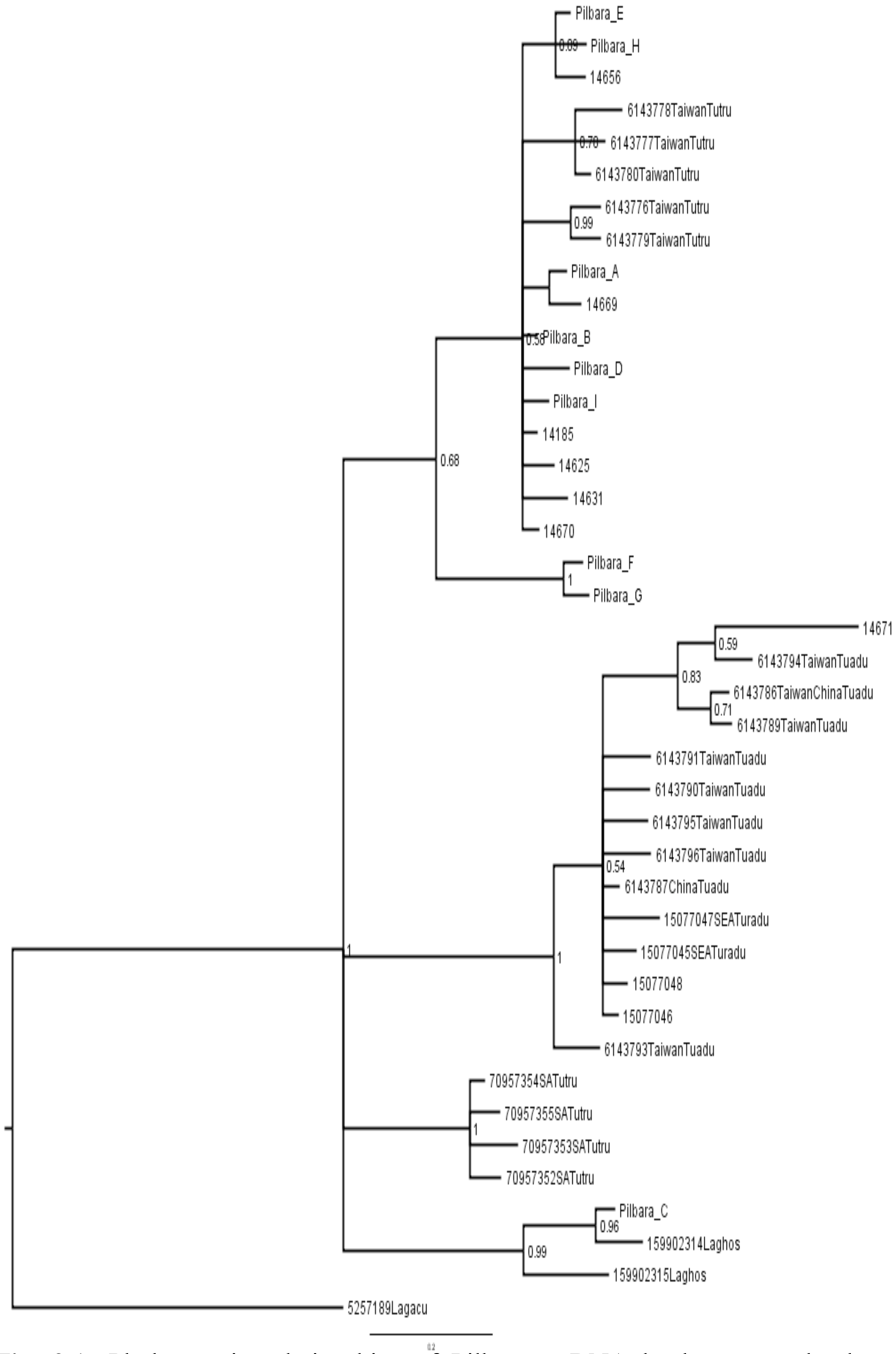

Fig. 2.1: Phylogenetic relationships of Pilbara mtDNA haplotypes and other delphinids. TaiwanTutru and TaiwanTuadu = Taiwanese *Tursiops truncatus* (common bottlenose dolphin) and *T. aduncus* (Indo-Pacific bottlenose dolphin); ChinaTuadu = Chinese *T. aduncus*; SEATuradu = South-eastern Australian *T. aduncus*; SATutru = South Australian *T. truncatus*; Laghos = *Lagenodelphis hosei* (Fraser's dolphin); and Lagacu = *Lagenorhynchus acutus* (Atlantic white-sided dolphin – outgroup). Note: individual 14671 was caught in 2006.

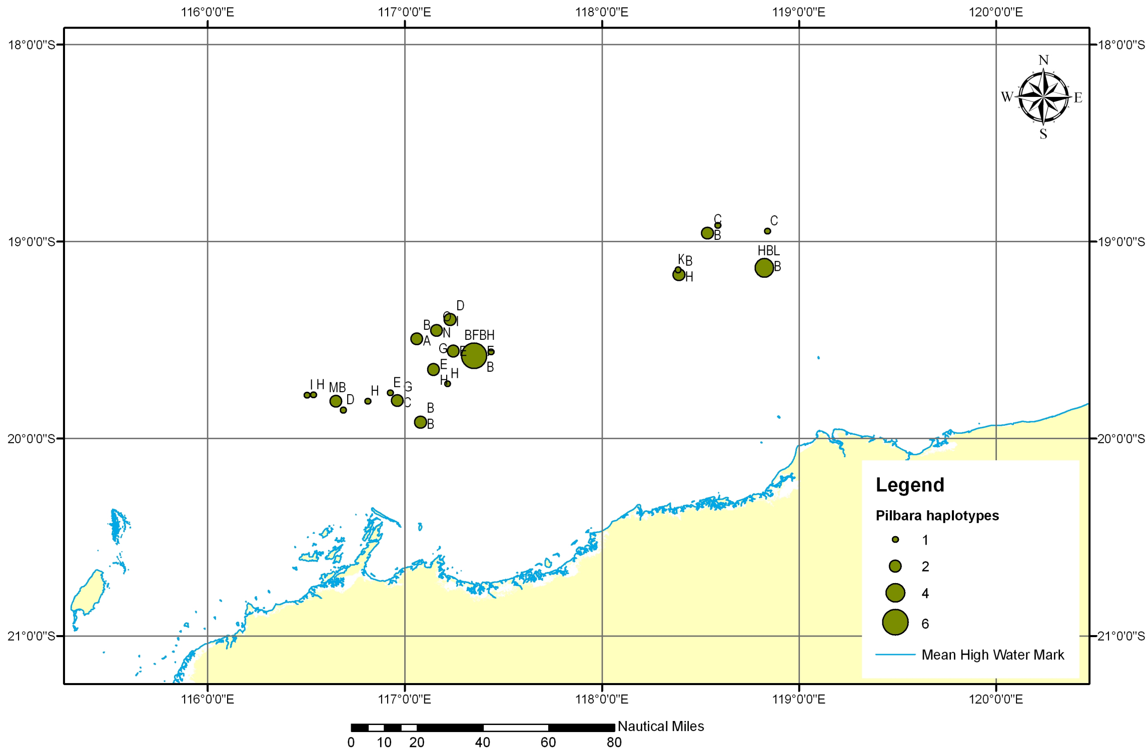

Fig. 2.2: Location and haplotypes of dolphins biopsy sampled within the PFTIMF.

Three dolphins were repeatedly biopsy-sampled on different days (Fig. 2.3). Distances between repeat sampling events of these individuals ranged from ~5 to 30 nm, which is within the expected ranging patterns of the common bottlenose dolphin.

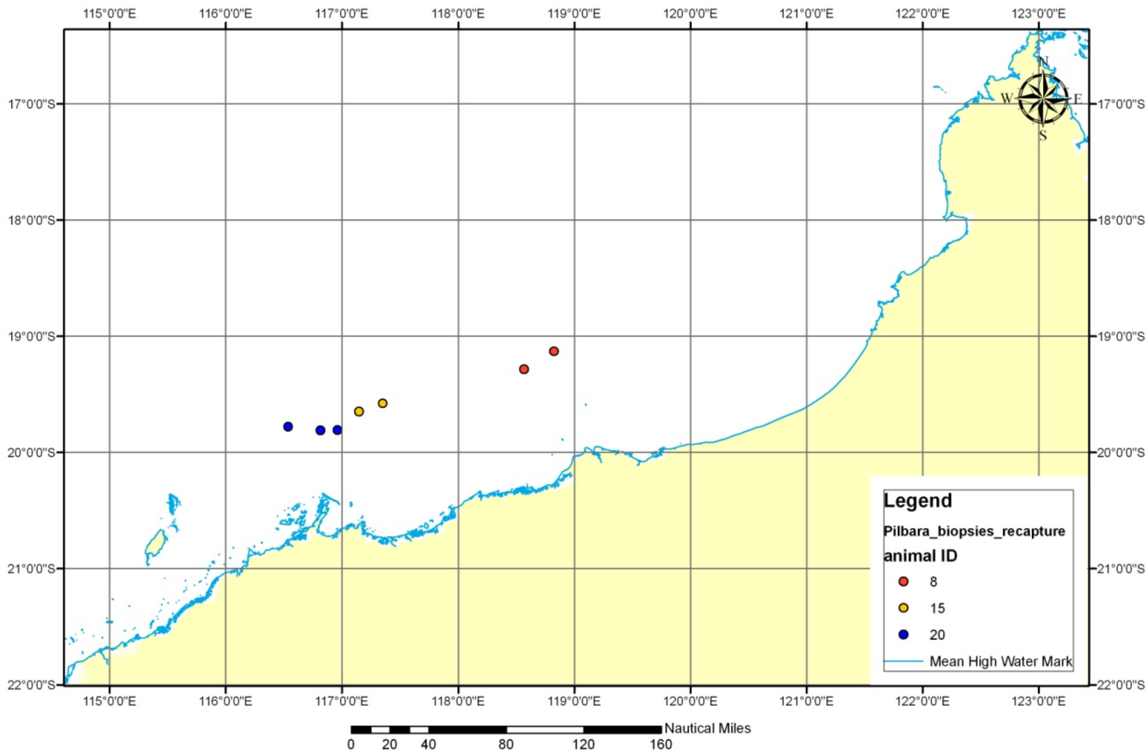

Fig. 2.3: Locations of repeated sampling of the same individual (revealed by microsatellite data). Some individuals were re-sampled from different vessels up to six days apart.

Biopsy sampled individuals were pooled according to the sampling location during biopsy attempts from the trawler's stern or bow (Table 2.1). Twenty-seven of the 33 individuals were males. All individuals sampled at the stern of the trawlers were males (n=13), while 30% of those sampled at the bow were female (Table 2.1). This is a significant departure from a random expectation assuming an equal sex ratio between males and females around the trawlers (p=0.035, Fisher's Exact test).

Table 2.1: Gender of individuals sampled at the bow and stern of trawlers in the PFTIMF.

	Sex		
Position	**Male**	**Female**	**Total**
Bow	14	6	20
Stern	13	0	13
Total	27	6	33

2.4 Discussion

Genetic status of dolphins in the Pilbara Fish Trawl Interim Managed Fishery

Most of the haplotypes found in the dolphins associated with the Pilbara Fish Trawl Interim Managed Fishery (PFTIMF) appear to be common bottlenose dolphins (*T. truncatus*). Common bottlenose dolphins ('bottlenose dolphins' hereafter) are a cosmopolitan species occurring in tropical and temperate latitudes, both coastally and in pelagic populations (Rice 1998; Reeves et al. 2002). In Australia, bottlenose dolphins are widely distributed and may mix with and/or replace the Indo-Pacific bottlenose dolphin (*T. aduncus*) in some near-shore, shallow environments (Hale 2008). Like all marine mammals within Australia's Economic Exclusion Zone, bottlenose dolphins are protected under the National Parks and Wildlife Act 1974 and the Environmental Protection and Biodiversity Conservation Act 1999. Although they may be abundant in Australian waters, they are listed as 'data deficient' in the Action Plan for Australian Cetaceans. Due to this lack of knowledge, assessments of the status of individual bottlenose dolphin populations are not possible. Further data on population size and connectivity need to be acquired before the viability, or capacity to absorb and recover from anthropogenic impacts, can be assessed.

An unexpected finding from our analyses was the occurrence of some individuals expressing haplotypes that share a close affinity to the Fraser's dolphins (*L. hosei*). Fraser's dolphins are usually found in tropical and subtropical oceans from 30°N to 30°S, occurring primarily in waters outside the 1,000 m depth contour (Reeves et al. 2002). They are rarely found in shallow waters or near-shore environs, although they may swim near islands surrounded by deep waters (Dixon 2008). Field guides and texts report that Fraser's dolphins have been found in mixed-species assemblages with melon-headed (*Peponocephala electra*), sperm (*Physeter macrocephalus*) and false-killer whales (*Pseudorca crassidens*), as well as pantropical spotted (*Stenella attenuata*) and striped dolphins (*S. coeruleoalba*; Carwardine, 1995; Reeves et al. 2002; Dixon 2008). Fraser's dolphins have not been observed in mixed assemblages with bottlenose dolphins. Fraser's dolphins are also regarded as data deficient.

There are three plausible explanations for the occurrence of the Fraser's dolphin haplotypes among the Pilbara dolphins. Firstly, both species may have been present in the biopsy-sampled groups of dolphins. The identification of cetaceans in the field can be challenging due to their rapid movements and the at-sea conditions (also, some biopsy sampling was conducted during the night). Many small cetacean species are distinguished by markings on their flanks, which can be difficult to observe. A careful re-examination of all photographs taken in the field revealed only the bottlenose dolphin phenotype. We cannot, however, exclude the possibility that some individuals were Fraser's dolphins, as we did not take simultaneous photographs of each individual biopsy-sampling event.

A second possible explanation could be that the Delphinidae includes some incomplete lineage sorting. In cases of recent speciation, which appears to have occurred in the Delphinidae (Rice 1998), the gene-tree and the species-tree can be discordant. Although the species are reproductively isolated and do not exchange genetic material with each other, similar haplotypes can still occur in both species, making it difficult to unambiguously distinguish both species based on their mtDNA alone. Under such a scenario, haplotypes that were shared in the ancestral population before the speciation event can still be extant in both daughter species.

A third, albeit remote, explanation for the occurrence of Fraser's dolphin haplotypes among the Pilbara dolphins is that an introgression event has occurred – i.e. Fraser's dolphin mtDNA exists in a bottlenose dolphin population through hybridisation. Under such a scenario, female Fraser's dolphins mate with male common bottlenose dolphins. Successive mating events of such offspring, if viable and able to reproduce, with common bottlenose dolphins would lead to a phenotypic appearance of common bottlenose dolphins with Fraser's dolphin mtDNA. Hybridisation yielding viable offspring has been observed frequently in the Delphinidae.

Resolving taxonomic uncertainties

Unfortunately, the current dataset is not adequate to address all three possibilities in detail. As an example, Möller et al. (2008) report on multi-gene evidence for a new bottlenose dolphin species in southern Australia. Their study was based on dolphins sampled around south-eastern Australia (South Australia, Victoria, Tasmania and New South Wales), which externally appear to be bottlenose dolphins (*Tursiops* spp.). The authors showed that there is no current gene flow between some of the southern Australian dolphins and populations from other taxa sampled nearby. Furthermore, these southern Australian dolphins form a monophyletic clade together with previously published sequences from Fraser's dolphins (Möller et al. 2008). While these findings may present interesting comparisons with this work, a shortfall of the study was the failure to include any osteological and/or morphometric data in the analyses. Such an omission means that the claims of a new species need to be treated with caution.

Given the uncertainty in the taxonomy of the genus *Tursiops* (Wang et al. 1999; Natoli et al. 2004), an inclusion of osteological and morphometric data will be essential to fully resolve the species status of the dolphins interacting with the PFTIMF. Delineating between sympatric and parapatric common and Indo-Pacific bottlenose dolphins (*T. truncatus* and *T. aduncus*, respectively) is possible by using a combination of morphometric and genetic data (e.g. Wang et al. 1999, 2000a, 2000b). Hence, we recommend retaining any incidentally captured dolphins so that qualified personnel can conduct post mortem analyses, including measuring morphometric characters and taking samples for genetic analyses, once they are returned to shore. These data will prove invaluable in species identification.

Sex-bias in sampling locations

Another issue requiring further consideration is the significant sex-bias in samples taken around the trawlers, such that large, adult males appear to be monopolising prime foraging locations around the stern of trawlers. Corkeron et al. (1990) suggested that large male bottlenose dolphins occupied the optimal positions for access to discards from prawn-trawlers in Moreton Bay, Queensland. In the Pilbara, foraging around trawlers may be a specialisation exhibited by a subset of the broader population. Bottlenose dolphins from Shark Bay, Western Australia, exhibit a number of foraging specialisations, but these are seen primarily in females and their offspring (Mann & Sargeant 2003). Given the high energetic demands of females during pregnancy and lactation, the pressure to exploit ecological niches is higher for females than for males. The existence of a strong male bias in the prime foraging positions raises the possibility that it may be females that forage inside the nets during trawling, increasing the risk of being incidentally caught. Alternatively, if males also dominate primary positions within actively trawling nets, females may be relegated to foraging in other high entanglement risk areas, i.e. around the head rope, lazy line or codend. Given the small lifetime reproductive output of delphinids (Whitehead & Mann 2000), the negative impact on the population's viability would be much higher if females are incidentally caught. The sex of all incidentally caught dolphins needs to be reliably ascertained in the future.

