Factors affecting cetacean bycatch in a New Zealand trawl fishery

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ABSTRACT

Incidental catch of cetaceans in commercial fisheries is a global phenomenon, occurring across a range of fishery types and affecting numerous species. In some cases such interactions have led to population declines, and may threaten viability of cetacean populations or species. In New Zealand, common dolphin (*Delphinus delphis*) bycatch often occurs during trawling for the commercial fish species jack mackerel *(Trachurus novaezelandiae*). Data gathered by New Zealand fisheries observers between the 2001/2002 and 2004/2005 fishing years (i.e. 01 October 2001 to 30 September 2005) were collated and examined to identify risk factors contributing to common dolphin bycatch in the jack mackerel trawl fishery. Exploratory analyses suggested that geographical area (represented by Fisheries Management Areas) had the most influence on dolphin bycatch. All observed bycatch events occurred in three out of eight Fisheries Management Areas. Using classification tree analysis, fishing depth emerged as an important predictor variable for dolphin bycatch during trawl tows for jack mackerel. Other potentially important predictors were total winch time and light conditions. Because of a large amount of missing data, extreme caution must be taken in generalising these results, but recommendations are made for future observer programmes and data management.

Keywords: classification tree analysis, common dolphin, *Delphinus delphis*, bycatch, trawl, jack mackerel, observer data, New Zealand

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1. Introduction

The incidental capture and mortality of marine mammals has been reported from a variety of fisheries globally, including trawl (Fertl & Leatherwood 1997; Morizur et al. 1999; Dans et al. 2003; Read et al. 2006), longline (Crowder & Myers 2002; Garrison 2003; Forney 2004), purse seine (Hall 1998; Archer et al. 2004), driftnet (Silvani et al. 1999; Barlow & Cameron 2003) and gillnet (setnet) fisheries (Shaughnessy et al. 2003; Dawson & Slooten 2005; Read et al. 2006). Despite several promising initiatives such as time/area closures (Dawson & Slooten 1993), take reduction plans (Bache 2001), changes in fishing practices and use of pingers (Barlow & Cameron 2003; Kaschner 2003), global bycatch of marine mammals is still thought to number in the hundreds of thousands (Read et al. 2006). The extent and severity of bycatch is such that it has been identified by several authors as the 'greatest immediate and well-documented threat to the survival of cetacean species and populations globally' (Reeves et al. 2005: 2).

Marine mammals can be captured on longline hooks, tangled in longlines, become ensnared (e.g. a fin or flipper caught) or completely enclosed in a variety of types of fishing nets (e.g. trawl or gillnet). Incidental catch has been implicated in the declines of several marine mammal populations, including Maui's dolphins (*Cephalorhynchus hectori maui*) (Pichler & Baker 2000), common dolphins (*Delphinus delphis*) (Bearzi et al. 2003), spotted dolphins (*Stenella attenuata attenuata*) and spinner dolphins (*Stenella longirostris*) (Gerrodette & Forcada 2005). In some cases, such as the vaquita (*Phocoena sinus*) (D'Agroas et al. 2000) and Hector's dolphin (*C. h. hectori*) (Slooten et al. 2000), the declines threaten the viability of populations or entire species. However, reducing bycatch does not necessarily guarantee that populations will recover (Gerrodette & Forcada 2005), and the ongoing potential for population declines is well recognised (Wilkinson et al. 2003).

The incidental capture of marine mammals in fisheries is, ultimately, a result of direct interaction with fishing gear. However, characteristics of fishing operations and gear, as well as environmental factors, can contribute to the likelihood of capture (Tregenza et al. 1997; Morizur et al. 1999; Smith & Baird 2005). For example, haulback procedures (the way in which trawl nets are retrieved) have been identified by several authors (Fertl & Leatherwood 1997; Morizur et al. 1999) as potentially important factors in cetacean bycatch. When trawl vessels stop hauling, the entrance of the net collapses, potentially trapping cetaceans that had previously entered the net. It has been suggested that these animals subsequently die if the net is kept in the water for a long period of time before being checked (Fertl & Leatherwood 1997). Given that no single mitigation measure is likely to eliminate cetacean bycatch, identifying which factors contribute to the likelihood of capture can lead to modifications of fishing practices or gear which may reduce capture risk (Hall 1998).

