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Update on New Zealand dolphins and fisheries

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SUMMARY

New information on dolphin distribution and the spatial distribution and intensity of fishing effort was used to provide Kernel Density maps of dolphins and fishing effort. Considerable overlap remains between NZ dolphins and fishing methods that cause dolphin mortality (gillnets and trawling). Bycatch is highly clustered and has had a strong influence on current dolphin distribution. To date, line-transect population surveys have been of insufficient intensity to adequately assess abundance in low density areas. Bycatch is also difficult to detect, especially in small dolphin populations, due to very low observer coverage (typically below 5%). Taken together, these two factors make it difficult to accurately estimate risk for small populations of NZ dolphins, including the North Island subspecies Maui dolphin. Insufficient information is available about other potential threats to NZ dolphin, including pollution, marine mining and disease, to quantify their impact. At this time, bycatch is the only impact for which the level of mortality is quantifiable and for which an effective solution is available. Over the last 40 years, high levels of fishing effort and overlap between dolphins and fishing have caused a substantial population declines and population fragmentation. In two populations, Maui dolphin and the Hector's dolphin population at Banks Peninsula, an increase in survival rate has been detected following partial protection.

INTRODUCTION

New information on dolphin distribution and updated information on the distribution and intensity of fishing effort is used to provide an update on the overlap of New Zealand (NZ) dolphins with gillnet and trawl fisheries. The endemic species *Cephalorhynchus hectori* consists of the subspecies Hector's dolphin *Cephalorhynchus hectori hectori* and Maui dolphin *Cephalorhynchus hectori maui.* Here we use the term NZ dolphin to describe the species as a whole.

The most recent surveys of Hector's dolphin, funded by Fisheries New Zealand (a division of the NZ Ministry for Primary Industries, MPI), were conducted during 2013-2016 (MacKenzie and Clement 2014, 2016; Cooke et al. 2018). These surveys resulted in lower population estimates than previous line-transect surveys (Dawson et al. 2004; Slooten et al. 2004, 2006) in all areas except the east coast of the South Island, where the most recent estimate was about five times higher than the previous estimate. This large difference is partly explained by the much greater offshore extent of the latest survey compared to the previous survey – 20 nautical miles (nmi) compared to 4 nmi offshore. Issues with field protocols and analysis methods may also have contributed to the very high population estimate off the east coast of the South Island. For example, model "blow outs" resulted in extremely high population estimates from some of the models, and issues with field protocols such as incomplete overlap between observers and issues with identifying duplicates. For a discussion of these issues, see IWC (2016).

The apparent population decline, indicated by comparing the most recent two abundance estimates was consistent with predictions from Population Viability Analyses (Slooten 2007; Slooten and Dawson 2010), which have been updated using the most recent abundance estimates (Slooten and Dawson 2016). A relatively recent (since 2001) development in information on gillnet and trawl effort is the routine recording of latitude and longitude. This allows for more detailed spatial analysis of the overlap between dolphins and fishing.

MATERIALS AND METHODS

Sightings from line transect population surveys were mapped in ArcMap (v. 10.16; ESRI). We used fixed Kernel density estimates (KDe; Worton 1989) to investigate the distribution of Hector's dolphins. Sightings data for each region were pooled from separate aerial surveys conducted by the Marine Mammal Research Group, University of Otago (Dawson et al. 2004; Slooten et al. 2004) and from surveys commissioned by MPI (Clement et al. 2014, 2016). Data on survey effort, in the form of on-effort survey tracks, were available for each survey. Effort data were summarised as km of survey effort in each of the survey strata for each region. Strata were either inshore (<4nm of coastline) or offshore (<20 nm of coast) for each survey area. As survey effort was not apportioned equally among strata (typically, inshore strata had far greater survey effort), we weighted each sighting according to the amount of effort (km of survey line on effort, per km^2 of survey area). Therefore, sightings made in survey strata with low effort had a higher weight than sightings in survey strata with high survey effort. This ensures that density values are comparable. KDe analyses of weighted sightings were performed on a 2x2 km grid in ArcMap (v. 10.16; ESRI). The bandwidth value for each regional KDe was calculated using a least squares cross validation approach in package adehabitatHR (Calenge 2015) in *R* (R Core team 2019).

Kernel density estimates for Maui dolphin come from an individual-based model (de Jager et al. 2019). For each run of the model, simulated movements were compared with field data. The resulting Goodness-of-Fit estimates were used to calibrate the model. The number of 1 kilometre moves per hour varies for each dolphin and every hour in the model. The number of moves per hour follows a Poisson distribution which the scaling exponent μ. This resulted in movements that approximate a Weibull distribution, resulting in a very good fit to the field data. The dolphins' depth preferences follow a sigmoid function: $(1 + 0.01^{1-d/\delta})^{-1}$ where d is water depth (in metres) and δ is the depth-preference exponent. We used a simple step function for the dolphins' schooling preference, with dolphins moving to a new location at each time step with preference = 1 if there are no dolphins present and $1+ \sigma$ if there are other dolphins present in the new location. After calibration, the best fitting parameters were: Movement exponent $\mu = 5.1$, depth preference $\delta = 50$, home range exponent $\eta = 27.5$ and schooling preference $\sigma = 322$. More information about this model is available in de Jager et al. (2019).