Implications for bycatch mitigation and future research

The results of this research suggest the need for more directed effort toward matching osteological and morphological data with genetic data from the impacted and neighbouring dolphin populations in order to: (a) Resolve the taxonomic uncertainties (i.e. how many dolphin species are interacting with the fishery?); and (b) Better inform protected species bycatch mitigation efforts (i.e. how many, and which, dolphin species should the focus of bycatch reduction efforts?). A more complete genetic dataset (larger sample size of biopsies) would allow the calculation of effective population size (*N*e) for the dolphin population/s interacting with the PFTIMF. The detection of changes in population size due to recent anthropogenic influences using an individual-based Bayesian approach will also be possible. These methods should be applied to the population/s impacted by the fishery in order to assess their remaining genetic potential to cope with ongoing anthropogenic pressure.

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3. Chapter Three: Spatial and temporal patterns of dolphin bycatch in the Pilbara Fish Trawl Interim Managed Fishery of north-western Australia

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Abstract
Some populations of small cetaceans are at risk of extinction from the direct and indirect impacts of interactions with demersal trawl fisheries. Between late 2003 and September 2009, a total of between 150 and 350 common bottlenose dolphins (*Tursiops truncatus*) were caught in the Pilbara Fish Trawl Interim Managed Fishery (PFTIMF), operating off the northwest of Australia. Data from skipper logbooks and independent observers were used to assess the spatial and temporal patterns of dolphin bycatch relative to fishing effort in the PFTIMF. Three broad categories of net designs were also assessed: trawl nets with no exclusion grid or escape hatch; trawl nets with exclusion grids and bottom-opening escape hatches built in to the aft end of the net extension (just in front of the codend); and, trawl nets with exclusion grids and bottom-opening escape hatches moved forward to the start of the net extension. Both logbook and observer data indicate that dolphins were caught in all four fishery management areas, across all depth categories, and on a year-round basis. Data on dolphin behaviour in Chapter 4 show that dolphins typically interact with trawl nets in over 90% of trawling operations. Data from observer records, while based on a much smaller number of trawls than the skipper logbooks, explained much more of the variation in the number of dolphins caught than data in the logbooks. The most significant predictors of dolphin bycatch were: (1) which particular vessel was fishing (one of four vessels caught the greatest proportion of dolphins); (2) the time of day of fishing activity (the lowest proportion of dolphins was caught between 00:00 and 05:59); and (3) whether or not nets included bycatch reduction devices (there was a ~50% reduction in dolphin catch rates after the introduction of exclusion grids). However, the trends in skipper and observer reported catch rates were not consistent for the grid forward net design, probably due to the low observer coverage and the relatively low incidence of dolphin catches. The results suggest that spatial or seasonal modifications to the management of trawl fishing effort, other than an overall reduction in effort across the fishery, would be unlikely to reduce dolphin bycatch rates. Furthermore, exclusion grids and escape hatches have reduced the number of dolphins being landed on deck by ~50%. Future research should be directed at trials of bycatch reduction devices that include top-opening escape hatches from which air-breathing megafauna can escape. This will require observer coverage and the deployment of net-mounted video camera to validate the efficacy of the net design in reducing bycatch (i.e. less dolphins being landed equates to less dolphins being caught during trawling operations – see also Chapter 5). Assessing the viability of the dolphin population and its vulnerability to the current level of trawling in the fishery is not possible without further information on the biology of the dolphins and the connectivity of dolphin populations in this region with other regions. This research has recently been funded by the Australian Marine Mammal Council.

3.1 Introduction
Demersal trawl fishing for crustaceans, cephalopods and fish is a fishing method that is destructive to benthic environments and results in large quantities of incidental catch, or bycatch, of non-targeted species (Kennelly 1995; Pauly et al. 2002; Kelleher 2005). Gillnetting and purse-seining fisheries also cause a large proportion of fisheries-related cetacean mortalities worldwide (Northridge 1991; Read et al. 2006; Read 2008). Several small cetacean populations and species, for example, New Zealand's north island Hector's dolphin (*Cephalorhynchus hectori*) and the vaquita (*Phocoena sinus*) of the Sea of Cortez, are

now at risk of extinction having been subject to the impacts of gill-netting and trawl fisheries, respectively (Dawson et al. 2001; Jaramillo-Legorreta et al. 2007).
Trawl fisheries operate in many regions of Australia's State and Commonwealth waters (Larcombe et al. 2006). Western Australia's North West Shelf region has been fished since the early 1970's, with the Taiwanese pair-trawl fishery catching in excess of 100,000 tons of fish, cephalopods and other invertebrates in the mid-1970s (Althaus et al. 2006). Catches declined rapidly and were less than 10,000 tons per annum by the mid-1980s, when Chinese and Korean stern trawlers also fished the area and an experimental management regime (including area closures) was introduced (Sainsbury 1987). Shortly after this new management regimen, the foreign fleet diminished and an Australian trawl fishery developed (Althaus et al. 2006). Catches in the Pilbara Demersal Scalefish Fishery (including line, trap and trawl fishing) have fluctuated between 2,000 and 3,500 tons per annum. While this is a greatly reduced level of yield than was taken by the foreign fishery, it has remained the most productive scale-fish fishery in Western Australia for the last decade.

Due to ongoing problems with bycatch of a number of protected and listed species, the trawl fishery has yet to gain 'Managed Fishery' status from the Department of Fisheries Western Australia. Various attempts have been made to mitigate against the bycatch of common bottlenose dolphins (*Tursiops truncatus*) since the problem was first documented (Stephenson & Chidlow 2003). Acoustic pingers proved ineffective in deterring dolphins from interacting with trawl gear (Stephenson & Wells 2008), similar to their efficacy in mitigating against dolphin interactions with other trawl and fishing gear types (e.g. Richardson & Würsig 1997; Cox et al. 2003). Field trials of exclusion grids and escape hatches resulted in reductions of dolphin bycatch rates and they were made compulsory across the trawl fishery in March 2006 (Stephenson & Wells 2008). Despite this apparent improvement in reducing the rates of dolphin capture, further reductions in the capture of protected and listed species have been required. Skippers' logbook and independent observer data from mid-2003 to August 2009 have been used to conduct a fine-scale spatial and temporal assessment of dolphin bycatch rates across the Pilbara Fish Trawl Interim Managed Fishery (PFTIMF). We aimed to assess the spatial, seasonal and daily data on fishing effort and dolphin interactions, and to evaluate the effectiveness of different net designs (those with and without bycatch exclusion devices and escape hatches) in reducing dolphin bycatch.

3.2 Methods and materials

The fishery

The Pilbara Fish Trawl Interim Managed Fishery (PFTIMF) is bound by longitudes of 116º to the west and 120º to the east, and by an approximation of the 50m-depth contour to landward and the 100m-depth contour to seaward. The four Management Areas currently open to trawling total an area of just under 13,000 km^2 (7,000 nm^2). Currently, the fishing fleet consists of four vessels that operate year-round, with slightly reduced effort from December to March when cyclones are more frequent. Trawlers generally stay at sea for five to twelve days at a time.

Net and trawl characteristics

Trawl vessels in the PFTIMF tow a single net at a speed of approximately three to three and a half knots with twin otter boards maintaining net spread. Most nets used consist of four main sections: the wings, which form the opening or mouth of the net; the belly and neck, which are immediately behind the mouth of the net and where the net tapers; the extension, a tubular section; and the codend, where the catch is collected (Fig. 3.1). The diameter and mesh size decrease in each panel with distance from the opening of the net, the minimum mesh size being 100 mm. The length of the head rope must not exceed 36.58 m, while the total length of the net, including cables, sweeps and bridles, is limited to 274.32 m. The footrope is weighted and contains bobbins (<35 cm in diameter) that are spaced at around 30 cm apart and roll along the sea floor.

Nets used in the PFTIMF consist of diamond mesh. The first section of the net belly measures 21 meshes of 9 inch (22.86 cm) stretch mesh made of 3 mm thick twine, which equates to a length of 4.8 m when the net is stretched. This section has a height of 66 meshes where it joins the wings (Fig. 3.1). In October 2008, the belly and neck section of the nets was shortened to allow for a shorter escape route for dolphins that enter the net and interact with the exclusion grid (Fig. 3.1). Based on stretch mesh measurements, the nets are approximately 44 m long from the footrope to the start of the cod-end, although whilst operational they are likely to range between 60-70% of that length.

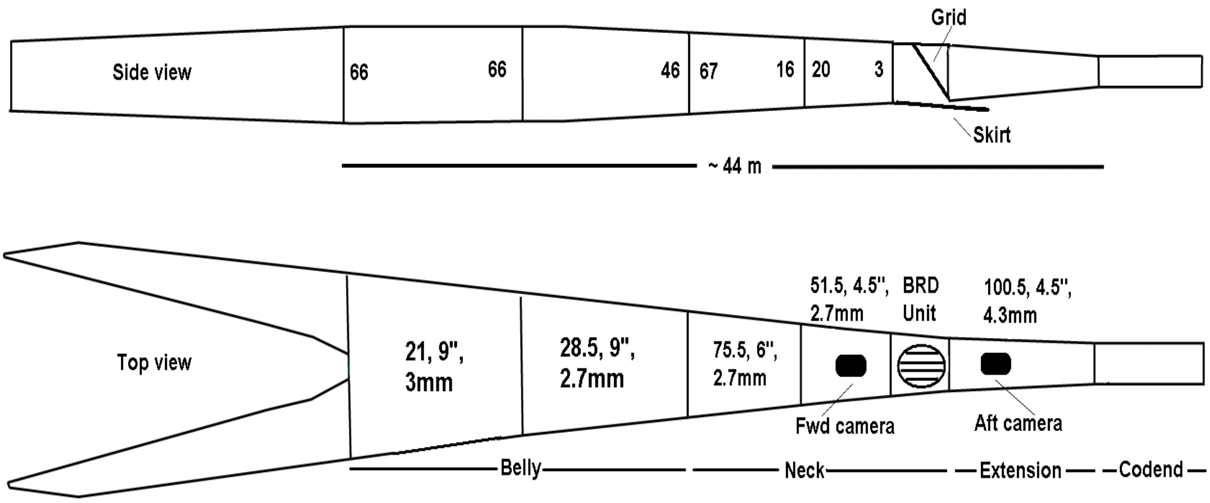

Fig. 3.1: Schematic of a typical trawl net used in the Pilbara Fish Trawl Interim Managed Fishery in 2008 and 2009 showing the side and top views, location of the bycatch reduction device (BRD Unit), forward and aft cameras (see Chapters 4 and 5) and the skirt covering the bottom escape hatch. Lengths of the different panels are given as number of meshes, mesh length (in inches) and diameter of twine (in mm). In the side view, the height of each panel is given as the number of meshes. Diagram not drawn to scale. Modified from Stephenson et al. (2006) following net plans by H. McKenna/Neptune Trawls for the 'Magnet Box Diamond Net' with shortened neck.

Exclusion grids and escape hatches

Bycatch exclusion grids and escape hatches were trialled in 2004 and 2005, then fitted into all nets used in the PFTIMF in March 2006 (Stephenson & Wells 2008). The bycatch reduction devices currently in use consist of a semi-flexible metal grid and a bottom-opening escape hatch, through which large animals can leave the net. A loose skirt of netting to prevent the loss of target species covers the escape hatch. The exclusion grid is fitted at the start of the extension, where the net has a diameter of 100 meshes, and it is held upright by a number of floats. The grid lies at an angle with the float-equipped top section anterior to the lower section, so that bycatch and benthos are deflected down toward the bottom-opening escape hatch. In June 2008, the grids were moved forward in the net, from just before the codend, to the start of the extension. This was done to prevent dolphins from backing down into the tubular extension and to provide a shorter escape route between the exclusion device and the opening of the net. All grids feature vertical bars made of stainless tube and central sections of braided stainless wire (such that they can be wound onto the net drums when not in use)

Data analyses

The skipper logbook data and independent observer data from 2003 to August 2009 for the PFTIMF were stored in a MS Access database. Structured query language (SQL) queries were written to filter the dolphin bycatch data. These data were then examined by sorting all relevant data fields in MS Excel and plotting relevant shot data in ArcGIS. Outliers, including obvious data entry errors and fields that contained missing information, were removed. The remaining data were then categorised for use in the data analyses (Table 3.1). Summary graphs and binary logistic generalised linear models were run in SPSS 16.01.

Spatial plots

MS Excel files containing latitudes and longitudes of trawl shots were used to create point files in ArcGIS. For the start and end latitudes and longitudes of logbook and observer reported shots, the shot start and end point files were combined using the MERGE function and then converted to lines. Lengths of the line segments were calculated (in nm) and data were screened for shots that were primarily outside the managed trawl areas and/or line segments longer than 21 nm. Line density of shots was then calculated using the Line Density function in ArcGIS.

Table 3.1: Description of variables and their categories used in analyses of PFTIMF skipper logbook and independent observer dolphin bycatch data from 2003-2009.

Description	**Database column**		**Categories**
	Skipper logbook	**Independent observer**	
Dolphin bycatch: binary data indicating the presence/absence of dolphin bycatch	CATCH	Count	Bycatch = 1, No bycatch = 0
Net type: whether a grid was present / absent and position	SelectionGrid	Flexible Grid Hard Grid	No Grid = 1, Grid = 2, Grid Forward = 3
Net type: presence / absence of a grid (either position)	SelectionGrid	Flexible Grid Hard Grid	No Grid = 1, Grid = 2
Time of day of trawling activity	EDATE	Edate	Morning [06:00-11:59] = 1, Afternoon [12:00-17:59] = 2, Night [18:00-23:59] = 3, Early morning [00:00-05:59] = 4
Trawl area: management area in which trawl took place	MAREA	MAREA	1, 2, 4, 5
Trawl season: trawling season	EDATE	Edate	[Dec-April] = 1, [May-Nov] = 2
Vessel: trawl vessel	VESSEL	VESSEL	1, 2, 3, 4
Trawl time: duration of each trawl	TRTIME	Stime Etime	[0.1 hr - 1 hr] = 1, [1.1 hr - 2.0 hr] = 2, [2.1 hr - 3.0 h] = 3, [3.1 hr - 4.0 hr] = 4
Trawl distance: distance of each trawl	DIST	Slat, Slong Elat, Elong	[0.1 nm - 5.0 nm] = 1, [5.1 nm - 10 nm] = 2, [10,1 nm - 15.0 nm] = 3, [15.1 nm - 20.0 nm] = 4
Trawl depth: depth of each trawl	SDEPTH EDEPTH	StartDepth EndDepth	[51 m - 60 m] = 1, [61 m – 70 m] = 2, [71 m - 80 m] = 3, [81 m - 90 m] = 4, [91 m - 100 m] = 5

Summary graphs
Summary graphs were generated in SPSS 16.01 to show dolphin bycatch per 1,000 shots for each categorical variable. Regression plots were also generated to show the total dolphin bycatch against the total number of shots with regard to the presence or absence of an exclusion grid by: trawl area (1, 2, 4, 5), time of day (6 hr blocks) and vessel (1, 2, 3, 4). Two of each of these was generated: one based on skipper logbook data and the other on independent observer data.

Binary logistic generalised linear models
Net type, time of day, trawl area, trawl season (wet vs dry), vessel and trawl duration were used as individual predictors with the outcome variable dolphin bycatch in binary logistic generalised linear models. Models were developed for both the logbook data and the observer data seaprately. These models were used to determine which variables were significant in predicting the presence compared to the absence of dolphin bycatch. The significant predictors were then used in combination in multi-predictor binary logistic generalised linear models (GLMs). The multi-predictor GLMs were used to determine which combination of predictors would produce the highest probability of the presence compared to the absence of dolphin bycatch.

3.3 Results

Overall dolphin bycatch rates and sample sizes
The logbook data set provided by DoFWA for the last six years of fishing in the PFTIMF comprises information on targeted catch and bycatch from 30,685 shots and the observer data subset contains similar details from 4,940 shots. A total of 172 dolphin capture events were recorded in skippers logbooks at an overall rate of 5.6 dolphins caught per 1,000 shots (or approximately 28-33 dolphins per year), while observer reports contain records of 49 dolphin capture events at an overall rate of 10.1 dolphins per 1,000 shots (or 51-61 dolphins per year). After removing outliers and excluding erroneous data points and missing values, approximately 91% of the logbook data and 85% of observer data remained for conducting further analyses. Dolphin capture events typically involve single dolphins at a time, although two dolphins have been caught in one shot on four occasions and three dolphins were caught in one shot on one occasion (based on observer data).

Spatial dolphin bycatch and fishing effort
Fishing effort was most intense in Management Area 1 and least intense at the northern and eastern regions of Area 5 (Fig. 3.1). The catch of dolphins appeared to largely reflect the intensity of fishing effort (Fig. 3.1).

From the logbook data, dolphin capture rates were greatest in Area 4, but for observer data they were highest in Area 2. However, these differences in dolphin catch rates among areas were not significant in predicting bycatch (Fig. 3.2; Table 3.2).