In New Zealand, confirmed captures of several species of cetaceans have been reported from trawl fisheries (Fertl & Leatherwood 1997). Reported captures include Hector's dolphins, which are globally classified as endangered (IUCN

2006). Common dolphins and dusky dolphins (*Lagenorhynchus obscurus*) have also been reported captured in trawl nets (Baird & Bradford 2000; Duignan 2003; Duignan et al. 2003a, b; Norden 2004; Duignan et al. 2004; Duignan & Jones 2005). There have also been reported captures of pilot whales (*Globicephala* spp.), bottlenose dolphins *(Tursiops truncatus)*, killer whales (*Orcinus orca*), and an unidentified beaked whale (Fertl & Leatherwood 1997). More recently, 6 long-finned pilot whales (*Globicephala melas)* were caught in jack mackerel (*Trachurus novaezelandiae*) trawls off the west coast of the North Island during the 2005/2006 fishing year (DOC/ Ministry of Fisheries, unpublished data).

In this paper, we examine operational fishing practices and environmental conditions that may affect the incidence of common dolphin bycatch in the jack mackerel trawl fishery operating off the west coast of New Zealand's North Island. Reported capture events of dolphins tend to be spatially and temporally clumped (Norden 2004), and the numbers of dolphin mortalities have prompted the New Zealand government to work cooperatively with fishing companies to identify factors that contribute to bycatch and fishing practices that may reduce captures.

2. Methods

2.1 FISHERY

Trawling was undertaken for jack mackerel in eight Fisheries Management Areas (FMAs) in New Zealand waters in the 2001/2002 to 2004/2005 fishing years (Fig. 1). A 'fishing year' begins on 01 October and runs through to 30 September of the following year, so in this study, data cover the period from 01 October 2001 through to 30 September 2005.

Fishery observers have accompanied commercial fishing vessels in New Zealand waters since the 1980s, and collect catch effort data, biological information and other information related to the Quota Management System. Observers may also gather information on protected species bycatch, which can assist government agencies in quantifying such problems and understanding the circumstances that contribute to these captures. Observer data from trip reports, observer diaries, debrief forms, and non-fish bycatch forms were collated and examined to obtain data on dolphin capture rates (the dependent or response variable), and on operational factors considered to potentially influence dolphin capture rates (the independent or explanatory variables). Data were collated both at the level of the trip (where dolphin captures would be expressed as a proportion of the number of jack mackerel tows on the trip), and at the level of the tow (i.e. a trawl event; where dolphin captures were expressed as number of dolphins caught on each tow, or as capture/no capture on each tow). Data were collated at the two different levels because data for some variables were not usually available at the level of the tow, whereas other variables (for example, phase of the moon) were not meaningful at the level of the trip.