To plot the distribution of commercial setnet and trawl fisheries, KDe analyses were undertaken on fishing events data provided by MPI. Data on the locations of setnet and trawl events were available for two periods: 2001 – 2008 and 2009 – 2017, before and after the last change in protection measures (implemented late 2008). It is important to note that effort data are incomplete – they do not cover all fishing events. This is particularly so for the earlier dataset in which approximately 30% of vessels routinely reported effort data including latitude and longitude. KDe analyses were carried out to determine any regional hotspots of fishing effort. Additionally, to allow an appraisal of hotspots in fishing pressure throughout NZ dolphin habitat, KDe analyses were conducted on fishing event data pooled throughout the dolphins' range. Like the analyses of dolphin distribution, KDe was carried out on a 2x2 km grid and bandwidth selection following a least squares cross validation approach (Calenge 2019).

Fishing effort data from 1983 onwards were available from MPI, at the level of statistical areas (Figure 1), for both gillnet and trawl fisheries. Before 1983, only data on catches and number of vessels are available. New Zealand's total marine catch (deepwater and inshore) was approximately 30,000 tonnes per year in the 1950s and increased to about 58,000 tonnes per year until the mid-1970s (FAO 2018a). Rapid growth in the late 1970s saw the inshore finfish catch rise from 14,000 tonnes in 1975 to 129,000 tonnes in 1981. This quantity was unsustainable and the overfished stocks crashed in the 1980s (Walrond, 2006; MPI 2017). Overall catch increased steadily until the late 1990s, with a peak in 1997 and 1998 of nearly 650,000 tonnes. The catch has since gradually declined to less than 450,000 tonnes a year (FAO 2018b). These figures are biased low due to underreporting (Simmons et al. 2016)

Uncertainty in the risk to NZ dolphin is high, due to low observer coverage. Although many other catches are reported, most of the observed catches come from an observer programme that was carried out in the late 1990s (Baird and Bradford 2000, Starr and Langley 2000). Video monitoring on gillnet vessels has demonstrated that Hector's dolphin bycatch can be recorded by video cameras (e.g. McElderry et al. 2007; MPI 2013b). Expanding observer coverage, through a combination of human observers and video monitoring would help to reduce uncertainty in the bycatch estimate (MPI 2017).

Since 2001, MPI has collected latitude-longitude data for gillnet and trawl fisheries. The proportion of fishermen who provide these more detailed data has increased gradually over the years. Additional data on the total amount of fishing effort from 2002 onwards are available publicly from Dragonfly Consulting (2019).

The first records of gillnet bycatch of NZ dolphin date back to the 1970s. Interviews of fishers (Dawson 1991) and dissections of dolphins they provided (Slooten 1991; Slooten and Lad 1991) established that gillnet bycatch was a serious problem. The first observer programme dedicated to quantifying bycatch was carried out in the 1997-1998 fishing season, with observer coverage of 42% (Baird and Bradford 2000). Subsequent observer programmes have had much lower observer coverage, but have resulted in comparable capture rates.

Trawl bycatch is less well understood than gillnet bycatch. Nineteen trawl mortalities of Hector's dolphins have been officially reported (MPI 2017; DOC 2019), with one of the earliest reports dating back to 1973 (Baker 1978). However, MPI only use observer data in their estimates of catch rate and total bycatch (MPI 2017). Due to very low observer effort, only one trawl bycatch has ever been observed, in the first observer programme in 1997-1998 (Baird and Bradford 2000). Therefore, the estimate of bycatch in NZ trawl fisheries is based on one NZ dolphin caught in 1998.

RESULTS

The sightings data match water depth much more closely than distance from shore (Figure 2). NZ dolphin sightings extend to the full 20 nmi offshore extent of the population surveys in relatively shallow waters, such as the areas north and south of Banks Peninsula off the east coast of the South Island. Sightings are concentrated much closer to shore in areas with steeper depth contours, such as the west coast of the South Island. A small number of sightings were made in waters > 100 m deep, however such sightings are relatively rare in areas where survey effort extends well beyond the 100 m depth contour (Figure 3). Dolphin density is highly uncertain in areas where the 100 m depth contour is well beyond the 20 nmi offshore extent of the surveys, as indicated in Figure 3.

Kernel density plots of dolphin distribution (Figure 4) suggest that dolphins are absent or at very low densities in areas like Otago and the north coast of the South Island. However, small-boat surveys have consistently found dolphins in these areas (Figure 2). As expected, line transect surveys optimised for estimating abundance provide relatively poor information for low-density areas. The level of survey effort required to provide accurate dolphin densities and offshore distribution in low density areas is very high for a line transect survey (Slooten et al. 2004). Photo-ID surveys from small boats are better suited for research on abundance and distribution in low-density areas. For example, photo-ID mark-recapture estimates for the Otago population (red dots at the south-eastern end of the South Island east coast) indicate a population of 42 (CV = 41%, CI = 19 - 92) off Otago (Turek et al. 2013) and 49 (95% CI 44-55) in Porpoise Bay (Webster and Rayment 2008).