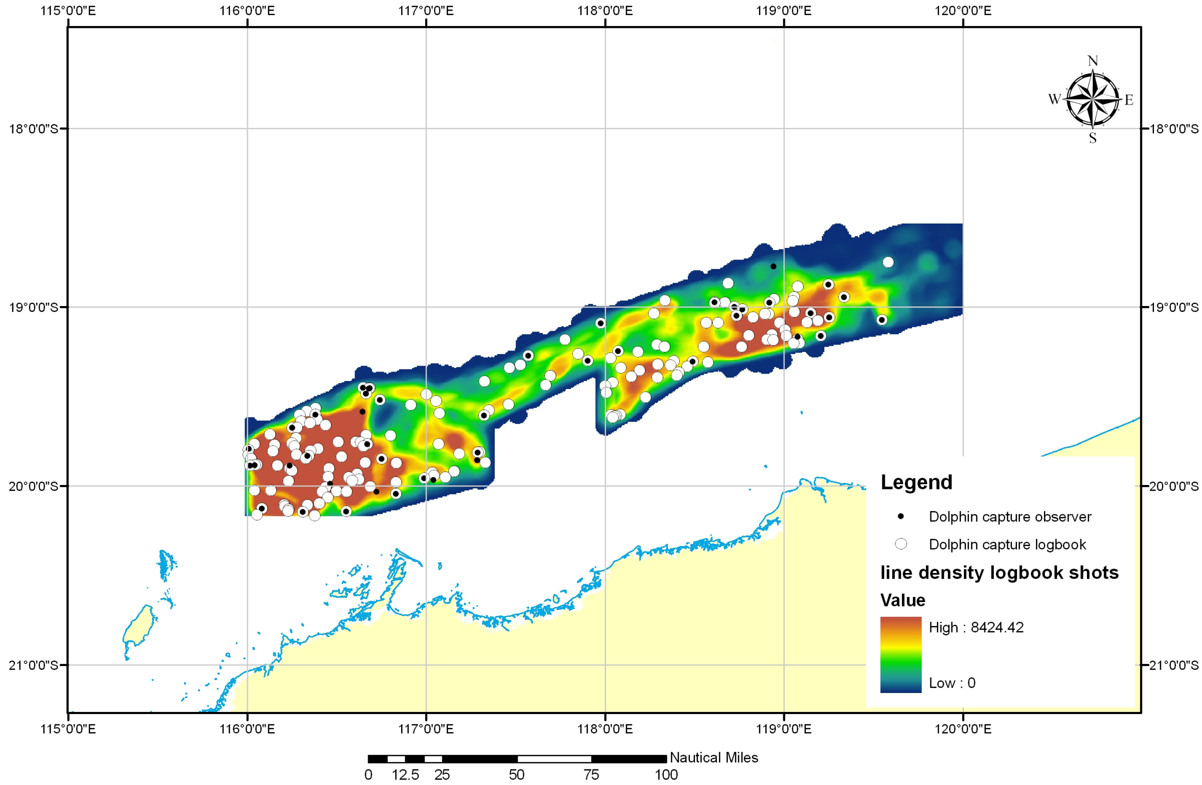

Fig. 3.1: Spatial density of fishing effort in the PFTIMF based on logbook shots (mid-2003 and August 2009). Logbook and observer reported dolphin capture events are overlayed.

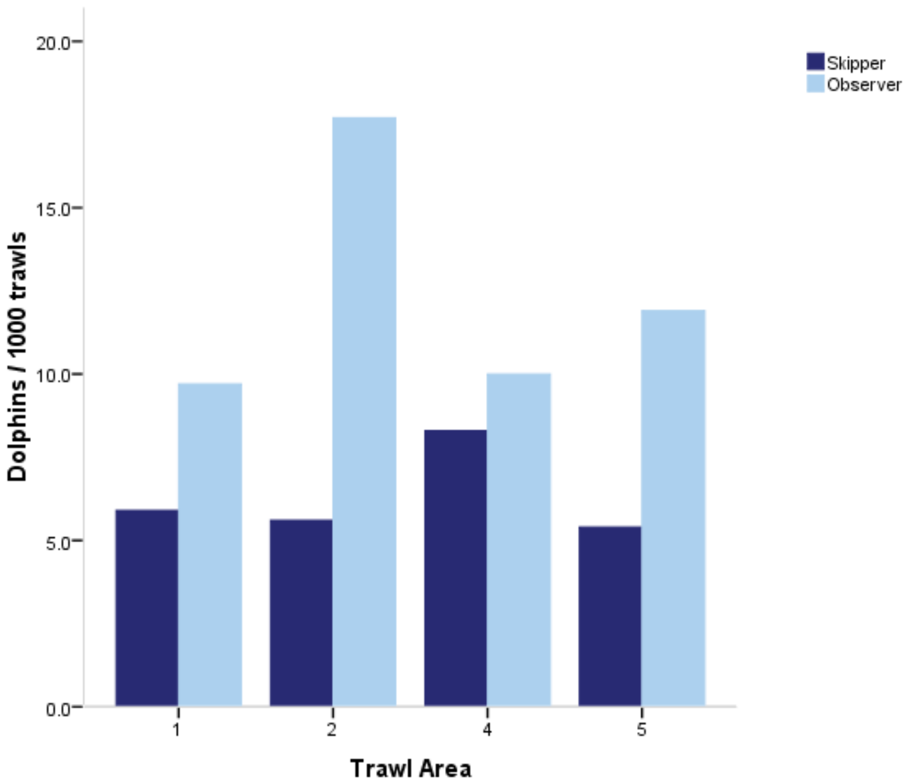

Fig. 3.2: Histogram of bycatch rates (dolphins/1,000 shots) by trawl management area (Skipper logbook n = 27,914; Independent observer n = 4,178).

Individual predictors of dolphin bycatch

When time of day, net type, vessel and trawl time (duration of shots) were used as individual predictors in binary logistic generalised linear models, they were each significant in predicting the occurrence of dolphin bycatch in the PFTIMF when based on the skipper logbook data (Table 3.2). In contrast, trawl management area and season (wet vs dry) were not significant in predicting the occurrence of dolphin bycatch (Table 3.2).

The results from modelling the observer data differed from those from the logbooks: when the same predictors were used based on the independent observer data, only vessel, time of day and net type (with 'no grid' and 'grid') were significant in predicting the occurrence of dolphin bycatch (Table 3.2).

Table 3.2: Individual predictor binary logistic generalised linear models (GLMs) to predict the presence of dolphin bycatch in trawl nets based on skipper logbook data and independent observer data (skipper logbook n = 27,914; independent observer n = 4,178 - except for the predictor trawl time, where logbook n = 27,489 and observer n = 4,153).

Predictor		**Skipper Logbook**		**Independent Observer**	
	df	Likelihood ratio (χ^2)	p	Likelihood ratio (χ^2)	p
Time of day (morning [06:00 – 11:59], afternoon [12:00 – 17:59], night [18:00 – 23:59], early morning [00:00 – 05:59])	3	44.03	<0.001	8.388	0.039
Net type (no grid, grid, grid forward)	2	18.18	<0.001	5.18	0.075
Net type (no grid, grid and grid forward pooled)	1	17.89	<0.001	5.06	0.025
Vessel (1, 2, 3, 4)	3	8.20	0.042	11.76	0.008
Trawl time (0.1 - 1 hr, 1.1 – 2.0 hrs, 2.1 – 3.0 hrs, 3.1 – 4.0 hrs)	3	12.22	0.007	3.48	0.323
Trawl area (1, 2, 4, 5)	3	3.95	0.267	2.87	0.413
Season (Dec –Apr, May – Nov)	1	0.01	0.904	0.34	0.853

Summary graphs of individual predictors of dolphin bycatch

The following six summary graphs present dolphin bycatch per 1,000 shots (based on skipper and observer datasets) for each categorical predictor variable. The first two (time of day, vessel) represent the variables that proved significant in predicting dolphin bycatch in the observer data (Figs. 3.3 and 3.4), while the subsequent four (trawl duration, trawl distance, season and depth) were not significant (Figs. 3.5 to 3.8). While the magnitudes in rates of capture differ between logbook and observer data, the patterns in the rates of dolphin capture tend to follow a similar pattern for each variable. However, dolphin capture rates by trawl duration and trawl distance should be directly correlated and this does not appear to be the case (Figs. 3.5 and 3.6).

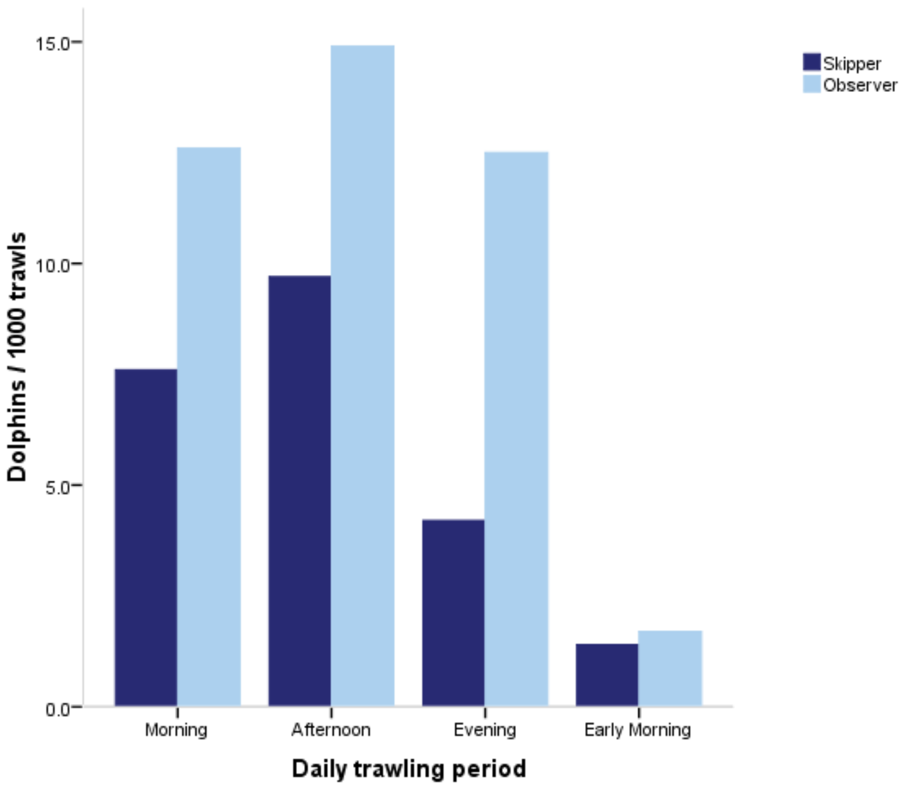

Fig. 3.3: Histogram of dolphin bycatch rates by daily trawling period = time of day (‘Morning’ = 06:00–11:59; ‘Afternoon’ = 12:00–17:59, ‘Evening’ = 18:00–23:59; ‘Early Morning’ = 00:00– 05:59; skipper logbook n = 27,914; independent observer n = 4,178).

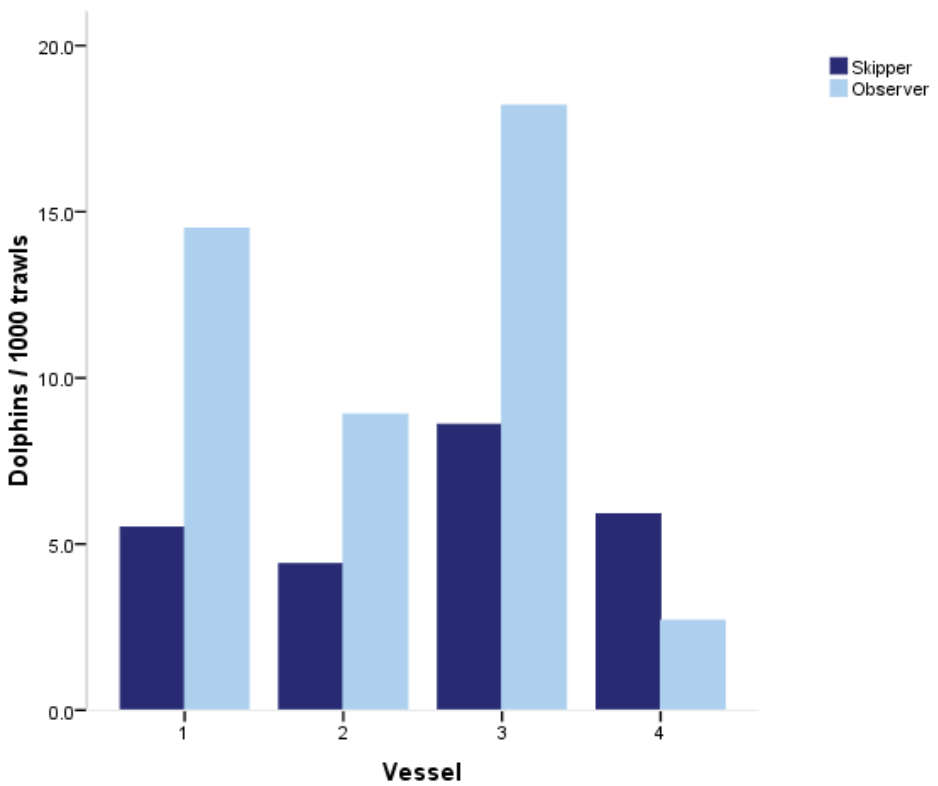

Fig. 3.4: Histogram of dolphin bycatch rates by vessel (1, 2, 3 and 4; skipper logbook n = 27,914; independent observer n = 4,178).

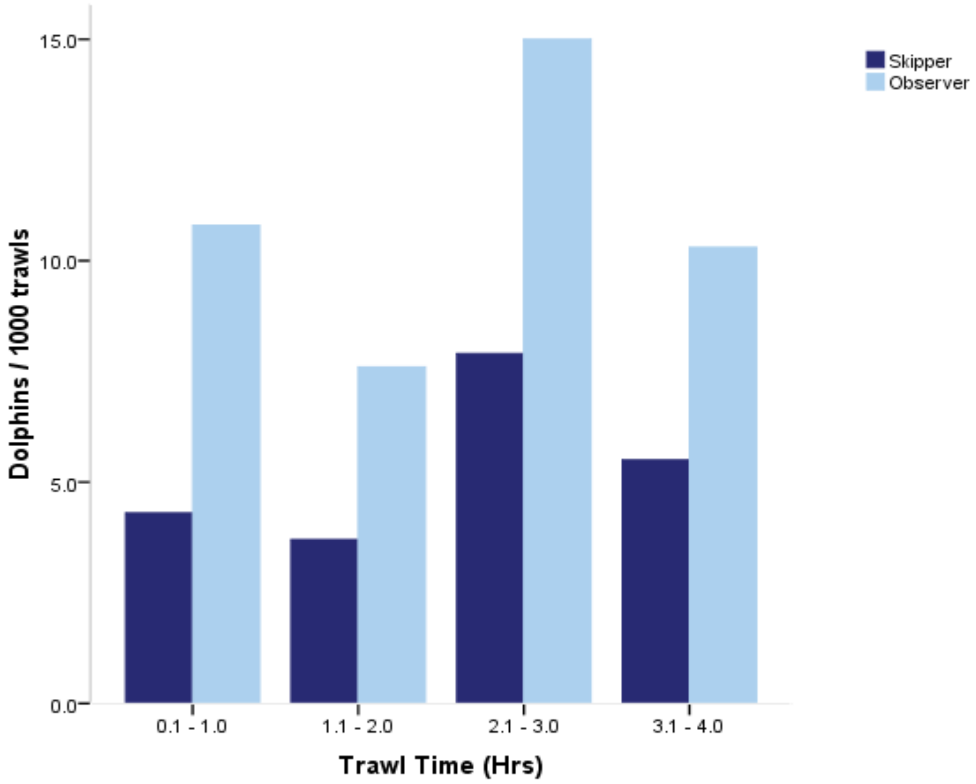

Fig. 3.5: Histogram of dolphin bycatch rates by trawl duration (skipper logbook n = 27,489; independent observer n = 4,153).

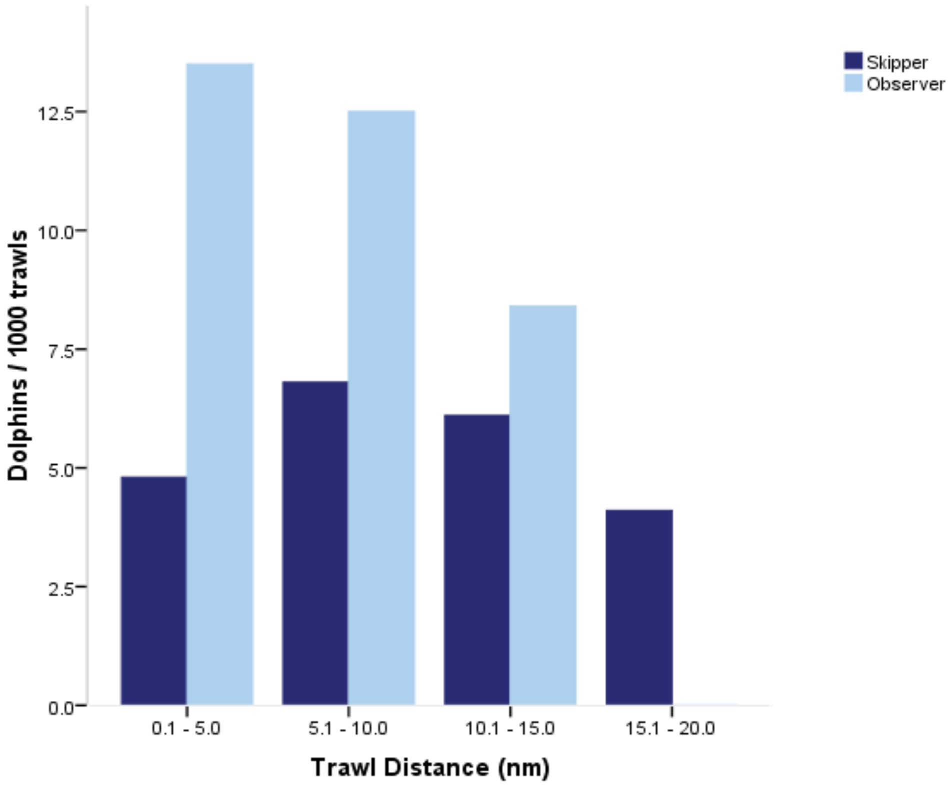

Fig. 3.6: Histogram of dolphin bycatch rates by trawl distance (skipper logbook n = 27,712; independent observer n = 3,691; No dolphin bycatch observed in trawl distances >15 nm).