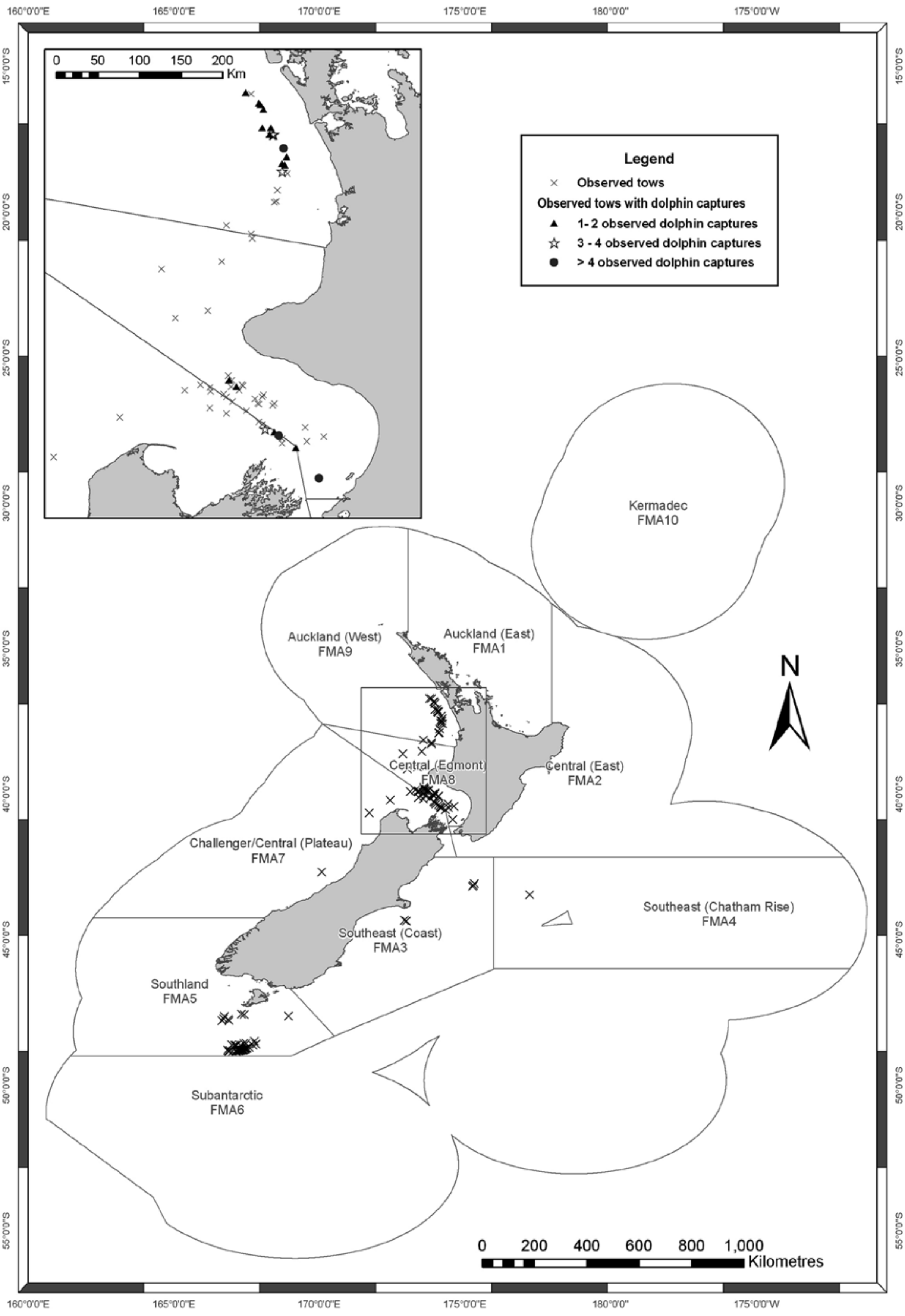


Figure 1. Map showing Fishery Management Areas (FMAs), location of observed tows, and location of observed dolphin captures during this study.

2.2 DATA ANALYSIS

Relationships between the independent variables and capture rate (dependent variables) were explored one variable at a time, by comparing dolphin capture rates under different levels of each indpendent variable. Correlations between independent variables were also explored.

A classification tree was constructed using Answer Tree 3.1 (implemented in SPSS v13; SPSS Inc., Chicago, USA), to determine which independent variables had the most power to predict how many dolphins were caught in a tow. The exhaustive chi-squared automatic interaction detection (exhaustive CHAID) was implemented as the analysis algorithm. CHAID provides a summary diagram (the classification tree) that shows the predictor categories which make the most difference to the response variable (in this case, the number of dolphins caught per tow). The classification tree shows those predictor variables that have the strongest influence on the outcome. A key strength of classification trees is their ability to deal with missing data. The nature of the output clearly differs from a logistic regression, but is well suited to the goal at hand; which is to investigate which factors might be more likely to result in dolphin bycatch. In comparison, a logistic regression seeks to provide an equation for prediction of the selected outcome.