Fishing effort, observed effort and cetacean bycatch in gillnet and trawl fisheries are shown in Tables 1-4 and Figures 5-12. Fishing effort was much higher in the 1980s and 1990s than it is today. For example, total effort in the gillnet fishery is just under 16,000 km per year currently and was almost twice that level in the early 2000s (just over 28,000 km). By comparison, gillnet fishing effort was almost 50,000 km per year in the early 1980s and higher still in the 1970s (e.g. Davies et al. 2008). In addition to the much higher fishing effort in the 1980s and 1990s, there was much greater overlap between dolphins and the distribution of gillnet and trawl fisheries. Before 1988 there were no protected areas. From 1988 to 2003, there was only one small protected area at Banks Peninsula, in the middle of the east coast of the South Island. These were the only two protected areas from 2003 until 2008. Only for the last 10 years has there been at least some protection in most of the areas where NZ dolphins are found.

There has been no gillnet observer coverage at Banks Peninsula since 2002. Observer coverage in the gillnet fishery is so low (typically 2% per year or less) that bycatch is at the boundary of detectability. Most years, 0, 1 or 2 NZ dolphin captures are observed, with an estimated total catch of 32.3 (95% c.i.:13.8–65.8) in gillnet fisheries and 41.3 (95% c.i.: 19.1–77.7) in gillnet and trawl fisheries (MPI 2017). For a more detailed discussion of these issues, see Slooten and Dawson (2017).

Estimates of the total number of NZ dolphins caught typically assume that bycatch is a poisson process in which captures are independent events (e.g. MPI 2017). However, the number of capture events in which two or more dolphins are caught in the same event indicate that this is not the case. For example, a third of the capture events (2/6) during the first observer programme in 1997-98 involved two dolphins (Baird and Bradford 2000). Likewise, several of the most recent bycatch events have been multiples (Figure 13). This may be due to social processes (e.g. group size), behavioural factors (e.g. dolphins coming to investigate a dolphin caught in a gillnet), or shared habita-related needs (e.g. foraging).

Observer coverage in the trawl fishery is higher than in the gillnet fishery (Table 4). However, nearly all trawl observer coverage is in offshore fisheries, beyond the range of NZ dolphin. In addition, the catch rate per day fishing appears to be lower for trawling than for gillnetting. This makes it even more challenging to ensure enough observer coverage to obtain an unbiased estimate.

In addition to the statistical bias issues discussed above, another potential form of bias is the potential for fishermen to behave differently on days when they carry an observer. Fishers have admitted to avoiding fishing in areas where they have experienced high dolphin bycatch in the past (S. Childerhouse, pers comm.).

Considerable overlap between the distribution of NZ dolphins and fishing effort using gillnets and trawling remains, despite the major change in dolphin protection measures in 2008 (Figures 7-12). This is resulting in continued bycatch (Figure 13) in areas where there has been high bycatch historically (Figure 14).

DISCUSSION

The distribution of NZ dolphin sightings is strongly related to water depth, with very few sightings in waters >100 m deep. The offshore extent of their distribution ranges from about 7 nmi in areas with relatively steep depth contours to at least 20 nmi offshore in shallower areas. Even accounting for the much lower survey effort in deeper water, the 100 m depth contour closely describes the offshore range of the species.

There is still a considerable amount of gillnet and trawl effort in waters < 100 m deep and hence overlap between NZ dolphins and fishing methods that cause small cetacean mortality. Most of the remaining uncertainty about the degree of overlap relates to the data on current and past distribution of fishing effort. Until recently, fishing effort was reported at the level of very large fisheries areas. Many areas have little or no observer coverage, and even in those that do, observer coverage is low and often from many years ago (Taylor et al. 2018).

Some of the uncertainty about the degree of overlap between dolphins and fishing is due to uncertainties in dolphin distribution data. As expected, dolphin distribution is most uncertain in low-density areas. This is problematic, because these are the populations at highest risk. The resulting source-sink dynamics and population fragmentation can also increase risk to the species as a whole (Slooten 2013, Slooten and Dawson 2010, 2016).
Habitat modelling might be a potential way to cope with gaps and uncertainties in the dolphin distribution data to help improve estimates of the overlap between dolphins and fishing. Research at Banks Peninsula shows very consistent hotspots in NZ dolphin distribution over three decades (Brough 2018, Brough et al. 2018). Dolphin prey were more abundant and dolphins spent more time foraging in these hotspots than in other areas. Prey, depth, dominant habitat type, current velocity, and to a lesser extent reef coverage, were important in determining which areas were dolphin hotspots (Brough et al. 2018). Unfortunately, this level of detail is not available at larger, regional scales. Therefore, the current MPI approach is largely based on broad-scale variables of low information content, such as water turbidity.

Another important consideration is that dolphin density at the larger, species distribution scale is influenced not only by physical and biological habitat features but also by current and past fishing pressure. Habitat models use current distribution to predict where dolphins ‘should’ be. However, this species has experienced depletion to the point of local extirpation in several areas due to differences in fishing pressure in different parts of the species’ range (Taylor et al. 2018). Differential depletion is also expected because Hector’s dolphins show high site fidelity as evident from photo-id and genetic studies, and because protection measures have been implemented in differing amounts at different times and in different areas. Historical evidence shows that local Hector’s dolphin populations have been extirpated, or reduced to much lower levels than historical abundance (e.g. Diver 1866), most likely due to high fishing pressure in those areas.