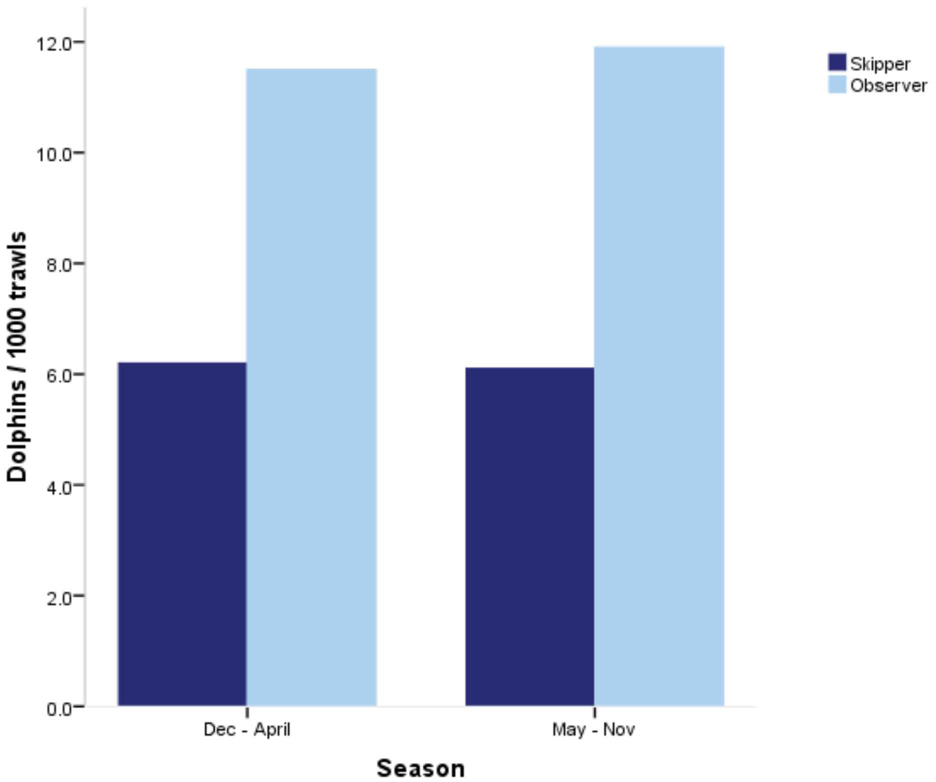

Fig. 3.7: Histogram of dolphin bycatch rates over trawling season (wet vs dry; skipper logbook n = 27,914; independent observer n = 4,178).

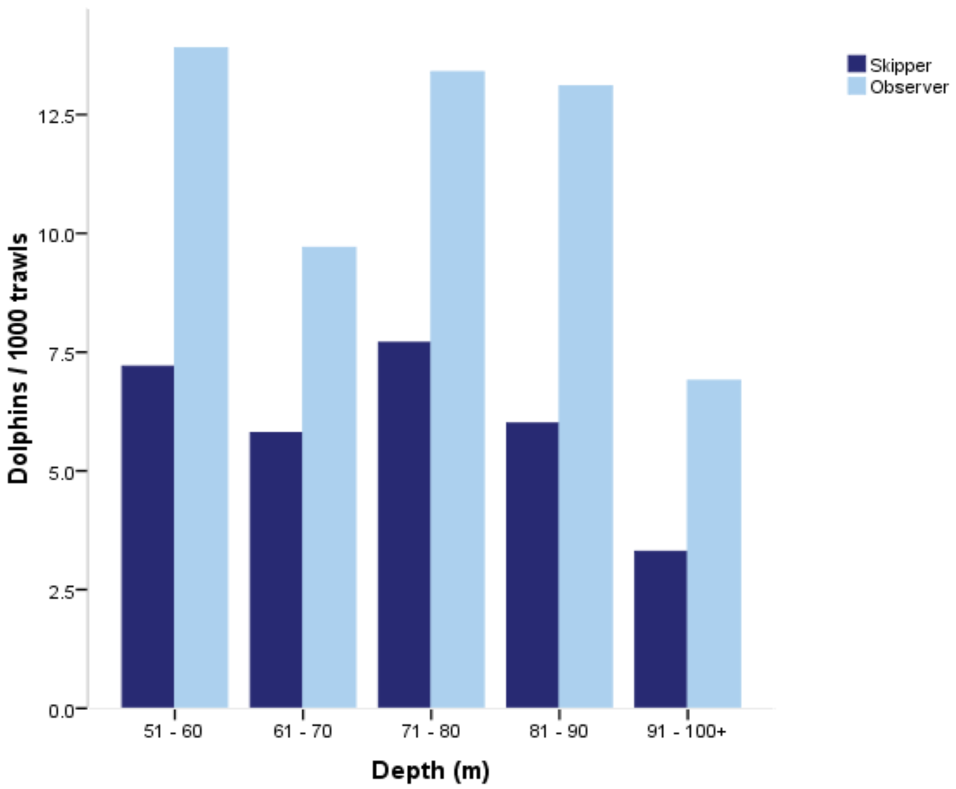

Fig. 3.8: Histogram of dolphin bycatch rates by depth (skipper logbook n = 27,117; independent observer n = 4,097).

Bycatch reduction devices and dolphin bycatch rates

The mean rates of dolphin bycatch have differed between logbooks and observer reports. Observer reported bycatch rates have been 1.6 to 3.7 times higher than logbook reported rates (Table 3.3). The rate of dolphin bycatch from both the skipper and observer records declined by ~50% after the introduction of bycatch reduction devices. However, after the devices were moved forward in the nets, the logbook data showed a further decline in dolphin capture rates, while the observer data indicated a slight increase in dolphin catch rates (Table 3.3; Fig. 3.9).

Table 3.3: Dolphin bycatch reported in skipper logbook data and independent observer data, number of trawl shots observed, and dolphin bycatch rate (in financial years, including the introduction of bycatch reduction devices and the grid being moved forward in the extension).

Period	**Skipper logbook**			**Independent observer**		
	# dolphins bycaught	(Number of shots)	Logbook Rate/1,000	# dolphins bycaught	(Number of shots)	Observer Rate/1,000
a) No grid						
Nov03-Jun04	18	(3138)	5.7	1	(46)	21.7
Jul04-Jun05	48	(4793)	10	9	(481)	18.7
Jul05-Feb06	32	(3002)	10.7	10	(537)	18.6
b) Grid						
Mar06-Jun06	6	(1569)	3.8	5	(657)	7.6
Jul06-Jun07	28	(5345)	5.2	9	(1055)	8.5
Jul07-May08	15	(3871)	3.9	5	(429)	11.7
c) Grid forward						
Jun08-Jul09	19	(4652)	4.1	7	(521)	11.3
Aug09-Sep09	1	(445)	2.2			

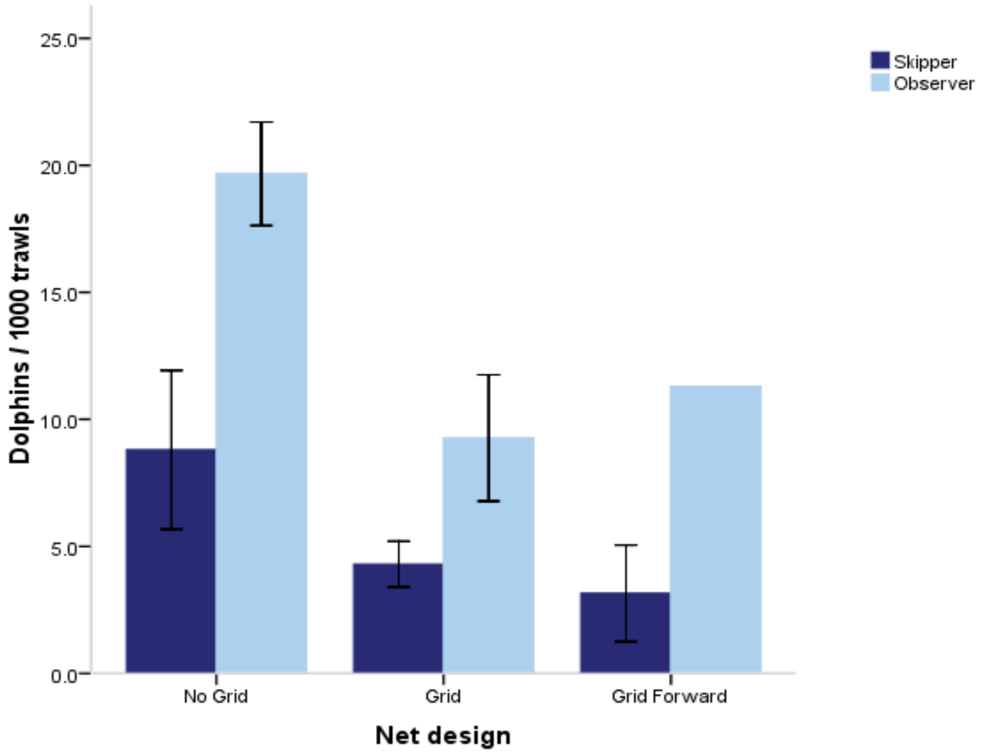

Fig. 3.9: Histogram of dolphin bycatch rates by differing net designs ('Grid' = exclusion grid and escape hatch fitted just forward of the codend and at the aft end of the tubular net extension; 'Grid forward' = grid and escape hatch moved to the forward end of the extension).

Regressions of dolphin bycatch and fishing effort (interactions between predictors)
Each of the regressions for the relationship between dolphin bycatch and fishing effort showed that dolphin bycatch increased with increasing fishing effort. The observer data on fishing effort (number of shots) explained a higher proportion of the variation in catch rate (R^2 = 0.36 to 0.53) than logbook data on these variables (R^2 linear values ranging between 0.03 and 0.15).

Multi-predictor binary logistic generalised linear models (GLMs) for dolphin bycatch
Using skipper logbook data, each predictor (time of day, net type, vessel) was significant in predicting dolphin bycatch, as was the interaction net type * vessel, although the effect was not as strong (Table 3.4).

Table 3.4: A binary logistic generalised linear model for predicting the occurrence of dolphin bycatch in the Pilbara fishery using time of day, net type, vessel and (net type * vessel) as predictors based on skipper logbook data (n=27,914). Model comparison compares the full model with the reduced model to indicate the significance of the additional predictor.

Predictors	**df**	**Model Log-likelihood**	**Likelihood ratio (χ^2)**	**p**
$B_0 + \beta_1$(Vessel) + β_2(Trawl period) + β_3(Net type) + β_4(Net type * Vessel)	10	-959.54	82.63	<0.001
		Model comparison		
		Likelihood ratio (χ^2)	p	
Intercept	1	33323.66	<0.001	
Time of day	3	46.99	<0.001	
Net type	1	15.15	<0.001	
Vessel	3	12.58	0.006	
Net type * Vessel	3	8.57	0.035	

The multi-predictor model based on independent observer data indicates that vessel and time of day are the strongest predictors of dolphin bycatch, with a marginally non-significant net type effect (Table 3.5).

Table 3.5: A binary logistic generalised linear model for predicting the occurrence of dolphin bycatch in the Pilbara fishery using vessel, trawl period and net type as predictors based on independent observer data (n=4,178). Model comparison compares the full model with the reduced model to indicate the significance of the additional predictor.

Predictors	**df**	**Model Log-likelihood**	**Likelihood ratio (χ2)**	**p**
$B_0 + \beta_1$(Vessel) + β_2(Trawl period) + β_3(Net type)	7	-236.51	24.27	0.001
		Model comparison		
		Likelihood ratio (χ2)	p	
Intercept	1	3375.33	<0.001	
Vessel	3	11.05	0.011	
Time of day	3	8.89	0.031	
Net type	1	3.49	0.062	

3.4 Discussion

In general, the trends in dolphin bycatch rates from skipper logbook and independent observer datasets followed a similar pattern. However, the analysis of dolphin bycatch patterns on spatial, seasonal and daily scales, and comparisons among different net designs, found that our expectation that the greatest source of variation would be from the comparisons among net designs (no exclusion grid vs exclusion grid vs exclusion grid forward) was not the case. Most of the variation in dolphin bycatch was explained by the predictor variables of vessel type and time of day, with one vessel recording higher catches of dolphins than the others and dolphin catch rates being lower from midnight to dawn than at other times of day. In the full model, net design was close to significance. While the logbook data was a much larger dataset (around seven times that of the observer dataset), much clearer signals were apparent in the observer data and most of the discussion focuses on the results from the observer data.

Temporal patterns (time of day and season) of dolphin bycatch and fishing effort

Daily fishing effort data was divided into four six-hour blocks to examine dolphin bycatch rates by time of day. Observer reported dolphin catch rates in the early morning period (0000-0559) when the least fishing occurs were <15% of what they were in the other three time periods. Logbook records also indicated a similar pattern, although the difference between periods was not as marked as those from the observer data. It is difficult to determine why dolphins might be less likely to be caught in the early morning, as bottlenose dolphins inhabiting 'offshore' environs are not generally known to have a distinctly diel behavioural pattern and, in fact, they are seen foraging around the trawlers in the PFTIMF throughout the day and night (pers. obs.). Bottlenose dolphins also forage around trawlers throughout the day and night in other parts of Australia, for example, Moreton Bay, Queensland, and Spencer Gulf, South Australia (Chilvers & Corkeron 2001; Svane 2005). In a study of two fisheries off the north-eastern U.S. between 1977 and 1988, Waring et al. (1990) noted that bycatch of common dolphins (*Delphinus* sp.) and pilot whales (*Globicephala* sp.) tended to follow a diel pattern, with common dolphins being caught at night and pilot whales during the day, but went on to suggest that the observed patterns were inconclusive.

Both skipper logbook and independent observer data suggested that there was little to no influence of season (wet vs dry) on the likelihood of dolphin bycatch in the PFTIMF. Although little is known of the behaviour and movements of dolphins interacting with the fishery, this lack of an effect is not surprising.

Vessel and net type effects on the probability of dolphin bycatch

A fairly strong vessel effect was evident in both logbook and observer data, and in both single- and multi-predictor generalised linear models (GLMs). One particular vessel had higher bycatch rates than the other three. The difference in dolphin catch rates between vessels is difficult to interpret, especially given the similarities in boat configurations and nets between some of the vessels in this small fleet. However, it may be due to different fishing practises by skippers.

Net type was significant in the single and multi-predictor GLMs using logbook data. However, in the observer data, net type was significant in the single, but not the multi-predictor model, possibly because of the low number of observer trawls for the 'exclusion grid forward' net type and the relatively low incidence of dolphin capture. Net type became significant when the 'exclusion grid' and 'exclusion grid forward' were pooled into a 'grid' category for 'no grid' vs 'grid' comparisons. Furthermore, the relatively small sample size of observer coverage for the 'grid forward' design reduces the power to detect any change/effect among the three net designs.

Exclusion grids and escape hatches of various forms have been trailed to reduce bycatch of marine mammals, turtles and other megafauna in numerous trawl fisheries around Australia and the world. While detailed measures of their efficacy are often hard to come by, those that have met with some success include the following:

- Northridge et al. (2003, 2005) have experimented with exclusion grids and top-opening escape hatches in an English pelagic bass pair trawl fishery. They report on significant reductions in common dolphin bycatch without the loss of target species;
- Zeeberg et al. (2006) report on the use of tunnels and escape hatches to reduce bycatch of cetaceans and other megafauna in the Dutch trawl fleet fishing off Mauritania;
- Top-opening escape hatches and exclusion grids have reduced the bycatch of turtles, large sharks and rays in Australia's Northern Prawn Fishery (Brewer et al. 2006);
- The bycatch and mortality rates of fur seals (*Arctocephalus* sp.) has been reduced with the use of large, bottom-opening escape hatches in a pelagic, mid-water trawl fishery off Tasmania (Lyle & Willcox 2008).

Spatial patterns (management area and depth) of dolphin bycatch and fishing effort
Logbook data suggested that dolphin capture rates were highest in Area 4 of the PFTIMF, while observer data indicates a highest rate in Area 2. These differences did not prove significant in predicting dolphin capture in single- or multi-predictor GLMs based on observer data. Nor was there any marked difference in capture rates by depth for both the logbook and observer data. These results are to be expected because of the broad extent of dolphin interaction with PFTIMF trawlers and the extent of time that they associate with operating trawl nets - i.e. dolphin bycatch events are spread across areas and depths in the fishery.

Skipper logbooks versus independent observer data
While the database of both logbook and observer records formed the basis of this assessment of spatial and temporal patterns of dolphin bycatch in the PFTIMF, some issues require addressing. Firstly, the sizeable logbook dataset currently includes omissions, blank fields and erroneous data that meant only around 91% of the shot records were useful in these analyses. The smaller observer dataset appeared compromised by lax reporting in the earlier stages of observer coverage, resulting in only 85% of the observer records being useful for analyses. Furthermore, the summary graphs for trawl time and trawl distance (Figs. 3.5 and 3.6) should follow the same pattern of variation, assuming that trawling speed does not vary greatly between shots, and this is not the case. Sound reporting practices and validation checks should improve the power for future interrogation of this data and translate into better advice for management of the fishery.

Implications for the mitigation of dolphin bycatch in the PFTIMF
These results suggest that area closures or some other form of spatial management measure to reduce dolphin bycatch in the PFTIMF would be ineffective. A shift in fishing effort to the early morning period may see a reduction in dolphin bycatch, and placing upper limits for dolphin bycatch on individual vessels may also be warranted. Further trials of nets fitted with exclusion grids and top-opening escape hatches for air-breathing animals should be conducted. These trials will require a greater proportion of observer coverage than has been achieved to date, such that further assessments of bycatch mitigation have more power.