3. Results

3.1 OBSERVER DATA

A total of 877 out of 10 859 tows were observed on 25 trips in 6 FMAs during the course of this study (Table 1). Observer coverage (i.e. the percentage of tows observed) in these six FMAs ranged from 4% to 27% (Table 1). Fishing occurred in every month of the year, but December, June and October were the months with the most trawls (Table 2), and most of these were in FMAs 7, 8, and 9 (Table 2 and Fig. 1). Observed fishing occurred in every month except June, but the bulk occurred from October to December (Table 2).

Mid-water or bottom trawl nets were set to fish for jack mackerel either 24 h/day or jack mackerel were targeted at night only and other species targeted during the day. Mid-water trawl nets could be set to fish on the sea floor or in mid-water, and most tows lasted between 1 h and 5 h.

3.2 OBSERVED BYCATCH EVENTS

On 18 out of 25 trips with observers present, there were no dolphin bycatch events. Three trips caught 1 or 2 dolphins, while 4 trips caught between 3 and 20 dolphins. A total of 55 dolphins were incidentally caught during observed trawls (Table 3), with just two vessels accounting for 90% of dolphin captures. In one case, species identification was not possible. All other incidentally caught dolphins were common dolphins.

TABLE 1. OBSERVER COVERAGE BY FISHERIES MANAGEMENT AREA.

Number of tows targeting jack mackerel in each Fisheries Management Area during the combined fishing years 2001/2002 to 2004/2005, number of tows observed and the percentage coverage by observers. (Note: FMAs 7 and 8 are combined because of occasional uncertainty in which area a tow had occurred.)

FMA	OBSERVED TOWS (*n*)	TOTAL TOWS (*n*)	COVERAGE (%)
1	0	8	0.00
2	0	9	0.00
3	62	525	11.81
4	11	55	20.00
5	172	819	21.00
7/8	338	7830	4.32
9	294	1088	27.02
Total	877	10859	

TABLE 2. OBSERVER COVERAGE BY MONTH.

Number of observed tows targeting jack mackerel (all FMAs combined) in each month during the combined fishing years 2001/2002 to 2004/2005, total number of tows in each month and the percentage observer coverage by month.

MONTH	OBSERVED TOWS (*n*)	TOTAL TOWS (*n*)	COVERAGE (%)
Jan	15	557	2.69
Feb	43	68	63.24
Mar	69	410	16.83
Apr	152	745	20.40
May	55	711	7.74
Jun	0	2021	0.00
Jul	10	703	1.42
Aug	20	226	8.85
Sep	30	251	11.95
Oct	163	1440	11.32
Nov	176	665	26.47
Dec	144	2537	5.68

3.3 RELATIONSHIPS BETWEEN INDIVIDUAL FACTORS AND DOLPHIN CAPTURE EVENTS

Bycatch events occurred only in FMAs 7, 8 and 9 (Table 3). Specifically, trawls that caught dolphins were clustered in two general areas: off the west coast of the North Island from south of Kaipara Harbour entrance to north of Raglan Harbour, and in Cook Strait to the north and northeast of the Marlborough Sounds (Fig. 1).

The highest capture rates occurred in May (Fig. 2). However, the majority of tows in the three FMAs during this month occurred on only one trip, and on a vessel which had a particularly high bycatch-rate during the study period.

Most dolphin captures occurred during mid-water trawls, and predominantly during dark conditions of little or no moonlight (Fig. 3). Bottom trawls, all

TABLE 3. NUMBER OF DOLPHINS OBSERVED AS INCIDENTALLY CAUGHT BY YEAR, TRIP NUMBER AND FMA. THERE WERE NO DOLPHIN CAPTURES IN THE 2001/2002 FISHING YEAR.