Detectability is a problem, for both bycatch and dolphins at low densities. Generally, line-transect surveys for abundance allocate survey effort in proportion to animal density (e.g. Buckland et al. 2001; Dawson et al. 2008), hence low density areas usually get low survey effort. Line-transect surveys for abundance have failed to detect dolphin sightings in South Island areas with known, resident NZ dolphin populations (e.g. Otago coastline). A similar sampling problem occurs in observer programmes, which at low coverage produce annual estimates of observed bycatch that are biased low to due sampling artefact (GAMMS 2016). The significant number of multiple catches, with several NZ dolphins caught in the same gillnet or trawl, makes it even more difficult to obtain robust estimates of bycatch. Low detectability of both live dolphins and bycatch is especially problematic for quantifying impact on small, local populations. In areas with small dolphin populations, the probability of detecting bycatch is very low. Yet the risk of extirpation is very high. This reinforces the need to calculate risks and bycatch limits over small areas (e.g. GAMMS 2016). The current MPI approach is to do the opposite.

The Threat Management Plan, being revised this year "needs to include a firm basis for determining the current status of dolphin populations in relation to their historical abundance and distribution so that 'recovery' can be defined and worked towards." (Taylor et al. 2018). The International Expert Panel encouraged MPI to provide a summary of the conservation status of individual populations, in particular for populations "that are at numbers typically considered to be so low (below the low hundreds) that they are at high risk. For these populations it would be helpful to project the consequences of management options over the near future (say 20 years)." (Taylor et al. 2018). For small populations, with no local estimates of survival "the model has the potential of giving a picture that all is well, when there are no data that would give 'feedback' to indicate that the prior doesn't match the empirical data" (Taylor et al. 2018).

Aside from fisheries mortality, NZ dolphins are subject to a range of other threats, including pollution, marine mining, port developments and disease (DOC and Mfish 2007). Roe et al. (2013) studied disease in NZ dolphins and concluded that "Although toxoplasma infection has been widely reported in marine mammal species, it has previously only been recognised as a significant cause of mortality at a population level for southern sea otters (Kreuder et al. 2003; Miller 2008)." They believed toxoplasmosis was a potential cause of death in 7/28 (25%) of the dolphins in their study (2/3 Maui's dolphins and 5/25 South Island Hector's dolphins), suggesting that this disease is widespread in NZ waters (Roe et al. 2013). However, the 28 necropsies used to study toxoplasma can not be considered a representative profile of total mortality for the species. "There is no reason to believe that beachcast carcasses (and particularly such a small sample of these) are representative of deaths of all kinds throughout the dolphin population. Defining how and to what extent this sample of deaths could be biased is a nearly intractable problem". The Expert Panel stated "we are concerned that the results from the model could be seriously misleading. For this reason, we recommend that you 'back off' from forcing the model to produce conclusions which are supportable only when a series of questionable assumptions are made and which even then, are highly uncertain." (Taylor et al. 2018).

For toxoplasmosis, "where many assumptions are necessary to construct the spatial distributions required and to interpret the available data" the Expert Panel recommended "a simple narrative approach, listing what is actually known." (Taylor et al. 2018). They concluded that "Attempting to account for all causes of death – whether 'natural' or human-caused – in a credible quantitative analysis that fully incorporates uncertainty is an ambitious, and in our considered view unrealistic, goal." (Taylor et al. 2018). If the effects of disease are as large as the MPI estimates, NZ dolphin would be "in rapid free-fall towards extinction." (Taylor et al. 2018).

Banks Peninsula is one of the areas where toxoplasma has been identified in NZ dolphin (Figure 15). Sample sizes are very small, but one of two dolphins from this area that were examined for signs of toxoplasma, had the disease and it was judged to be the cause of death for that individual. This area has partial protection from fisheries mortality, with gillnetting banned to 4 nautical miles (nmi) offshore and trawling banned to 2 nmi, since 1988. The survival rate of Hector's dolphins in this area increased by 5.4% after these protection measures were implemented. The population had been declining at 6% per year, before protection from fisheries mortality. It is now almost stable (Gormley et al. 2012). This is inconsistent with the hypothesis that toxoplasma is an important source of mortality for NZ dolphins, as fisheries regulations resulted in a large increase in survival rate while nothing has been done to reduce disease.

Of the crucial variables, the level of fisheries mortality in gillnet and in particular trawl fisheries has highest uncertainty, due to very low and sporadic observer coverage in NZ's inshore fisheries. It is disconcerting that the first observer programme, carried out in 1997-98 on the east coast of the South Island (Baird and Bradford 2000), remains the most scientifically robust. Since then, observer data have been sparse but consistent with Baird and Bradford's (2000) estimates. One dolphin was caught in 90 observed sets in area 20 on the north side of Banks Peninsula and six dolphins were caught in 97 observed sets in area 22 on the south side of Banks Peninsula (Fig 1). The much higher catch rate in area 22 is consistent with much higher dolphin densities there. One of the dolphins in area 22 was caught in an area that has been protected since 2008, but was not yet protected in 1997-98. The remaining 5 dolphins caught in area 22 occurred in areas that are still unprotected, suggesting that the catch rates of 0.01 – 0.064 observed by Baird and Bradford (2000) represent current catch rates. Observer coverage was 45.9% in area 20 and 38.8% in area 22. Baird and Bradford (2000) recommended increasing observer coverage to 56 – 83% in order to achieve estimates of bycatch with a CV of 30% or better. Most of the observer programmes since 1998 have had observer coverage well below 10%.