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4. Chapter Four: Subsurface behaviour of bottlenose dolphins interacting with nets in the Pilbara Fish Trawl Interim Managed Fishery, Australia

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Abstract

Many delphinid populations overlap with commercial trawl fishing operations and most studies of these interactions have focused on their opportunistic feeding on discarded bycatch. However, relatively little is known about dolphin behaviour around actively fishing trawl nets. Here, we use underwater video footage recorded inside trawl nets to evaluate common bottlenose dolphin (*Tursiops truncatus*) subsurface behaviour in the Pilbara Fish Trawl Interim Managed Fishery, north-western Australia. A total of 85 hours of footage was collected over 36 daytime trawls. Interaction rates were high, with dolphins recorded inside trawl nets during 29 (81%) trawls and outside trawl nets in 34 (94%) trawls. Dolphins were present in and around trawl nets for up to 99% of the entire duration of an individual trawl. The proportion of foraging behaviours was significantly higher for dolphins inside the net than those outside the net, indicating that dolphins in the net are presented with a concentrated food source. Dolphins observed outside the net spent a larger proportion of time travelling than in any other behaviour. Some socialising was observed in dolphins both inside and outside nets. Dolphins thus appear to be motivated by several factors to approach and interact with active trawl nets. Inside the net, 29 individuals were identified based on various morphological characteristics. Some individuals returned to the net numerous times within each trawl, and also in different trawls within the same trip and on separate fishing trips. While most trawls featured a single adult dolphin inside the net, groups of up to seven individuals were also recorded inside the net at one time. These results suggest that entering trawl nets may be a specialisation exhibited by only a subset of the dolphin population in the region. Furthermore, they suggest that dolphins are highly motivated to interact with actively fishing trawl nets, and that spatial and/or temporal adjustments to fishing effort would do little to mitigate against dolphin bycatch.

4.1 Introduction

Due to their remarkable behavioural flexibility, in particular with regard to foraging strategies, many delphinids have learned to exploit fisheries as energetically efficient sources of food (Leatherwood 1975; Shane et al. 1986; Fertl & Leatherwood 1997). Associations between dolphins and trawlers are known from a number of locations around the world, including Moreton Bay in Queensland (Corkeron et al. 1990), Spencer Gulf in South Australia (Svane 2005) and the Pilbara in Western Australia (Shaughnessy et al. 2003). While these interactions provide dolphins with foraging opportunities, they also present the risk of injury or mortality through entanglement in fishing gear; fishing-related mortality is considered the most immediate threat to populations of small cetaceans worldwide (Read 2008).

Most research on the interactions between dolphins and trawl fisheries has focused on opportunistic feeding by dolphins on discarded bycatch (e.g. Leatherwood 1975; Corkeron et al. 1990; Hill & Wassenberg 1990; Svane, 2005). Operational and technological constraints have prevented more in-depth assessments and, subsequently, comparatively little is known of dolphin subsurface behaviour as they interact with actively fishing trawl nets (but see Northridge et al. 2005). Such information can be extremely valuable in informing bycatch mitigation strategies. Here, we use underwater video footage recorded inside trawl nets to evaluate temporal and behavioural aspects of interactions between common bottlenose dolphins (*Tursiops truncatus*) and actively fishing trawl nets in the Pilbara Fish Trawl Interim Managed Fishery, Western Australia.

4.2 Methods and Materials

Data collection

The 36 trawls analysed for dolphin presence/absence and behaviour inside and outside trawl nets were conducted during three fishing trips of approximately two weeks duration each, hereafter referred to as Trip 1, Trip 2 and Trip 3.

Video footage and analysis

Underwater video footage was collected using a Sony HDR-CX7. The cameras were placed in waterproof metal housings and secured to the trawl net by cable ties. Cameras were fitted 3.6m forward of the exclusion grid, hanging from the top of the netting. The camera faced upstream toward the net opening in order to film dolphins as they entered the net and swam along in front of the grid. Cameras were set to standard definition and night vision to allow for visibility at depths of 50-100m. Once recording was completed, image data were transferred to an external hard drive, where they were labelled with date, trip number and trawl number.

Video footage was viewed and analysed using EventMeasure v2.04. This program features an integrated movie player that supports efficient video analysis through fast forward playback and frame stepping functions. Events are logged by overlaying dot points on still images, with the identified individual marked by a red dot. Information and attribute fields can be loaded from a pre-defined text file and assigned to the overlayed points. At the end of a video sequence, data added to the information and attribute fields can be exported as a text file for subsequent analyses. EventMeasure also allows reference images or clips to be captured and recalled via an inbuilt viewer while analysing video sequences. This allows for individual animals to be identified.

Temporal association of dolphins with trawl nets

The first and last time a dolphin was observed inside and outside the net was recorded to obtain an approximate measure of the time dolphins interacted with the net. Estimates of the temporal occurrence of dolphins outside the nets are likely to be minimum estimates, as only a small area outside the net was in the camera's field of view. Estimates of the proportion of trawl time during which dolphins are present inside the nets, however, should be accurate. Six trawls were sub-sampled using focal individual follows in order to obtain an indication of the percentage of the total trawl duration during which individual dolphins were present inside the net, their average dive time inside the nets, as well as the number of times these individuals returned to the net in each trawl.

Dolphin identification and behaviour

Individual dolphins that entered the net were identified based on characteristics such as scars and irregularities of the dorsal fin or fluke. Behavioural data were collected from all focal dolphins present inside or outside the net. Specifically, a number of behavioural events within three behavioural states (travelling, foraging and socialising) were recorded. For example, 'fish chase' and 'fish catch' were two events recorded within the behavioural state 'foraging', while entering and exiting the net were events classified as travelling behaviours. The following information was recorded for every behavioural event: date, vessel name, trip number and trawl number. The following attributes were also recorded for every behavioural event: the dolphin's position in relation to the net, the behavioural event displayed and any comments, such as whether or not the dolphin was resighted or a suspected male/female. The following data were also recorded for dolphins that entered the net: individual identification number, the dolphin's gender (if discernible) and an image of the dolphin or a body part that had conspicuous markings such as nicks and scars, often the dorsal fin or the fluke, for later identification.

Image analysis

We used a scan sampling method to quantify dolphin behaviours in the throat of the net (i.e. detailed observation and recording of all behaviours exhibited during one minute of 'normal' speed footage, then fast-forwarding through the video footage for five minutes). It had the benefit of being an efficient way of quantifying behaviour across all 36 trawls. Sampling two full trawls validated the accuracy of this method: once using continuous sampling and once using the one minute in six scan sampling technique. The proportions of behavioural events recorded when using the scan and the continuous sampling methods were compared using a Kolmogorov-Smirnov test. The duration of a trawl was defined as 'from the time when the net was fully extended and fishing properly to the time when the net had collapsed completely on reaching the surface, or when the camera stopped recording'. This definition allowed for a direct comparison of dolphin presence in and around the net with the total duration of a trawl or, in three cases, the duration of the recording where it stopped before the end of the trawls.

Data analyses

Behavioural event data were exported from EventMeasure as text files and imported into Microsoft Office Excel 2003 for further exploration. Statistical analyses were performed in PASW Statistics v17 (formerly SPSS). A chi-square test for goodness-of-fit was used to test the hypothesis that the main motivation for dolphins to interact with trawl nets is the associated foraging opportunity. The expectation was that at least 50% of all behaviours displayed by dolphins that associate with the net, either inside or outside, would be foraging behaviours. This value was chosen to reflect a majority of feeding activity over travelling and socialising behaviours. The numbers of events in each behavioural state were used as the observational data, and data for the travelling and socialising states were summed into an 'other' category. A chi-square test of independence was then performed to test whether the proportion of foraging behaviours differed significantly between dolphins on the inside and on the outside of the net. In this test, Yates Continuity Correction was used to compensate for the overestimate of the chi-square value generated by the test as a result of using a 2x2 table consisting of two variables (behaviour and position) with two categories each ('foraging'/'other' and 'inside'/'outside').

4.3 Results

Assessments of behaviour were made from a total of 36 daytime trawls in which 85 hours of video footage were captured from three fishing trips between 11th October and 8th November 2008. The mean trawl time was 2 hrs 14 min ± 9 m (ranging from 33 min to 3 hrs 20 min).

Sampling method

The relative frequencies of behavioural events did not differ significantly between the scan and continuous sampling methods (K-S, $D = 0.43$, $p = 0.54$), so the more efficient scan sampling method was adopted.

Temporal association of dolphins with trawl nets

Dolphins were observed outside the net in 94% of trawls ($n = 34$) and entered the net in 81% of trawls ($n = 29$). The proportion of trawl duration that dolphins were present outside the net was 77% (range = 22% to 99%). Dolphins were visible inside the net during 59% of the total trawl time (range = 2% to 98%).

Observations of six individual dolphins that entered the net in six separate trawls indicated that dolphins entered the net more often if they were alone (mean = 11 ± 4 entries, $n = 3$

dolphins, range = 6–19 entries), than if other dolphins were inside the net during that trawl (mean = 6 ± 2 entries, n = 3 dolphins, range = 3–10 entries).
The longest recorded time for an individual inside the net was 7 minutes 2 seconds. The average time between an exit from the net and the next entry by an individual was 10 minutes 4 seconds (± 1 min 51 sec). Dolphins that formed part of a group spent a proportionally lower percentage of the total trawl time in nets (mean = 11%, n = 3) than solitary individuals (mean = 14%, n = 3).

Identified dolphins
Twenty-nine individually recognisable dolphins were identified recorded inside the net. The number of dolphins present in the net at any one time ranged from one during most trawls (n = 15 trawls) to seven during a trawl (n = 1). The highest number of individuals observed in the net at different times throughout one entire trawl was nine dolphins (Fig. 4.1).

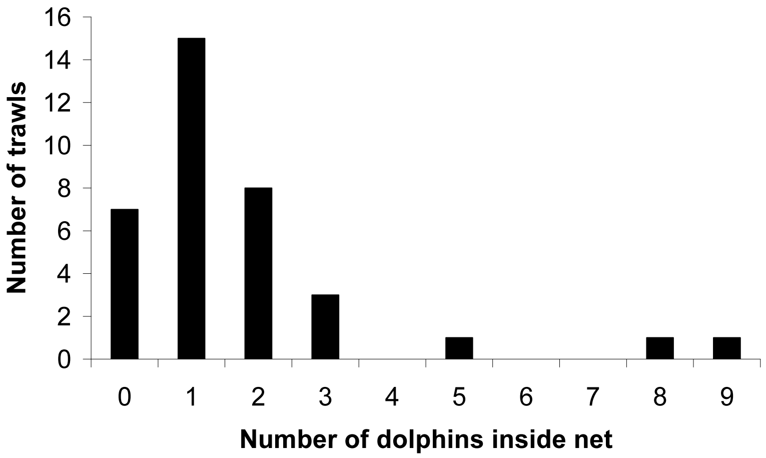


Fig. 4.1: The frequency distribution of the total number of dolphins entering the net per trawl.

Over all trips, the mean number of dolphins in the net per trawl was 2 ± 0.4 (range = 1-9). In the trawls assessed during Trip 1, 12 different dolphins entered the net on 16 occasions, while 22 different, individually recognisable individuals entered the net on 37 occasions during Trip 2. The number of individuals identified in the trawls (three) and the number of occasions on which dolphins entered the net (nine) were both much lower during Trip 3 than in both Trips 1 and 2.

One identifiable dolphin entered the net during all three trips. This suspected male was also the individual with the highest number of re-sightings. It was seen during a total of nine trawls - two in Trip 1, two in Trip 2 and five in Trip 3. Six other dolphins were sighted in two of the three trips. Recognisable dolphins were observed inside the net in all of the different management areas where trawling occurs (Fig. 4.2). Three recognisable dolphins were observed in one area only, while four individuals entered the net in two areas each (Fig. 4.2). Eight of the resighted dolphins were repeatedly observed in pairs, either in different trawls of the same trip, or during different trips.

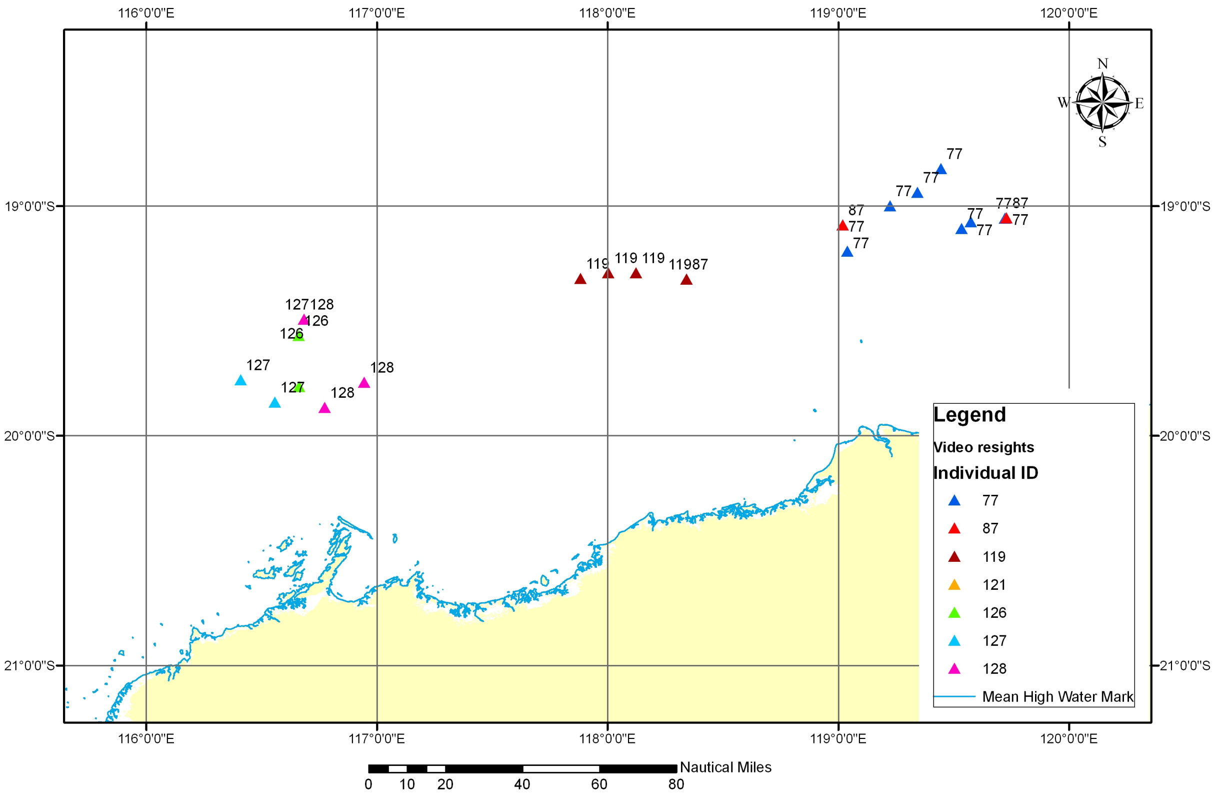


Fig. 4.2: Locations of dolphins resighted in different trawls within the PFTIMF.

Dolphin behaviour

A total of 1142 behavioural events, 736 outside and 406 inside the net, were recorded during the review of 36 video recorded trawls. Dolphins inside the net exhibited a wider variety of behavioural events overall in comparison to dolphins outside the net (Fig. 4.3). They exhibited a total of 14 different behaviours, while dolphins outside the net were only observed displaying eight behaviours (Fig. 4.3). Chasing fish was the predominant activity of dolphins in the net, while trampolining (bouncing) on the upper surface of the net (classified in this study as within the 'travelling' behaviour state) was the principal activity of dolphins outside the net (Fig. 4.3).

Foraging behaviours accounted for a greater proportion of the behavioural events displayed by dolphins inside (54%) than by those outside the net (31%) (Table 4.1). 'Fish chase' was the main foraging event recorded for dolphins inside the net, while inverted foraging was predominant foraging behaviour among dolphins outside the net (Fig. 4.4).

Social behaviours accounted for the lowest proportion of behavioural events recorded in all three fishing trips, with dolphins displaying a total of 36 events inside and only five events outside the net (Fig. 4.4). Both inside and outside the net, social inverting was observed most frequently and often involved an individual inside the net inverting to present its ventrum to a dolphin outside the net, or two dolphins outside the net presenting their ventra to each other, whereby one dolphin inverted. The two events of copulation attributed to dolphins in the net took place between a dolphin inside the net and a dolphin outside the net (Fig. 4.4a & 4.4b).