FISHING YEAR	TRIP NUMBER	FMA	NUMBER CAUGHT
2002/2003	1697	8	1
	1765	7	13
	1765	8	7
2003/2004	1847	8	1
	1847	9	14
	1985	9	2
2004/2005	2004	9	3
	2005	9	12
	2006	9	2

of which occurred during daylight, did not capture any dolphins; however there were five cases for which it was not recorded if the tow was mid-water or bottom.

In Answer Tree 3.1 (implemented in SPSS v13; SPSS Inc., Chicago, USA), the response variable used was number of dolphins caught per tow, and explanatory variables used were: month group (April–May, Jul–Oct, Nov–Jan); FMA; daylight or moonlight (dark: no moonlight, dark: some moonlight, daylight); bottom trawl/mid-water; headline height (the height at the entrance of the net); net spread (the width between the net doors, at the entrance of the net); winch time (to doors; i.e. the time from when winches start hauling the net to when the doors of the net are on the deck); total winch time (time until the codend of the net is on deck); and fishing depth.

The resulting classification tree (Fig. 4) consists of a parent node (node 0) and a number of child nodes. In each node, the two most relevant results

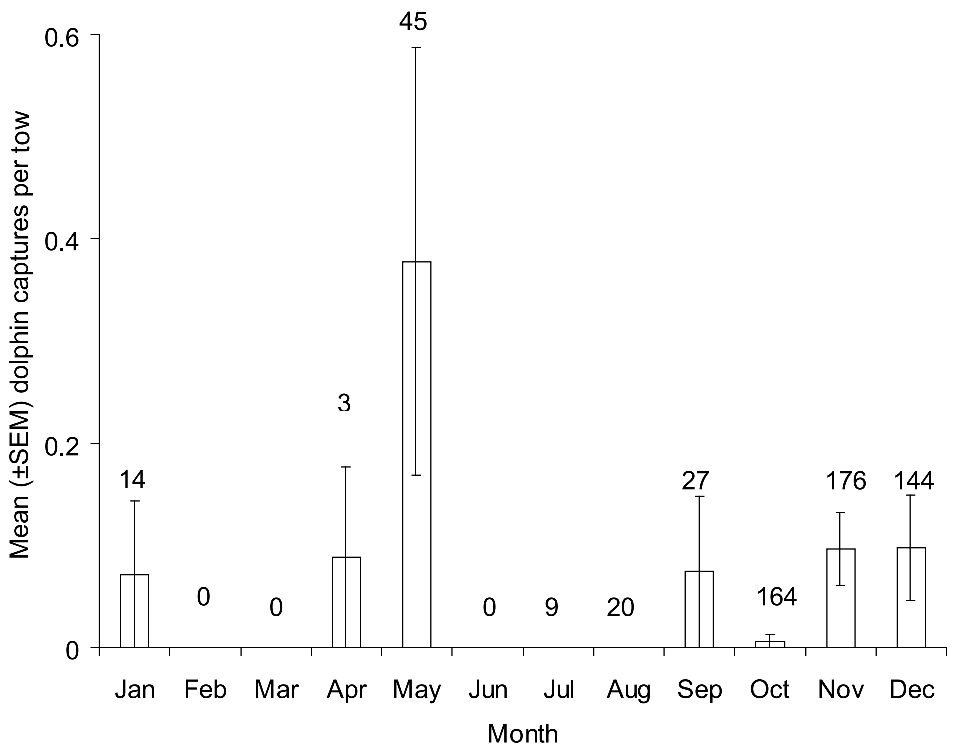
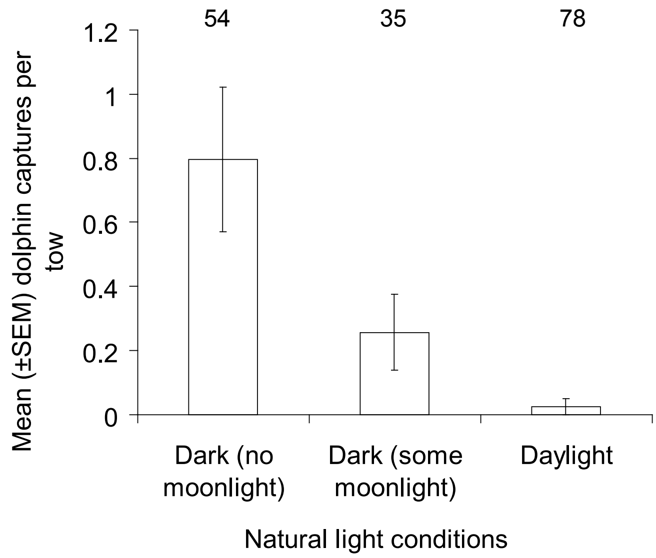