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Fishing year	**Bycatch**	**Target fish**	**Area**	**Latitude**	**Longitude**
2006/2007	Dusky dolphin	Rig	East Coast South Island	173.565	-42.497
2006/2007	Hectors dolphin	Rig	East Coast South Island	173.388	-42.884
2007/2008	Pilot whale	School shark	West Coast North Island	174.282	-38.126
2007/2008	Hectors dolphin	Rig	East Coast South Island	171.180	-44.581
2008/2009	Hectors dolphin	Tarakihi	East Coast South Island	173.575	-42.614
2009/2010	Hectors dolphin	School shark	East Coast South Island	173.652	-42.715
2009/2010	Dusky dolphin	Rig	East Coast South Island	170.984	-45.612
2009/2010	Dusky dolphin	Tarakihi	East Coast South Island	173.561	-42.582
2009/2010	Hectors dolphin	Rig	East Coast South Island	171.594	-44.206
2010/2011	Dusky dolphin	Moki	East Coast South Island	173.682	-42.439
2010/2011	Dusky dolphin	Moki	East Coast South Island	173.650	-42.475
2012/2013	Hectors dolphin	Rig	East Coast South Island	171.254	-44.578
2012/2013	Common dolphin	School shark	Taranaki	174.370	-38.340
2012/2013	Dusky dolphin	Ling	West Coast South Island	170.670	-42.590
2012/2013	Common dolphin	Common warehou	Taranaki	173.782	-39.146
2013/2014	Hectors dolphin	Elephant fish	East Coast South Island	171.437	-44.280
2013/2014	Common dolphin	Common warehou	Taranaki	173.820	-39.158
2013/2014	Common dolphin	Common warehou	Taranaki	173.750	-39.155
2014/2015	Common dolphin	Common warehou	Taranaki	173.860	-39.085
2015/2016	Dusky dolphin	School shark	East Coast South Island	170.889	-45.526
2016/2017	Hectors dolphin	Rig	East Coast South Island	171.286	-44.698
2016/2017	Common dolphin	Trevally	Taranaki	174.065	-39.005

Table 1. Cetacean bycatch on gillnetting vessels with fisheries observers between 2006 and 2017 (Dragonfly Consulting 2019).

Fishing year	**Bycatch**	**Target fish**	**Area**	**Latitude**	**Longitude**
2002/2003	Common dolphin	Jack mackerel	Taranaki	173.241	-39.771
2002/2003	Common dolphin	Jack mackerel	Taranaki	174.243	-40.535
2002/2003	Common dolphin	Jack mackerel	Taranaki	174.267	-40.539
2002/2003	Common dolphin	Jack mackerel	Taranaki	174.259	-40.564
2002/2003	Common dolphin	Jack mackerel	Taranaki	174.095	-40.394
2002/2003	Common dolphin	Jack mackerel	Taranaki	174.085	-40.400
2002/2003	Common dolphin	Jack mackerel	Taranaki	174.092	-40.375
2002/2003	Common dolphin	Jack mackerel	Taranaki	174.086	-40.415
2002/2003	Common dolphin	Jack mackerel	Taranaki	174.113	-40.411
2002/2003	Common dolphin	Jack mackerel	Taranaki	174.112	-40.376
2002/2003	Common dolphin	Jack mackerel	Taranaki	174.008	-40.276
2002/2003	Common dolphin	Jack mackerel	Taranaki	173.999	-40.286
2002/2003	Common dolphin	Jack mackerel	Taranaki	174.276	-40.570
2002/2003	Common dolphin	Jack mackerel	Taranaki	174.279	-40.570
2002/2003	Common dolphin	Jack mackerel	Taranaki	174.559	-40.809
2002/2003	Common dolphin	Jack mackerel	Taranaki	174.559	-40.799
2002/2003	Common dolphin	Jack mackerel	Taranaki	174.545	-40.782
2002/2003	Common dolphin	Jack mackerel	Taranaki	174.537	-40.802
2002/2003	Common dolphin	Jack mackerel	Taranaki	174.529	-40.816
2002/2003	Common dolphin	Jack mackerel	Taranaki	174.528	-40.777
2002/2003	Common dolphin	Jack mackerel	Taranaki	174.534	-40.792
2003/2004	Common dolphin	Jack mackerel	West Coast North Island	174.094	-37.199
2003/2004	Common dolphin	Jack mackerel	West Coast North Island	173.990	-37.024
2003/2004	Common dolphin	Jack mackerel	West Coast North Island	174.023	-36.991
2003/2004	Common dolphin	Jack mackerel	West Coast North Island	174.005	-36.989
2003/2004	Common dolphin	Jack mackerel	West Coast North Island	174.245	-37.685
2003/2004	Common dolphin	Jack mackerel	West Coast North Island	174.248	-37.716
2003/2004	Common dolphin	Jack mackerel	West Coast North Island	174.265	-37.681
2003/2004	Common dolphin	Jack mackerel	West Coast North Island	174.119	-37.209
2003/2004	Common dolphin	Jack mackerel	West Coast North Island	174.025	-36.905
2003/2004	Common dolphin	Jack mackerel	West Coast North Island	174.023	-36.922
2003/2004	Common dolphin	Jack mackerel	West Coast North Island	173.997	-36.887
2003/2004	Common dolphin	Jack mackerel	West Coast North Island	173.999	-36.907
2003/2004	Common dolphin	Jack mackerel	West Coast North Island	174.018	-36.922
2003/2004	Common dolphin	Jack mackerel	West Coast North Island	173.980	-36.919
2003/2004	Common dolphin	Jack mackerel	Taranaki	173.661	-39.777
2003/2004	Common dolphin	Jack mackerel	West Coast North Island	174.068	-37.053
2003/2004	Common dolphin	Jack mackerel	West Coast North Island	174.028	-37.035
2004/2005	Common dolphin	Jack mackerel	West Coast North Island	173.963	-36.861
2004/2005	Common dolphin	Jack mackerel	West Coast North Island	173.937	-36.825
2004/2005	Common dolphin	Jack mackerel	West Coast North Island	173.958	-36.827