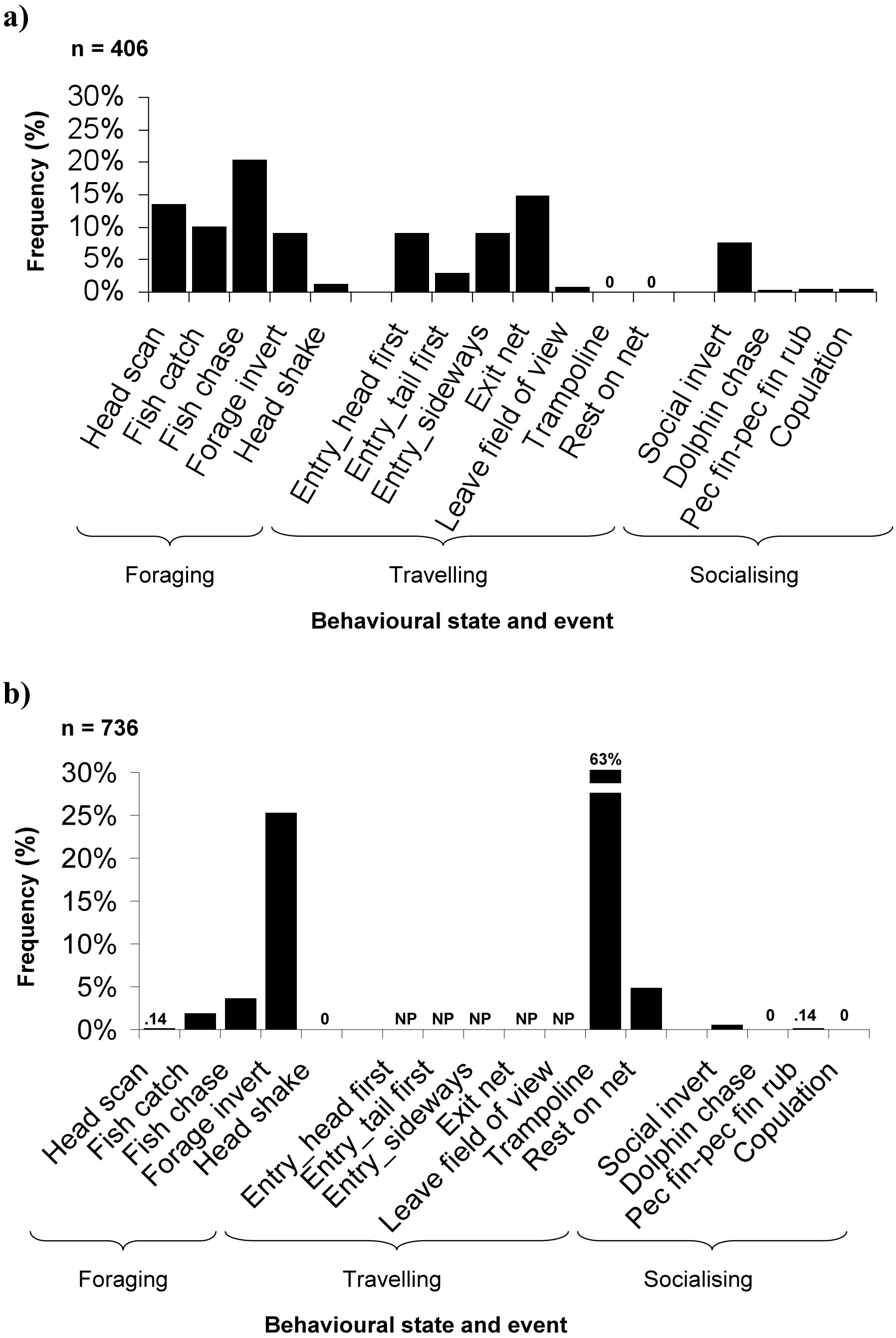
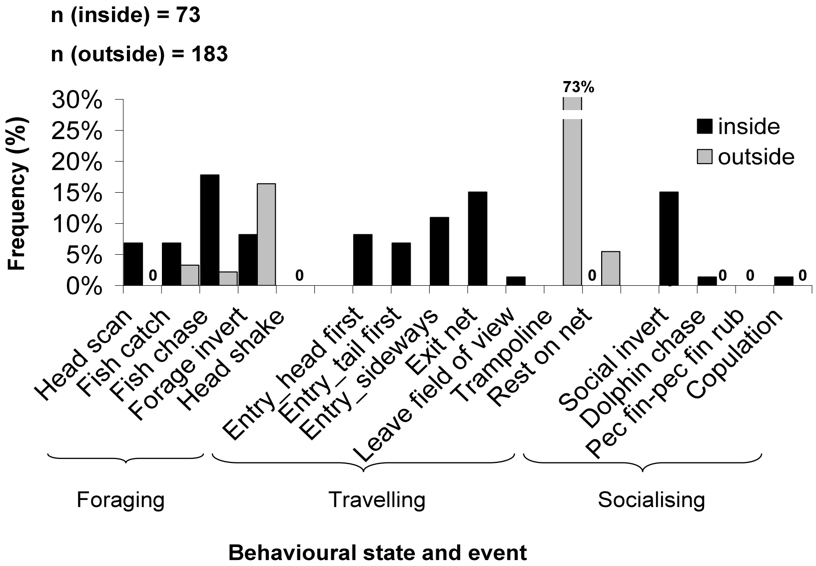


Fig. 4.3: Frequency of behavioural events within behavioural states recorded from video of dolphins **a)** inside the net and **b)** outside the net. NP = behavioural event not possible.

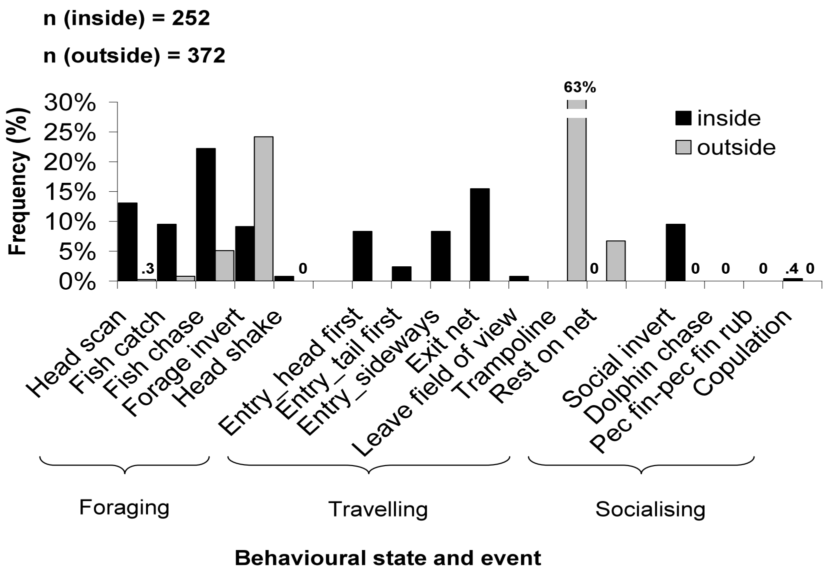
Table 4.1: Counts and percentages of behavioural events displayed by dolphins interacting with trawl nets in the PFTIMF between October and November 2008.

Position	**# foraging events**	**% foraging events**	**# non-foraging events**	**% non-foraging events**	**Total # events**
Inside	219	54%	187	46%	406
Outside	228	31%	508	69%	736
Total	**447**	**39%**	**695**	**61%**	**1142**

T1)



T2)



T3)

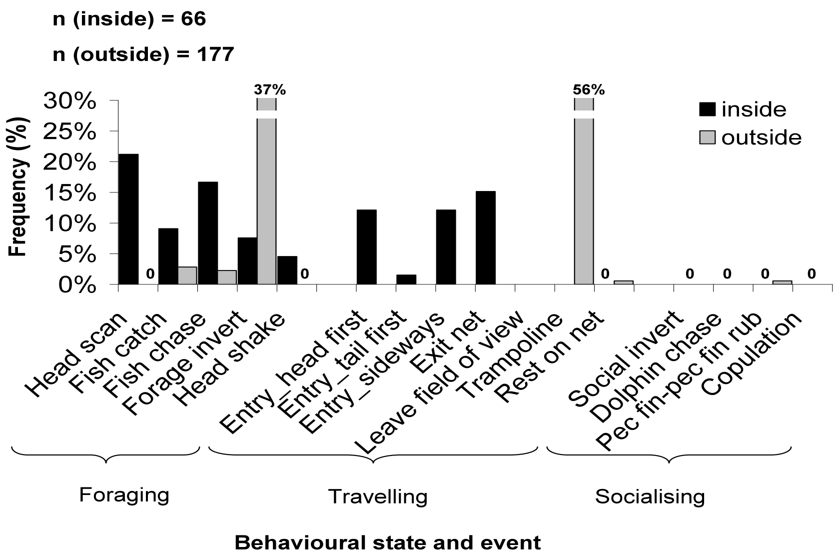


Fig. 4.4: Comparison of proportions of behaviours by dolphins displayed inside (in) and outside (out) nets in **T1)** Trip 1, **T2)** Trip 2 and **T3)** Trip 3 (0 = behaviour not observed).

The overall subsurface behavioural repertoire of dolphins (both inside and outside the net) consisted of 39% foraging behaviours and 61% other behaviours (57% travelling and 4% socialising; Table 4.1). The proportion of foraging behaviours was significantly lower than 50% ($\chi^2_{1, 1142} = 55.608$, $p < 0.001$). The proportion of foraging and non-foraging behaviours differed between dolphins inside and outside the net, however, with dolphins inside the net foraging in 54% of observations, followed by travelling (37%) and socialising (9%). Dolphins outside the net spent most time travelling (69% of behavioural events), followed by foraging (31%) and a small proportion of socialising (0.5%). The chi-square test for independence indicated a significant association between the position of dolphins in relation to the net and the proportion of foraging to non-foraging behaviours ($\chi^2_{1, 1142} = 58$, $p < 0.001$).

4.4 Discussion

Temporal association of dolphins with trawl nets

Reports of associations between delphinids and trawl fisheries often describe opportunistic feeding by the animals on discarded bycatch (Fertl & Leatherwood 1997) or association patterns of dolphins following trawlers (Chilvers & Corkeron 2001). Few studies have quantified subsurface dolphin behaviour around trawling operations. The interaction rates between bottlenose dolphins and the Pilbara Fish Trawl Interim Managed Fishery (PFTIMF) reported here are extremely high. These dolphins not only take advantage of discards when the nets are hauled up, but also interact extensively and closely with the nets while they are operational.

The first estimates of temporal associations between dolphins and trawl nets in the PFTIMF by Mackay (2008) indicated that dolphins entered the net in 66% of all trawls reviewed and were present inside the nets for up to 64% of the trawl time. Mackay (2008) did, however, qualify that these were likely to be minimum estimates. With the aid of improved video equipment and analytical tools, here we report that both the proportion of trawls in which dolphins interacted with the gear as well as the percentage of total trawl time during which dolphins were present either inside or outside the net, were very high. Dolphins entered the net in 81% of all trawls reviewed and there were dolphins inside the net for up to 98% of the total trawl duration. They were also present outside nets in 94% of trawls reviewed and for up to 99% of trawl duration.

The high temporal and spatial interaction rates reported here have direct implications for the reduction of dolphin bycatch in the fishery. Temporal and spatial closures are not likely to be effective bycatch reduction measures, which must necessarily focus on preventing dolphins that enter the nets from becoming caught, injured or killed in the fishing gear.

Dolphin behaviour in and around trawl nets

Dolphins interact with trawl nets in the PFTIMF for a number of reasons. Firstly, those that enter actively fishing trawl nets are presented with a concentrated food source. They also engaged in some social activities. Dolphins that remained outside the net, however, spent more time travelling and, in particular, ‘trampolining’ on the dorsal panel of the net. It is important to note here that, while the camera captured most of or the entire inside of the net from its aperture to the camera’s position (~3.6 meters in front of the grid), only a small part of the environment outside the net was captured. Certain behaviours exhibited by dolphins outside the net were likely not recorded and this should be taken into consideration. Nevertheless, fish are herded into the net by the vibrating sweeps as they are towed over the ocean floor, so the concentration of prey in the vicinity of actively fishing gear is most likely to be found between the sweeps and inside the net.

Dolphins outside the net were occasionally observed pulling out enmeshed fish or inverting when swimming beneath the net. There were also occasions in which fish swam underneath the net, providing dolphins outside the net with a food source that may not be found in similar proportions near the outer sides or upper surface of the net. This was supported by numerous observations of inverted foraging by dolphins underneath the net - the most frequently observed foraging method by dolphins outside the net. Dolphins have been observed pulling fish through the mesh in at least two Australian prawn trawl fisheries: bottlenose dolphins following trawl nets during haul up were seen to manipulate the codend and pull out enmeshed fish in Yamba, New South Wales (Broadhurst 1998) and in Spencer Gulf, South Australia (Svane 2005). Broadhurst (1998) also deployed cameras on a trawl net and recorded video footage of two bottlenose dolphins removing fish from the codend throughout a nocturnal trawl.

'Trampolining' was classified here as a travelling behaviour. However, since trampolining dolphins often turned and twisted their bodies while bouncing on the net, and because trampolining was sometimes preceded or followed by the individual rubbing its head and rostrum against the net, trampolining may serve to remove old skin, parasites or even remoras (which were observed on three individuals). Similar behaviour, which may serve the same purposes, has been observed in Northern Resident killer whales (*Orcinus orca*) in the Johnstone Strait, Canada (Jacobsen 1986). This community are known to engage in a behaviour termed 'beach rubbing', in which they interrupt foraging sessions to rub their bodies on smooth pebbles along a specific, shallow-water section of the shoreline (Jacobsen 1986). Interestingly, both killer whales in Johnstone Strait and bottlenose dolphins in the Pilbara often combined rubbing/resting on the pebbles and trampolining on the trawl nets with socialising with nearby conspecifics (Ford 1989, this study, respectively).

Dolphins that enter the net may do so not only because of the concentrated food source, but also because the net's surface provides a wall against which dolphins can herd and catch fish. Fish that were chased by dolphins sometimes swam into the mesh, where they became entangled and were easily captured. Trawl vessels operating in the PFTIMF present bottlenose dolphins with foraging opportunities beyond that of feeding on discards after haul-up. Foraging inside and underneath actively fishing nets provides dolphins with a concentrated food source as well as opportunities for travelling and socialising.

Identified dolphins, specialisation and population structure

A total of 29 dolphins were individually identified inside trawl nets in the 36 reviewed trawls, with some individuals and pairs being observed repeatedly across trawls and trips. This relatively small number of individuals implies that entering the nets may be a foraging specialisation exhibited by a limited number of individuals within a broader population. This is speculatively supported by the observation that, during five trawls, numerous dolphins were observed outside the net, but none of them entered the net. Similarly, the fact that identified dolphins which entered the net did so a number of times during the same trawl suggests that these individuals spent little or no time interacting with the outside of the net, but left the net only for a surfacing bout before returning to the inside of the net. Foraging in association with trawl nets or trawlers as a specialisation has been documented in a number of studies. Chilvers and Corkeron (2001), for example, identified two 'communities' of bottlenose dolphins within the Moreton Bay bottlenose dolphin population, Queensland. Members of one community fed in association with trawlers, while members of the other did not. Furthermore, foraging 'traditions' and specialised foraging tactics displayed by only certain groups or even matrilines within broader populations are reported from a number of other bottlenose dolphin populations (perhaps the most notable and well-documented of these is the bottlenose population in Shark Bay, WA - Krützen et al. 2005; Sargeant & Mann 2009).

In comparison to the size of the area fished by the PFTIMF (12,779 km^2) and the area covered in the reviewed trawls (Fig. 4.2), the number of dolphins identified inside the nets and those observed around the vessels after completion of haul up (usually 10 to 50 after most trawls – unpub. data) seems relatively small. Aerial surveys of Shark Bay, WA, a similar sized area, provided a population estimate of around 3,000 bottlenose dolphins (Preen et al. 1997). If the bottlenose dolphin population using the Pilbara fishery was of comparable size to that in Shark Bay and they all interacted with trawlers, many more dolphins might be expected around trawl vessels. While fishing-related mortality may have reduced the number of dolphins in the PFTIMF, the small number of dolphins observed around trawl vessels and interacting with fishing gear suggests that there may be a separate 'trawler-associated' community within a larger population of unknown size. Chilvers and Corkeron's (2001) research comparing 'trawler' and 'non-trawler' dolphin communities found differences in group sizes and habitat preferences, and also that the communities were socially segregated. Genetic interchange was thought possible based on observations of alliances of non-trawler males interacting with trawler females. Whether or not this occurs in the PFTIMF is worth investigating as it has ramifications for the level of impact resulting from bycatch. If only a subset of the broader population interacts with trawlers, then the impact of anthropogenic removal of individuals is likely to be much higher on that subset.

Some identified dolphins foraging inside trawl nets in this study tended to do so alone, while others were always seen as part of a group. Five pairs of dolphins were seen in the net on two separate occasions each. One pair, suspected allied males, was observed during two different fishing trips. This might indicate that dolphins retain their foraging preferences when they interact with trawl nets, i.e. foraging alone or as part of an alliance versus swimming in a larger group. Earlier research on bottlenose dolphins foraging around trawl nets suggested that beneficial positions are held by dominant adult males (Corkeron et al. 1990). This was based on the observation of aggressive behaviours by large individuals toward females or sub-adult males and the apparent occupation of primary positions around trawlers to forage on discards in Moreton Bay, Queensland (Corkeron et al. 1990). Similar observations have been made in the Pilbara (pers. obs.) and this is further supported by this video footage review and the unequivocal bias toward biopsy sampling large adult males at the stern of the PFTIMF trawlers (Ch2 this study). The social hierarchies observed around trawlers may hold around trawl nets. Foraging inside nets, and therefore improved access to fish, may thus depend on a dolphin's, or alliance or group of dolphins', position within a social hierarchy.

Implications for reducing the fishing-related mortality of dolphins

The high spatial and temporal overlap between the fishing vessels and bottlenose dolphins in the PFTIMF suggests that (1) spatial or temporal fishing ground closures other than a broad effort reduction across the entire fishery would be ineffective in reducing dolphin bycatch, and (2) bycatch events are relatively rare compared to the observed interaction rates. Dolphins that associate with trawl nets in the Pilbara are strongly motivated to do so, and the majority of dolphins that enter the nets do so repeatedly, either within the same trawl, or during different trawls and fishing trips. Attempting to prevent these individuals from entering the nets, with pingers (acoustic deterrents) for example, is therefore not likely to be a successful mitigation strategy. The dolphins observed in this study appeared acutely aware of the trawl net's dimensions and frequently used the net to herd and catch fish against. They also showed no signs of hesitation in physically contacting the nets, either to aid in foraging, to trampoline, scratch their heads or other body parts on the mesh, or to interact with a dolphin on the other side of the net. It is possible that dolphins use a number of cues as signals to leave the net before it collapses during haul up, e.g. the increased revolutions of the vessel's motors to flush fish into the codend before haul up, or a change in water flow, pressure and ambient light associated with the hauling of the net.

Bycatch events are thus likely to occur when dolphins have insufficient time to leave the net before haul up, or if the fishing gear is dysfunctional, e.g. if one of the otter-boards falls over, the net will at least partially collapse. In some reviewed trawls, resighted animals occasionally remained in the net during haul up, leaving it only shortly before the net reached the surface and collapsed. These individuals never appeared to leave the net in a hurried fashion, but rather swam upward in a spiral-like fashion as the net approached the surface, catching fish that were flushed down the net by the increased water flow. Moreover, dolphins were never observed to display a startle reaction when large sharks or boulders of coral approached them in the net, often forcing the dolphins to touch the mesh. This provides further evidence of the level of confidence and control expressed by most dolphins inside the net and suggests that bycatch events may also typically involve naïve, young or otherwise inexperienced animals entering the net, being startled by an interaction with the grid and either becoming caught between the grid's bars or dying of asphyxiation upon failing to find an escape route.