Figure 2. Mean (± SEM) dolphin captures per jack mackerel tow for each month. Numbers above bars show sample size (number of observed jack mackerel tows in FMA 7, 8, or 9).

Figure 3. Mean (± SEM) dolphin captures per jack mackerel tow according to the estimated predominant natural light conditions during the tow. Numbers above bars show sample size (number of observed jack mackerel tows in FMA 7, 8, or 9).



are the 'mean' and 'n'. The 'mean' in this case refers to the mean catch rate of dolphins per tow, and the 'n' is the number of tows falling under the classification of that particular node. For example, in Fig. 4, node 29 represents the tows where fishing depth is less than or equal to 115 m. The mean catch rate for this node is 1.2727 dolphins/tow, and there were 33 tows at a fishing depth equal to or less than 115 m. Thus, there were $1.2727 \times 33 = 42$ dolphins caught at fishing depths equal to or less than 115 m. Also given is the percentage of cases that fall into each node. As the tree expands, the percentage values for nodes on each successive branch will not sum to 100. Instead, they will sum to the percentage value of the node from which that particular branch has split. For example, the percentage values for nodes 29–32 (fishing depth) sum to 100, because that represents the first split in the classification tree. Whereas nodes 39–41 (winch time) have split from node 32 and, therefore, will sum to 93.24%.

The classification tree identified fishing depth as the most important predictor of dolphin bycatch (Fig. 4). Out of a total of 55 dolphin captures, 42 occurred at fishing depths equal to or less than 115 m. A further 9 occurred at fishing depths between 115 m and 184 m. There were four dolphin captures occurring on two separate trips and tows for which fishing depth was not recorded. In one bycatch event which accounted for two dolphins, total winch time was the next most important factor, with the bycatch occuring when total winch time exceeded 24 min. The remaining bycatch event (accounting for the final two dolphin captures) did not have winch time recorded, and light conditions were the strongest predictor variable, with the bycatch occuring during darkness (no moon).