2004/2005	Common dolphin	Jack mackerel	West Coast North Island	173.879	-36.773
2004/2005	Common dolphin	Jack mackerel	West Coast North Island	173.921	-36.771
2004/2005	Common dolphin	Jack mackerel	West Coast North Island	173.923	-36.798
2004/2005	Common dolphin	Jack mackerel	West Coast North Island	173.876	-36.824
2004/2005	Common dolphin	Jack mackerel	West Coast North Island	174.005	-36.917
2004/2005	Common dolphin	Jack mackerel	West Coast North Island	174.003	-36.914
2004/2005	Common dolphin	Jack mackerel	West Coast North Island	174.159	-37.294
2004/2005	Common dolphin	Jack mackerel	West Coast North Island	174.151	-37.302
2004/2005	Common dolphin	Jack mackerel	West Coast North Island	174.155	-37.309
2004/2005	Common dolphin	Jack mackerel	West Coast North Island	174.164	-37.292
2004/2005	Common dolphin	Jack mackerel	West Coast North Island	174.136	-37.289
2004/2005	Common dolphin	Jack mackerel	West Coast North Island	174.170	-37.290
2004/2005	Common dolphin	Jack mackerel	West Coast North Island	174.253	-37.665
2004/2005	Common dolphin	Jack mackerel	West Coast North Island	174.259	-37.636
2004/2005	Pilot whale	Jack mackerel	Taranaki	173.851	-38.695
2004/2005	Pilot whale	Jack mackerel	Taranaki	173.848	-38.687
2004/2005	Pilot whale	Jack mackerel	Taranaki	173.838	-38.712
2004/2005	Pilot whale	Jack mackerel	Taranaki	173.836	-38.705
2004/2005	Pilot whale	Jack mackerel	Taranaki	173.842	-38.690
2004/2005	Pilot whale	Jack mackerel	Taranaki	173.845	-38.724
2004/2005	Common dolphin	Jack mackerel	West Coast North Island	174.226	-37.347
2004/2005	Common dolphin	Jack mackerel	Taranaki	174.170	-38.400
2004/2005	Common dolphin	Jack mackerel	Taranaki	174.157	-38.422
2004/2005	Common dolphin	Jack mackerel	Taranaki	174.145	-38.414
2004/2005	Common dolphin	Barracouta	West Coast South Island	170.264	-42.598
2005/2006	Common dolphin	Jack mackerel	Taranaki	173.809	-39.972
2005/2006	Common dolphin	Jack mackerel	Taranaki	173.797	-39.954
2005/2006	Common dolphin	Trevally	West Coast North Island	174.032	-36.683
2005/2006	Common dolphin	Trevally	West Coast North Island	174.040	-36.711
2005/2006	Dusky dolphin	Jack mackerel	East Coast South Island	173.608	-44.115
2005/2006	Whale (unspecified)	Hoki	West Coast South Island	170.474	-42.255
2006/2007	Common dolphin	Jack mackerel	West Coast North Island	174.059	-37.008
2006/2007	Common dolphin	Jack mackerel	West Coast North Island	173.934	-36.795
2006/2007	Common dolphin	Jack mackerel	West Coast North Island	173.948	-36.819
2006/2007	Common dolphin	Jack mackerel	Taranaki	173.587	-39.823
2006/2007	Common dolphin	Jack mackerel	Taranaki	173.585	-39.946
2006/2007	Common dolphin	Jack mackerel	Taranaki	173.620	-39.943
2006/2007	Common dolphin	Jack mackerel	Taranaki	173.648	-40.403
2006/2007	Common dolphin	Jack mackerel	Taranaki	173.669	-40.376
2006/2007	Common dolphin	Jack mackerel	Taranaki	173.661	-40.393
2006/2007	Common dolphin	Jack mackerel	Taranaki	173.673	-40.409
2006/2007	Common dolphin	Jack mackerel	Taranaki	173.635	-40.423
2007/2008	Dolphin / odontocete	Oreos	Subantarctic	175.104	-48.556