Accordingly, mitigation of dolphin bycatch and mortality in the PFTIMF should focus on the development of more effective bycatch reduction devices, which consist of an exclusion grid and one or more escape hatches. Exclusion grids should be designed to prevent dolphins from backing down into the net extension and the codend, where the risk of entanglement and mortality is higher than in panels of the net that have a larger internal diameter. Escape hatches should be positioned in sections of the net where dolphins try to escape upon interacting with the grid. As all individuals observed in the 36 reviewed trawls were oriented in the direction of travel of the vessel and net, dolphins are likely to attempt swimming forward when coming into contact with the exclusion grid. The downward-opening escape hatch currently used in the fishery is therefore unlikely to be detected by stressed or panicking dolphins that try to swim away from the grid, either toward the vessel or to the surface. Accordingly, nets with the shortest possible distance between the exclusion grid and the head rope (where dolphins can freely swim to the surface) would be effective in reducing bycatch. Industry may also wish to further investigate their fishing operations to ensure that gear is maintained and functional – in the interests of both fishing efficiency and bycatch reduction.

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5. Chapter Five: Efficacy of exclusion grids in mitigating against bycatch in the Pilbara Fish Trawl Interim Managed Fishery of north-western Australia

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Abstract
Marine megafauna, such as large delphinids and sharks, fulfil key functional roles in marine systems. We assessed the species composition of six protected, listed or otherwise vulnerable taxonomic groups incidentally caught in the Pilbara Fish Trawl Interim Managed Fishery (PFTIMF). We also assess the efficacy of two different bycatch exclusion grids currently used in the PFTIMF. The number and escape rates of bycatch were recorded using underwater, in-trawl video footage of 44 trawls (22 with each grid design). A total of 86 individuals from 19 identified species of dolphin, shark, ray, sea snake, turtle and pipefish was captured. Over the 44 trawls, only 34% of all bycatch escaped or fell out the bottom-opening escape hatch, while the remaining 66% was retained in the net. Between one and two thirds of caught dolphins, large sharks and rays escaped or fell out of the escape hatch, while most sea snakes and all pipefish passed through the grids into the codend. The results also indicated that the older grid excluded significantly more bycatch of these species than the newer grid (50% and 24%, respectively, n = 22 trawls each). Some dolphins, sea snakes and sharks swam upward upon interacting with grids, indicating that grids should include an upward-opening escape hatch. Data from independent observer reports for the 44 trawls revealed that 77% of the landed bycatch was dead when discarded. Furthermore, the animals discarded alive may have low survival rates due to the risk of predation around the trawlers and other causes of post-trawl mortality. These results demonstrate the need for improved grid and escape hatch designs, in particular, top-opening escape hatches for air-breathing wildlife. The direct and indirect fishing-related mortality of non-targeted wildlife has been shown to be high in the PFTIMF and requires more effective mitigation.

5.1 Introduction
Large delphinids and sharks are apex predators that fulfil key functional roles in marine food webs, including prey control in numerous other mammals, elasmobranchs, teleost fishes and invertebrates (e.g. Kenney et al. 1997; Estes et al. 1998; Myers & Worm 2003). As such, they make vital contributions to the functional health of marine ecosystems worldwide. Various forms of fishing activity have removed largely disproportionate numbers of marine predators in all oceans, either as targeted species or as incidental bycatch (Jackson et al. 2001; Read et al. 2005; Myers et al. 2007). Mortality in fishing gear is now recognised as one of the most severe threats to many cetacean and shark populations, and therefore marine ecosystems, worldwide (Halpern et al. 2007; Read 2008).

The Pilbara Fish Trawl Interim Managed Fishery (PFTIMF) has an ongoing problem of dolphin bycatch, as well as the incidental capture of various other protected and listed species. The industry has a responsibility to demonstrate ongoing and successful bycatch reduction efforts in line with conservation regulations set by the Australian Environmental Protection and Biodiversity Conservation (EPBC) Act 1999. While efforts to minimise dolphin bycatch in the fishery are likely to have had a positive effect in reducing large shark and ray bycatch, the testing and implementation of several bycatch mitigation methods (including acoustic pingers and net modifications with various exclusion grid designs) has met with equivocal results to date. It remains unproven, for example, that less dolphins and large sharks and rays being landed on deck equates to lower numbers of these animals being harmed or killed when interacting with active trawl nets.

By assessing video footage of interactions between dolphins and other megafauna with exclusion grids and escape hatches and comparing this with observer reports detailing the catch composition of landed non-targeted species, the primary aims of this research were to: (a) assess the efficacy of exclusion grids currently used in the PFTIMF in reducing the fishing-related injury and mortality of dolphins and other marine megafauna; and, (b) make recommendations for future research and best practice management approaches to the mitigation of fishing-related mortality of dolphins and other megafauna.

5.2 Methods and Materials

Exclusion grids and escape hatches

Bycatch exclusion grids and escape hatches are fitted in all nets used in the PFTIMF to reduce the bycatch of dolphins, turtles, sharks and rays. The bycatch reduction devices currently used in the fishery consist of a semi-flexible metal grid and a bottom-opening escape hatch, through which large animals can leave the net. A loose skirt of netting to prevent the loss of target species covers the escape hatch. The exclusion grid is fitted at the start of the extension, where the net has a diameter of 100 meshes, and it is held upright by a number of floats. The grid lies at an angle with the float-equipped top section anterior to the lower section, so that bycatch and benthos are deflected down toward the bottom-opening escape hatch (Fig. 5.1).

The two grids assessed here include a larger grid with a horizontal cross-bar positioned at the beginning of the extension at a low angle (~40°), hereafter referred to as the 'old grid' (Fig. 5.1a), and a smaller grid implemented for testing in August 2009 lacking a cross-bar and positioned at a steeper angle (~70°), hereafter referred to as the 'new grid' (Fig. 5.1b). Both grid types feature vertical bars made of stainless tubing and central sections of braided stainless wire. While the old grid has five vertical bars spaced at 15.5 cm, the new grid has four vertical bars spaced at a distance of 15 cm from each other.

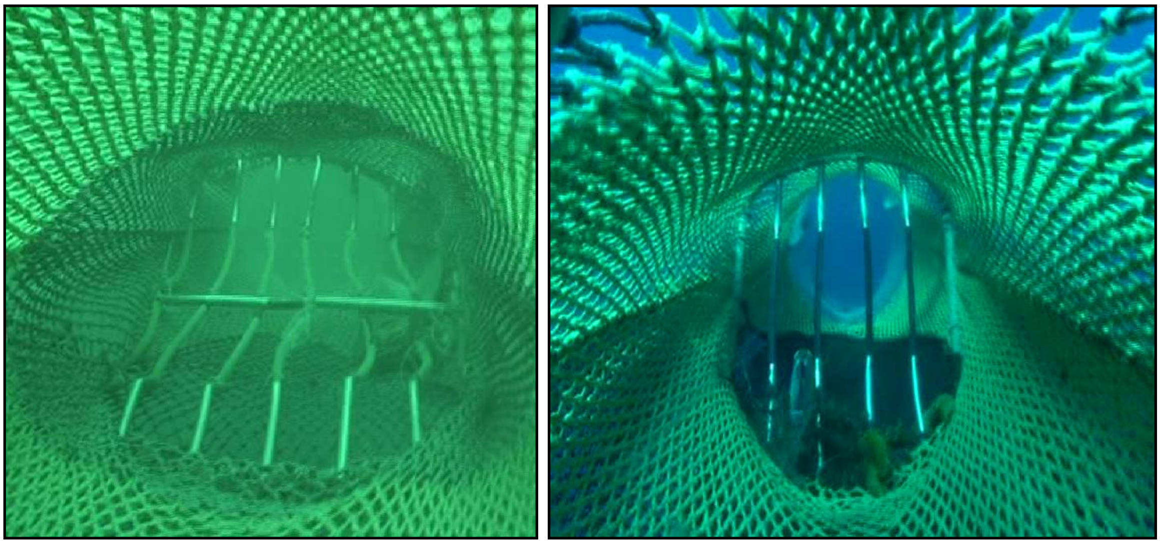

Fig. 5.1: Images from video showing the old grid (left) and the new grid (right).

Data collection

Underwater video footage of actively fishing nets was recorded during seven fishing trips between September 2008 and October 2009. An independent observer and fishers deployed video cameras in all four Management Areas of the fishery. Cameras were fitted inside the net extension, facing upstream toward the exclusion grid and escape hatch. Independent observers completed trip reports documenting the quantities of retained and discarded catch and information about each trawl. The observer reports were compiled to allow for a comparison of the number of animals that interacted with the exclusion grid and those that were landed.

Video footage
All cameras were set on 'standard definition' and 'long play' settings to maximise battery life. Some daytime trawls were recorded using day settings, but most trawls were recorded using the night vision setting to improve visibility at depth. On retrieval of the cameras, the movie files were transferred onto an external hard drive and labelled with date, trip number and trawl number.

Video analysis
Continuous sampling was used while reviewing the entire length of each trawl to ensure that all behavioural events associated with grid interactions of the focal wildlife species were recorded. A grid interaction was defined as any form of contact between these animals and the grid and/or the escape hatch. This included full contact of large animals (dolphins, large sharks and rays) with the exclusion grid, as well as brief physical contact between smaller animals (such as pipefish, sea snakes and some rays) and the grid bars.

To avoid a false estimation of the mortality rates, all individuals that left the net through the escape hatch or through the mesh were defined as 'escaped', while animals that remained inside the net to the end of the trawl were described as 'retained' (noting that this does not imply they were later retained by the fishers). Species identifications were made to the lowest taxonomic level possible.

Data analyses
Attribute and information data on the recorded grid interactions were exported from EventMeasure in text file format to Microsoft Office Excel. All categorical values were converted into numerical codes for subsequent analyses in the software package PASW Statistics v17. In order to obtain an estimate of the numbers of wildlife caught annually in the fishery, all grid interactions recorded during video analyses were scaled up by a factor of 120 (i.e. from 44 trawls to the approximate annual fishing effort of 5,280 trawls). It should be noted that this estimate has a high degree of uncertainty and provides only an approximation of the total number of wildlife interactions with the exclusion grids and escape hatches per year.

All identified species were categorised into six higher taxonomic groups, including: dolphins (Delphinidae), sharks (Selachimorpha), rays (Batoidea), sea snakes (Hydrophiidae), turtles (Cheloniidae) and pipefish (Sygnathidae). The proportion of caught individuals escaping or falling from the escape hatches positioned below the respective grids determined the efficacy of each grid (both as a percentage of the total wildlife interactions, and as the percentage of grid interactions of animals within each taxonomic group). A chi-square test of independence was used to test whether there was a significant difference between the proportions of animals that escaped or fell through the escape hatch in nets that were fitted with the old grid, compared to nets fitted with the new grid. No turtles or pipefish were recorded interacting with the old grid, so these two groups were excluded from this test.

5.3 Results

Video footage
A total of 115 hours of video footage from 44 trawls were analysed. The total trawl time of these trawls was 113 h and 23 min, with an average trawl duration of 2 h 35 min ± 8 min (range = 33 min to 3 h 38 min). A total of 86 wildlife (non-target species) interactions were recorded from 42 trawls; no interactions were observed during two trawls with the old grid. From those 86 grid interactions, six shark species, nine ray species and one species each of dolphin, sea snake, turtle and pipefish were identified. In addition to these animals, thirty-eight individuals that interacted with the grids could not be identified to species level.

Capture rates

The number and species composition of wildlife interactions with nets fitted with the old grid and new grids varied considerably (Fig. 5.2). Thirty-two grid interactions were observed in the 22 trawls with the old grid, compared to 54 interactions in the 22 trawls with the new grid. Of the three dolphins that were recorded, two interacted with the old grid and one with the new grid. More sharks were recorded caught during trawls with the new grid. Sea snakes also occurred in higher numbers interacting with the new grid. In contrast, more rays interacted with the old grid than the new grid. No pipefish or turtles were observed interacting with the old grid, but three pipefish and one turtle interacted with the new grid (Fig. 5.2).

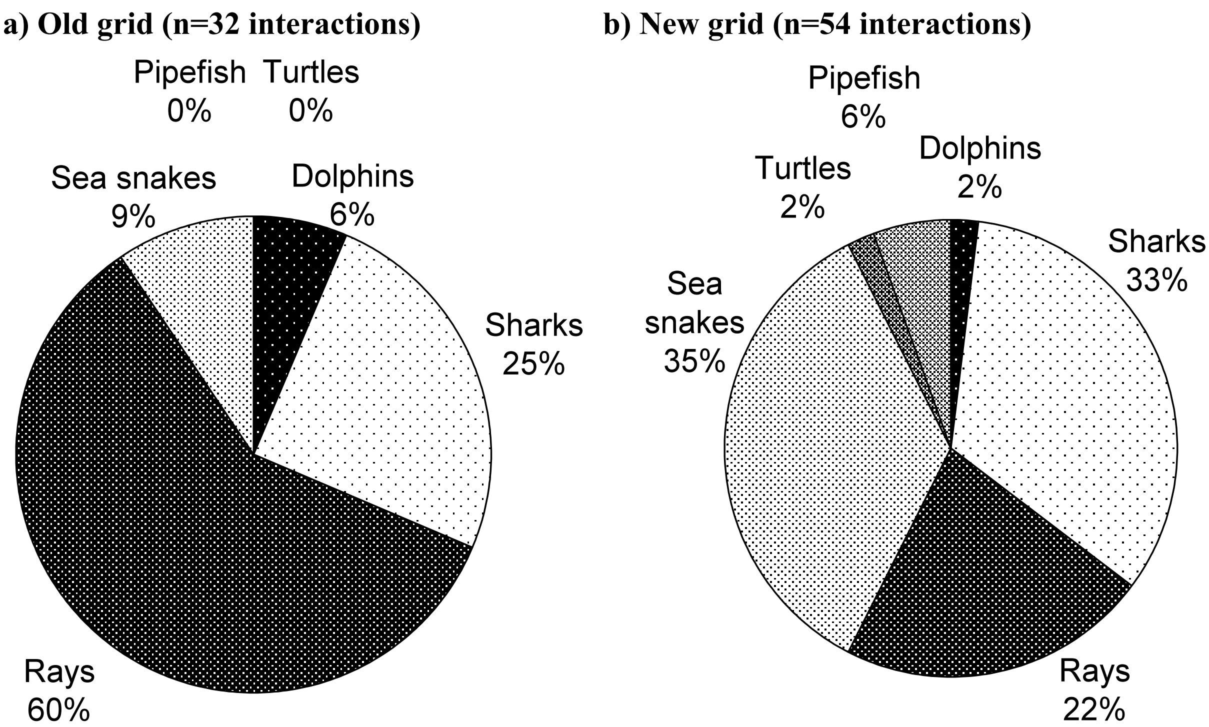

Fig. 5.2: The composition of wildlife interactions by taxonomic group with each grid.

Escape rates

More wildlife was excluded (either through actively escaping or falling out) from nets with the old grid (16 animals, 50%) than those with the new grid (13 animals, 24%; Fig. 5.3). The two caught but non-landed dolphins represented 6% and 8% of the total bycatch that fell motionless from the bottom-opening escape hatches in the old and new grid, respectively. Rays were the group that interacted most frequently with the old grid and they also represented the highest proportion of wildlife that escaped or fell from the nets fitted with old grids. Conversely, sharks comprised a majority of wildlife interactions with the new grid and represented the largest proportion of all animals that actively escaped or fell motionless from the new grid's bottom-opening hatch. However, a larger proportion of captured sharks escaped or fell from nets with the old grid than those fitted with the new grid. Three of the 19 sea snakes caught in nets with a new grid swam upward after coming into contact with the grid and escaped through the mesh (Fig. 5.3). The proportion of wildlife that escaped or fell through the escape hatches differed significantly between nets fitted with the old grid and those with the new grid ($\chi^2_3 = 56.74$, $p < 0.001$).

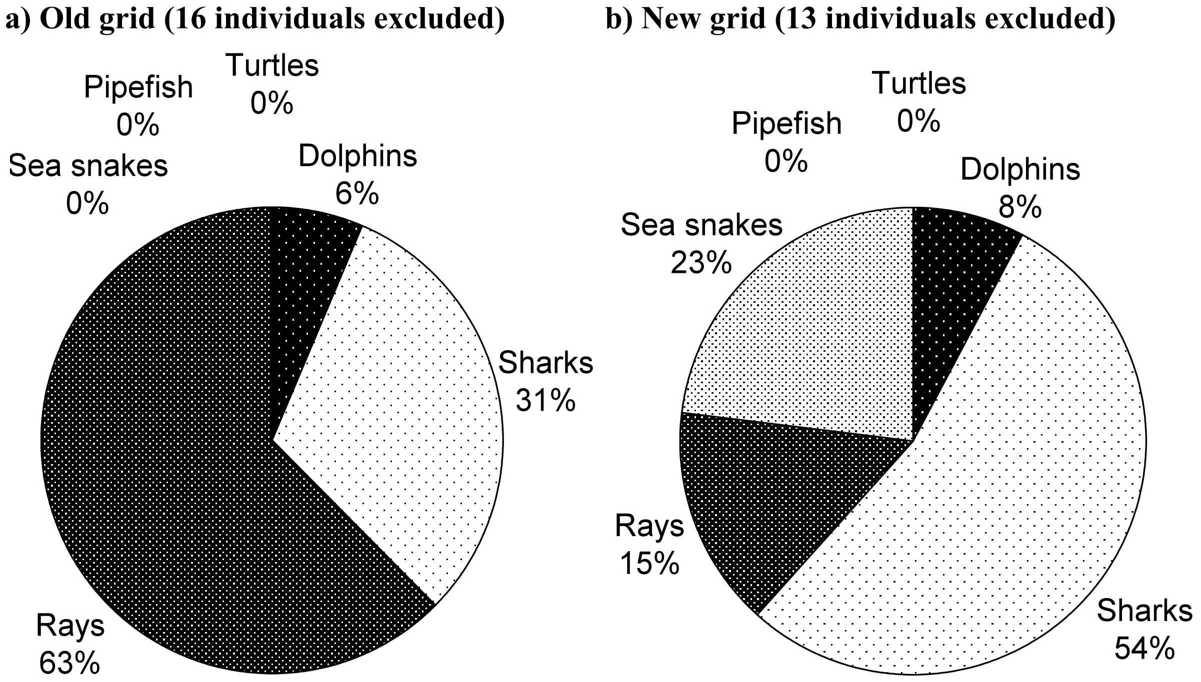

Fig. 5.3: Composition of wildlife excluded from nets fitted with old and new exclusion grids.