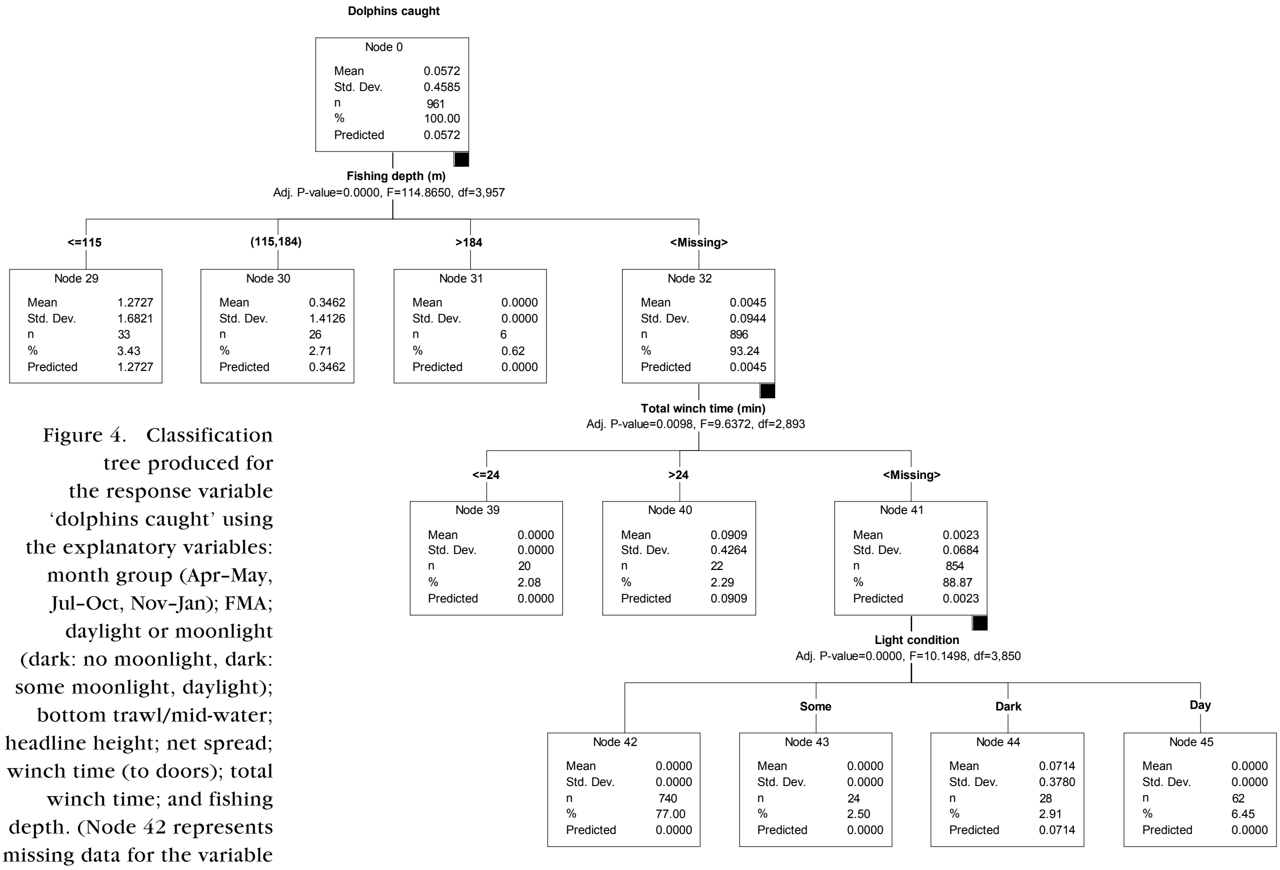


Figure 4. Classification tree produced for the response variable 'dolphins caught' using the explanatory variables: month group (Apr–May, Jul–Oct, Nov–Jan); FMA; daylight or moonlight (dark: no moonlight, dark: some moonlight, daylight); bottom trawl/mid-water; headline height; net spread; winch time (to doors); total winch time; and fishing depth. (Node 42 represents missing data for the variable 'light condition'.)

4. Discussion

Dolphins were only caught off the west coast of the North Island and in Cook Strait, despite a number of jack mackerel tows also occurring off the south, west and east coasts of the South Island. However, there was no evidence that dolphin capture risk differed among the three FMAs where captures did occur. There was also no evidence that capture risk changed with time of year. Most captures occurred during mid-water trawls. Elsewhere in the world, mid-water trawls are thought to be more likely to catch cetaceans than bottom trawls (Fertl & Leatherwood 1997). Possible reasons include: mid-water trawls tending to target smaller, pelagic fish species which may also be prey for cetaceans; mid-water trawls often being towed faster (which may result in higher bycatch as animals have less time to escape the net); and finally, pelagic trawl nets often having greater overall dimensions than bottom trawl nets, which makes them likely to catch more animals.