2007/2008	Common dolphin	Jack mackerel	West Coast North Island	174.017	-36.971
2007/2008	Common dolphin	Jack mackerel	West Coast North Island	173.942	-36.916
2007/2008	Common dolphin	Jack mackerel	West Coast North Island	173.957	-36.879
2007/2008	Common dolphin	Jack mackerel	West Coast North Island	173.974	-36.890
2007/2008	Common dolphin	Jack mackerel	West Coast North Island	173.951	-36.882
2007/2008	Common dolphin	Jack mackerel	West Coast North Island	173.928	-36.885
2007/2008	Common dolphin	Jack mackerel	West Coast North Island	173.929	-36.892
2007/2008	Common dolphin	Jack mackerel	West Coast North Island	173.996	-36.978
2007/2008	Common dolphin	Jack mackerel	West Coast North Island	174.013	-37.015
2007/2008	Common dolphin	Jack mackerel	West Coast North Island	174.017	-36.988
2007/2008	Common dolphin	Jack mackerel	West Coast North Island	173.999	-37.022
2007/2008	Common dolphin	Jack mackerel	West Coast North Island	173.979	-37.019
2007/2008	Common dolphin	Jack mackerel	West Coast North Island	174.018	-36.996
2007/2008	Common dolphin	Jack mackerel	West Coast North Island	174.006	-37.022
2007/2008	Common dolphin	Jack mackerel	West Coast North Island	173.978	-36.984
2007/2008	Common dolphin	Jack mackerel	West Coast North Island	174.013	-37.011
2007/2008	Common dolphin	Jack mackerel	West Coast North Island	174.176	-38.274
2007/2008	Common dolphin	Jack mackerel	West Coast North Island	174.130	-38.098
2007/2008	Common dolphin	Jack mackerel	West Coast North Island	174.151	-38.105
2007/2008	Common dolphin	Jack mackerel	West Coast North Island	174.127	-38.111
2007/2008	Bottlenose dolphin	John dory	Northland and Hauraki	174.910	-36.456
2008/2009	Common dolphin	Jack mackerel	West Coast North Island	173.928	-36.859
2008/2009	Common dolphin	Jack mackerel	West Coast North Island	174.078	-38.149
2008/2009	Common dolphin	Jack mackerel	West Coast North Island	174.081	-38.146
2008/2009	Common dolphin	Jack mackerel	West Coast North Island	174.110	-38.148
2008/2009	Pilot whale	Jack mackerel	Taranaki	172.655	-40.269
2008/2009	Pilot whale	Jack mackerel	Taranaki	172.628	-40.254
2008/2009	Common dolphin	Jack mackerel	Taranaki	174.126	-38.408
2008/2009	Common dolphin	Jack mackerel	Taranaki	174.149	-38.398
2008/2009	Common dolphin	Jack mackerel	Taranaki	174.157	-38.413
2008/2009	Common dolphin	Jack mackerel	Taranaki	174.160	-38.379
2008/2009	Common dolphin	Jack mackerel	Taranaki	174.142	-38.415
2008/2009	Common dolphin	Jack mackerel	Taranaki	173.776	-40.394
2008/2009	Common dolphin	Jack mackerel	Taranaki	173.805	-40.386
2008/2009	Common dolphin	warehou	Taranaki	173.742	-40.529
2008/2009	Common dolphin	warehou	Taranaki	173.559	-40.664
2008/2009	Common dolphin	warehou	Taranaki	173.554	-40.672
2008/2009	Common dolphin	warehou	Taranaki	173.813	-40.537
2008/2009	Common dolphin	warehou	Taranaki	173.571	-40.716
2008/2009	Common dolphin	warehou	Taranaki	173.569	-40.713
2008/2009	Common dolphin	warehou	Taranaki	173.536	-40.717
2008/2009	Common dolphin	warehou	Taranaki	173.553	-40.700
2008/2009	Common dolphin	Barracouta	Taranaki	173.218	-40.685