Observer reports

The data from observer reports illustrates the fate of animals retained in the net and landed on deck (Table 5.1). The analyses of 44 video-recorded trawls indicated that 66% of all caught wildlife was retained in the net and thus likely to be landed on deck. Of the 129 bycaught animals landed, 99 (77%) were discarded dead, while 30 animals (23%) were discarded alive. Taken together, the retention rate observed inside the nets (66%) and the mortality rate observed on board (77%) equates to a total mortality rate of around 51% for wildlife that is caught in trawl nets in the PFTIMF. This represents a bare minimum estimate, since some wildlife that falls out of the escape hatch is already dead, and a proportion of wildlife that is discarded overboard alive may then die through predation or other means.

Table 5.1: Landed bycatch reported by the observers from the 44 video-reviewed trawls.

Taxon	Total landed	Discarded alive	Discarded dead
Delphinidae (dolphins)	2	0	2
Selachimorpha (sharks)	66	6	60
Batoidea (rays)	53	18	35
Hydrophiidae (sea snakes)	5	5	0
Cheloniidae (turtles)	1	1	0
Sygnathidae (pipefish)	2	0	2
Total	**129**	**30 (23%)**	**99 (77%)**

5.4 Discussion

The results of this study suggest that bycatch reduction devices consisting of exclusion grids and bottom-opening escape hatches can reduce the catch of non-target species by around 34% in the PFTIMF. However, this equates to two thirds of non-targeted, bycaught wildlife being retained in nets. Furthermore, the efficacy of the two exclusion grids differs significantly. Although fishers reported that the new grid design noticeably reduced the loss of commercially valuable fish, this grid was not as effective as the old grid in reducing the number of landed dolphins, sharks, turtles and sea snakes. The most likely cause of this difference appears to be the lack of a horizontal bar across the vertical bars of the new grid. This permits some large rays and sharks (>1.5 m) to squeeze through the new grid and into the codend. A horizontal bar across the grid effectively halves the height of the gap between two vertical bars, making it much more difficult for a large animal to push through.

Furthermore, air-breathing animals and some sharks appear to respond to physical contact with the grid by swimming upward in the net. This reaction prevented at least one dolphin, a turtle and numerous sharks from locating the bottom-opening escape hatch, resulting in the death of the dolphin and likely injury to the turtle and sharks. The incidental capture of dolphins is of particular concern to this fishery as it currently prevents any move beyond 'interim' managed status and may well preclude Wildlife Trade Operation certification under the Environment Protection and Biodiversity Conservation Act 1999. This highlights the need for continued improvements of the bycatch mitigation techniques used in the PFTIMF.

Dolphins

DoFWA has documented interactions between dolphins and the PFTIMF since conducting a short assessment of bycatch in 2002 (Stephenson & Chidlow 2003). Since skippers and independent observers have been recording protected species interactions, the rate of dolphin captures has been 5.6 and 10.1 dolphins per thousand trawl shots, respectively, or approximately 30-60 dolphins per year (unpub. data). Almost all bycaught dolphins asphyxiate or drown in the nets and are dead when landed (Stephenson & Chidlow 2003; unpub. data). Even if captures of protected species are reported accurately by skippers and observers, a significant number of unobserved bycatch events may occur if dolphins fall out of trawl nets through the bottom-opening escape hatches. This study indicates that the number of dolphins falling out of the nets prior to being landed in the PFTIMF may be significant. A proportion of unrecorded dolphin deaths is further cause for concern for this fishery.

Another dolphin that was not detected on camera was landed on deck during the 44 video-recorded and observed trawls. This dolphin was caught by its tail in the head rope, suggesting that a combination of underwater video footage and observer coverage on board the vessels is required to accurately estimate the actual levels of dolphin bycatch in this fishery.

There remains no estimate of the population size of bottlenose dolphins in the waters off the Pilbara (either coastally or in the managed fishery areas). It is therefore not possible to determine whether the current level of dolphin bycatch in the PFTIMF is sustainable or not. A stock or population estimate would allow the Potential Biological Removal (PBR) of the dolphin population to be calculated. The PBR is an estimate of the number of individuals that can be removed from a population, not including natural mortalities, without affecting the population's ability to reach or maintain its optimum size (Wade 1998). Calculation of the PBR of the dolphin population that interacts with trawl vessels in the Pilbara would provide much needed direction to mitigation efforts.

Elasmobranchs – sharks and rays

Sharks and rays compose a high percentage of the total bycatch in the PFTIMF and the scaled estimates from the 44 analysed trawls suggest that <7,000 sharks and rays are caught annually by the fishery. A considerably larger proportion of sharks were expelled from nets with the old grid than from those with the new grid. The fact that large (>1.0m) sharks could pass, or actively swim, through the new grid suggests that the horizontal bar in the middle of the old grid plays an important role in excluding these larger animals from the codend. An additional factor contributing to the effectiveness of the grids in excluding larger sharks and rays seems to be the angle at which they are positioned in the net. The old grid was fitted at a lower angle than the new grid, which meant that large animals were guided toward the escape hatch.

The exclusion rates reported in this study are lower than those found in a study of bycatch reduction devices in Australia's Northern Prawn Trawl Fishery (NPF). Sharks and rays above >5kg were excluded most effectively, with high exclusion rates for large sharks (86%) and rays (94%), including the narrow sawfish (73.3%; Brewer et al. 2006). Unlike the Brewer et al. (2006) study, observer reports from the PFTIMF suggest that sawfish captures usually involve severe entanglement and that they rarely survive capture in fish trawl nets. Sawfish catches are of concern as this family has been overfished in many parts of the world and northern Australian waters host some of the last significant sawfish populations (Stevens et al. 2000, Brewer et al. 2006). Sawfishes are also listed as critically endangered on the International Union for the Conservation of Nature (IUCN) red list of endangered species. There are numerous PFTIMF observer accounts of sawfish being wound onto the net drum to facilitate their removal from the net (by breaking the rostrum or killing the individual). Thus, changes in fishers' behaviour may prove critical for improving the survival chances of sawfish caught in the PFTIMF.

Other elasmobranch bycatch included more than six shark species and ten species of ray. A large (~3m) hammerhead shark (*Sphyrna lewinii*) was seen in the net during haul up; it was already dead when it came into the camera's view and fell out of the escape hatch. Other shark and ray captures included leopard sharks (*Stegostoma fasciatum*), giant shovelnose rays and (*Glaucostegus typus*) and white-spotted guitarfish (*Rhynchobatus australiae*) - all listed as vulnerable on the IUCN red list. Near threatened species caught during this study were the manta ray (*Manta birostris*) and sandbar sharks (*Carcharhinus plumbeus*). Other than the green sawfish, none of these species are currently protected under the EPBC Act 1999 and some are not on the IUCN red list. This further highlights the need for improved bycatch mitigation strategies in order to advance conservation efforts for vulnerable apex predators.

Sea snakes

Sea snakes are susceptible to overexploitation by fisheries and frequently caught in demersal trawls (Wassenberg et al. 2001). They are protected under the EPBC Act and minimising the impact of fishing activity on sea snake populations should be another priority management objective. In this study, 19 sea snakes swam through the bars of the grid and into the codend. However, only five of these were landed on deck and all were reportedly released alive. Wassenberg et al. (2001) found that sea snakes caught in prawn trawls of 30 minutes duration had higher survival rates than those caught during longer trawls. They also found that 50% of all sea snakes landed alive during fish trawls on the North West Shelf died within four days of capture. This suggests that post trawl mortality is high and that approximately half of the sea snakes discarded alive in the PFTIMF might still die after being released. Fourteen percent of all captured sea snakes were observed escaping from the net in this study. While bycatch reduction devices designed for the release of fish, such as square-mesh windows, are most likely to allow sea snakes to escape from trawl nets (Wassenberg et al. 2001). Such measures should be considered for trials in the PFTIMF.

Turtles

Before the compulsory introduction of turtle exclusion devices, trawling caused high mortality rates in many populations of sea turtle species (Crowder et al. 1995). Although trawling no longer presents a serious threat to some sea turtle populations (Brewer et al. 2006), six of the seven extant sea turtle populations remain endangered due to their slow recovery rates (Harrington et al. 2005). The only turtle caught in a trawl net during this study (a flatback turtle – *Natator depressus*) was unable to swim through the bottom-opening escape hatch because it continually attempted to swim to the sea surface, pushing against the upper surface of the net. It fell through the opening when the net was hauled over the stern.

Upward-swimming behaviour in response to contact with the exclusion grid was not only observed in air-breathing bycatch (turtles, dolphins and sea snakes), but also in some sharks and rays. This points to the introduction of a top-opening escape hatch to offer upward-swimming animals an escape path. Top-opening escape hatches have been implemented successfully in England's pelagic bass pair trawl fishery to reduce the fishery's bycatch of common dolphins (*Delphinus delphis*; Northridge et al. 2003) and have greatly reduced the bycatch of sea turtles, large sharks and rays in Australia's NPF (Brewer et al. 2006).

Pipefish

Only three pipefish were recorded during video analyses in this study and all three swam through the bars of the grid and into the codend. Observers on board the trawl vessel recorded only one pipefish, which suggests that, like some sea snakes, pipefish may escape through the codend. To reduce the risk of bycatch, injury and mortality to pipefish caught in the PFTIMF, fisheye or square-mesh bycatch reduction devices (used elsewhere to reduce the bycatch of non-targeted teleost fishes) could be trialled. Pipefishes and other sygnathids (seahorses, pipehorses and sea dragons) have a number of life history characteristics, such as low fecundity, long parental care, mate fidelity and small geographic ranges, which make them highly vulnerable to the impacts of fishing activity. Australian waters host the world's highest diversity of sygnathids and many are protected under the EPBC Act and international legislation (IUCN red list, CITES Appendix II). Although poorly studied, trawling is likely to have a significant impact on a number of pipefish species (Martin-Smith & Vincent 2006).

Estimated survival rates

This research demonstrated that up to 66% of all non-targeted wildlife incidentally captured in the PFTIMF (albeit from a relatively small sample of trawls) are retained in the net and landed on deck. Of these, 77% were discarded dead and 23% were discarded alive. In terms of survival rates, these are likely overestimates as observer reports suggest that attacks from sharks and dolphins following discarding overboard may account for additional post-release mortality. This level of bycatch and lack of survivorship of bycaught wildlife indicates that improved bycatch mitigation is necessary. The level of impact that this is having is also impossible to determine without a better understanding of the basic ecology (e.g. abundance) of the populations being impacted upon.

Conclusions

The diversity and abundance of protected and vulnerable species bycatch is high in the PFTIMF. Bycatch reduction techniques should be further tested and implemented. Wildlife that is retained in the net and brought on board alive may die when returned to the sea as a consequence of injuries resulting from interaction with the fishing operation or from post-release predation. Further video and observer monitoring and the development of improved bycatch mitigation should be the highest of priorities. The collection of length/weight measurements of bycaught wildlife species by observers would form the basis for a detailed study on the biomass of bycatch in the fishery. This would lead to a more meaningful estimate of incidental captures than can be achieved by simply counting numbers of individuals and interactions. Furthermore, the ecosystem effects of high mortality rates of bycaught wildlife and the energy transfer of discards to predatory or scavenger species should be studied to advance our understanding of the impacts of trawling on the marine environment.

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Appendices

Appendix 1: Fieldwork in the Pilbara Fish Trawl Interim Managed Fishery (PFTIMF) October/November 2008 – Summary notes

CI Simon Allen joined one vessel's skipper and crew for a ten-day fishing trip in the Pilbara Finfish Trawl Interim Managed Fishery. This was followed shortly by a six-day voyage on another vessel and, finally, a half-day coastal journey through part of the Dampier Archipelago with a Fisheries officer.

Target species caught during trawler trips included red emperor, mangrove jack and crimson, saddletail, moses, five-band and brownstripe snapper (*Lutjanus sebae*, *L. argentimaculatus*, *L. erythropterus*, *L. malabaricus*, *L. russelli*, *L. carponotatus* and *L. vitta*, respectively), rankin cod (*Epinephelus multinotatus*), blue-spotted and spangled emperor (*Lethrinus hutchensi* and *L. nebulosis*), painted sweetlip (*Diagramma labiosum*), rosy threadfin and frypan bream (*Nemipterus furcosus* and *Argyrops spinifer*), plus various trevally (Carangidae), parrotfish (Scaridae) and perch species (e.g. *Glaucosoma buergeri*).

Discarded teleosts included triggerfish (Balistidae), lizardfish (Synodontidae), barracuda/pike (Sphyraenidae), some trevally (Carangidae) species and various angelfish (e.g. *Pomacanthus imperator*) and coral fish (e.g. *Chelmon rostratus*). The elasmobranchs caught during trawling included a tasselled wobbegong (*Eucrossorhinus dasypogon*), a juvenile sandbar and a juvenile oceanic white tip shark (*Carcharhinus plumbeus* and *longimanus*, respectively), several large guitarfish (Rhynobatidae) and an unquantified number and range of small carcharinids and rays. Also, as many as 20-30 sizable carcharinids were observed off the stern of the vessels during trawling and winch-up. Avian species foraging on discarded bycatch included: lesser crested and bridled tern (*Sterna bengalensis* and *anaethetus*, respectively), lesser frigatebird (*Fregata ariel*), brown and masked booby (*Sula leucogaster* and *dactylatra*) and wedge-tailed shearwater (*Puffinus pacificus*).

Protected species bycatch included one dolphin on one vessel (recorded and sampled by independent observer Gavin Kewan) and one dolphin recorded and sampled on board another vessel (by CI Simon Allen). Also, a juvenile grey nurse (*Carcharius taurus*) was caught. A number of turtles and sea snakes were observed free swimming, but no other protected species were caught.

A biopsy pole and a biopsy rifle for sampling free-swimming dolphins were both used during fieldwork. A total of 47 skin/blubber biopsies were collected (39 using the biopsy pole from the stern and bow of trawl vessels; six using the biopsy rifle from a small runabout; and the two from dolphin bycatch events). This brings the total number of biopsy samples from the fishery to 51 (four were kept from bycatch events in 2005 and 2006).

Despite some sources (e.g. old video footage – see appendix 2) suggesting that dolphins might interact with trawl operations as much as 67% of the time fishing operations occur, observations during this field trip indicate that the rate of interaction is higher still. Dolphins were observed around the net or the vessels during almost every active trawl shot and were also bow-riding at other stages (e.g. transit between winch-up and re-setting of nets). Several conversations with skippers and crew with regard to trawling techniques, the dolphin bycatch issue and the various mitigation measures trialled in the past five or six years revealed mixed feelings. There appear to be divergent opinions with regard to whether or not:

(a) The fishery will continue (dependent on the dolphin bycatch issue);
(b) Dolphin bycatch can be resolved or, in fact, has already been resolved; and,
(c) Dolphin exclusion grids are functional in reducing bycatch/maintaining target species catch.

Some fishers believe that exclusion grids reduce dolphin bycatch, but also reduce target species catch. Others believe grids do not reduce fishing efficiency and, indeed, that the grids and escape hatches are useful in reducing large shark/ray bycatch and ejecting large rocks, sponges, corals and other debris.

Finally, during a three-hour voyage through the Dampier Archipelago, a group of five Indo-Pacific humpback dolphins (*Sousa chinensis*) was observed in Withnell Bay. Conversations with local boaters and employees of various coastal development operations around Dampier suggest that Indo-Pacific bottlenose dolphins (*Tursiops aduncus*) and snubfin dolphins (*Orcaella heinsohni*) also frequent near-shore coastal waters of the Pilbara.

Appendix 2: Fieldwork in the Pilbara Fish Trawl Interim Managed Fishery (PFTIMF) March/April 2009 – Summary notes

CI Simon Allen and Honours student Vanessa Jaiteh travelled to Exmouth for a meeting with MGKailis managers and skippers. They then joined the skipper and crew on one vessel for a ten-day fishing trip to the PFTIMF. Halfway through the fishing trip, Simon transferred at-sea for a further three days onboard another vessel (Westmore Seafoods).

Onboard the first vessel, a new top-opening escape hatch-equipped net was trialled. Approximately ten tonnes of the usual target species were caught, including a variety of emperor and snapper species (*Lethrinus* and *Lutjanus* spp.), plus numerous trevally (Carangidae) and parrotfish (Scaridae). Discarded catch from trawling operations were dominated by triggerfish (Balistidae) and lizardfish (Synodontidae). Protected species bycatch included a number of sea snakes, but no dolphins.

Dolphins were present during almost all trawling operations; Thirty one (31) dolphins were biopsy sampled from one vessel; another eight (8) were sampled from the second vessel. This brought the total number of biopsy samples from within the fishery to 90 (with the original 51 collected in Oct/Nov 2008 being analysed for the purposes of this report).

Again, shipboard conversations with skippers and crew revealed that some fishers believe exclusion grids and escape hatches to be effective in reducing dolphin bycatch, but that they also reduce target species catch. Others believe grids and escape hatches do not reduce fishing efficiency, but that they are useful in reducing large shark/ray bycatch and ejecting rocks, sponges, corals and other debris.

Most skippers and crew are reluctant to continue trials of top-shooting escape hatches as they represent ‘just another hole for fish to escape’, but licensees/managers Gary Kessell (Westmore Seafoods) and Stephen Hood (MGKailis) both support future trials of the top-shooting escape hatches built into two nets by net-maker Hugh McKenna (Neptune Trawls).