The classification tree suggests that fishing depth is a key factor in determining whether dolphins will be caught during jack mackerel tows. However, because of the large amount of missing data (i.e. variables not recorded for a particular trip or tow), extreme caution must be taken when extrapolating from such results. Additionally, it is not possible to distinguish between the depth at which bycatch may have occurred and the depth of the actual tow.

One common problem with the observer data is that many variables were not recorded when no dolphins were caught. This creates a serious limitation in the dataset. While it may seem that these data are not as important as those from when there were dolphin captures, this is not the case. Because of those missing data, there is very little potential for comparison of variables for tows with bycatch, and tows without.

Using fishing depth as an example, there are just 65 tows out of a total of 961 for which depth is recorded. Many of those were tows where dolphin bycatch occurred. That leaves 896 tows for which fishing depth was not recorded, and very few comparisons of tows with fishing depth recorded that caught dolphins, versus those for which depth was recorded and dolphins were not caught. The first split in the classification tree may have been quite different had those depths been recorded. Similarly, looking at subsequent splits in the tree, there were 854 tows for which total winch time was not recorded, and 740 tows for which light conditions were not recorded and could not be determined post hoc.

The key result for the main objective of investigating factors which result in dolphin bycatch is that there is a strong geographical component to bycatch risk: all dolphin captures occurred off the west coast of the North Island and in Cook Strait. Unfortunately, because of the missing data, it would be unwise to draw strong conclusions with regards to the influence of fishing depth, total winch time and light conditions.

Other studies have encountered similar difficulties in isolating operational and biological factors that may contribute to cetacean bycatch. For example, Morizur et al. (1999) did not identify any operational factors in northeast Atlantic pelagic trawl fisheries that correlated clearly with bycatch. Dolphin bycatch occurred only at night, possibly because dolphins are more likely to feed or scavenge around trawl nets during night trawls to avoid competition with other scavenger species such as seabirds. The authors did not feel that enforcing daytime-only trawling was practical (Morizur et al. 1999).

5. Conclusions

The biological implications of common dolphin bycatch in New Zealand are unknown and difficult to determine on the basis of current information. There are no abundance estimates available for common dolphins in New Zealand waters, and distribution is not well documented, though is likely to be influenced by prey (Neumann & Orams 2005). Common dolphins are considered globally abundant; however, several regional populations are thought to be in serious trouble, often as a result of incidental and directed bycatch (Reeves et al. 2003). In addition to documented bycatch in trawl fisheries, common dolphins in New Zealand also appear to be vulnerable to bycatch in coastal recreational gillnets (K. Stockin, Massey University, pers. comm., April 2006). Given this situation, the commercial bycatch events such as those documented here cannot be considered in isolation, and must be treated as one of a number of non-natural sources of mortality. In the absence of abundance data, the goal should be to undertake a more rigorous investigation of factors which may lead to bycatch, and to develop mitigation techniques to reduce common dolphin bycatch in New Zealand waters. Given the problems already identified with current observer data and the high importance of resolving these issues, this would probably require a collaborative effort between DOC and the Ministry of Fisheries.

6. Recommendations

Observer programmes and investigations of operational factors that lead to bycatch have the potential to provide useful guidance to managers (NMFS 2004; Hamer & Goldsworthy 2006). However, such guidance can only come as a result of robust statistical analysis, and for this to occur, data quality needs to be high, and observers need to be encouraged to record all data on observer programme forms. Despite the outlined data deficiencies, useful recommendations can be made based on the results of this study:

- The problems caused by missing data highlight the need for early exploratory data analysis. Such analyses may provide reassurance that data are being collected in an appropriate manner, or highlight problems that can be rectified for subsequent data analysis.
- A database should be created for recording and storing observer programme data. A well-designed database would allow data gaps to be quickly and easily highlighted, summary reports generated and subsets of data exported to spreadsheet or statistical software packages.

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