2008/2009	Dolphin / odontocete	Arrow squid	Stewart Snares Shelf	167.992	-48.456
2008/2009	Dolphin / odontocete	Arrow squid	Auckland Islands	166.569	-50.227
2008/2009	Baleen whales	Arrow squid	Stewart Snares Shelf	167.305	-48.804
2008/2009	Baleen whales	Arrow squid	Stewart Snares Shelf	167.713	-48.662
2009/2010	Common dolphin	Jack mackerel	West Coast North Island	174.115	-37.786
2009/2010	Common dolphin	Jack mackerel	Taranaki	174.136	-40.481
2009/2010	Common dolphin	Jack mackerel	Taranaki	174.161	-40.524
2009/2010	Common dolphin	Jack mackerel	Taranaki	174.159	-40.501
2009/2010	Bottlenose dolphin	Tarakihi	Bay of Plenty	176.067	-36.554
2010/2011	Common dolphin	Jack mackerel	West Coast North Island	174.168	-37.763
2010/2011	Common dolphin	Jack mackerel	West Coast North Island	174.178	-37.436
2010/2011	Common dolphin	Jack mackerel	West Coast North Island	173.785	-38.161
2010/2011	Common dolphin	Jack mackerel	West Coast North Island	174.096	-37.768
2010/2011	Common dolphin	Barracouta	East Coast South Island	173.801	-43.530
2010/2011	Common dolphin	Jack mackerel	Taranaki	174.183	-40.270
2010/2011	Common dolphin	Jack mackerel	Taranaki	174.214	-40.245
2010/2011	Common dolphin	Jack mackerel	Taranaki	174.696	-40.470
2010/2011	Common dolphin	Gurnard	East Coast North Island	177.547	-39.166
2011/2012	Common dolphin	Jack mackerel	West Coast North Island	174.112	-38.194
2011/2012	Common dolphin	Jack mackerel	Taranaki	174.161	-38.311
2011/2012	Common dolphin	Jack mackerel	Taranaki	174.137	-38.304
2011/2012	Common dolphin	Jack mackerel	Taranaki	173.841	-38.698
2011/2012	Common dolphin	Jack mackerel	Taranaki	174.009	-40.427
2012/2013	Common dolphin	Jack mackerel	West Coast North Island	174.198	-37.500
2012/2013	Common dolphin	Jack mackerel	West Coast North Island	174.192	-37.477
2012/2013	Common dolphin	Jack mackerel	West Coast North Island	174.180	-37.512
2012/2013	Common dolphin	Jack mackerel	West Coast North Island	174.224	-37.506
2012/2013	Common dolphin	Jack mackerel	West Coast North Island	174.194	-37.518
2012/2013	Common dolphin	Jack mackerel	West Coast North Island	174.178	-37.517
2012/2013	Common dolphin	Jack mackerel	Taranaki	174.162	-38.517
2012/2013	Pilot whale	Jack mackerel	Taranaki	174.130	-38.500
2012/2013	Pilot whale	Jack mackerel	Taranaki	174.135	-38.449
2012/2013	Pilot whale	Jack mackerel	Taranaki	174.169	-38.464
2012/2013	Pilot whale	Jack mackerel	Taranaki	174.147	-38.444
2012/2013	Pilot whale	Jack mackerel	Taranaki	174.130	-38.474
2012/2013	Common dolphin	Jack mackerel	West Coast North Island	174.154	-38.242
2012/2013	Common dolphin	Jack mackerel	Taranaki	174.133	-38.553
2012/2013	Common dolphin	Jack mackerel	Taranaki	174.173	-38.530
2012/2013	Common dolphin	Jack mackerel	Taranaki	174.146	-38.563
2012/2013	Common dolphin	Jack mackerel	Taranaki	174.161	-38.529
2012/2013	Common dolphin	Barracouta	Taranaki	173.174	-40.258
2012/2013	Common dolphin	Jack mackerel	Taranaki	173.379	-40.107
2012/2013	Common dolphin	Jack mackerel	Taranaki	173.450	-39.993

2012/2013	Common dolphin	Jack mackerel	Taranaki	173.840	-40.063
2012/2013	Dusky dolphin	Hoki	East Coast South Island	174.347	-43.040
2012/2013	Pilot whale	Hoki	West Coast South Island	170.311	-41.703
2012/2013	Common dolphin	Hoki	Cook Strait	174.672	-41.503
2013/2014	Common dolphin	Jack mackerel	West Coast North Island	174.167	-38.182
2013/2014	Common dolphin	Jack mackerel	Taranaki	173.868	-40.155
2013/2014	Common dolphin	Jack mackerel	Taranaki	173.829	-40.130
2013/2014	Common dolphin	Jack mackerel	Taranaki	173.832	-40.126
2013/2014	Common dolphin	Jack mackerel	Taranaki	173.852	-40.156
2013/2014	Common dolphin	Jack mackerel	Taranaki	173.847	-40.144
2013/2014	Common dolphin	Jack mackerel	Taranaki	173.536	-39.831
2013/2014	Common dolphin	Jack mackerel	Taranaki	173.530	-39.868
2013/2014	Common dolphin	Jack mackerel	Taranaki	173.528	-39.839
2013/2014	Common dolphin	Jack mackerel	Taranaki	173.560	-39.867
2013/2014	Common dolphin	Jack mackerel	Taranaki	173.564	-39.847
2013/2014	Common dolphin	Jack mackerel	Taranaki	173.531	-39.867
2013/2014	Common dolphin	Jack mackerel	Taranaki	173.472	-40.162
2013/2014	Common dolphin	Jack mackerel	Taranaki	173.474	-40.149
2013/2014	Common dolphin	Jack mackerel	Taranaki	173.429	-40.173
2013/2014	Common dolphin	Jack mackerel	Taranaki	173.432	-40.175
2013/2014	Common dolphin	Jack mackerel	Taranaki	173.466	-40.171
2013/2014	Common dolphin	Jack mackerel	Taranaki	173.841	-39.956
2013/2014	Common dolphin	Jack mackerel	Taranaki	173.837	-39.956
2013/2014	Common dolphin	Jack mackerel	Taranaki	173.427	-39.652
2013/2014	Common dolphin	Jack mackerel	Taranaki	173.431	-39.658
2013/2014	Common dolphin	Jack mackerel	Taranaki	173.456	-39.662
2013/2014	Common dolphin	Jack mackerel	Taranaki	173.447	-39.649
2013/2014	Common dolphin	Jack mackerel	Taranaki	173.466	-39.674
2013/2014	Common dolphin	Jack mackerel	Taranaki	173.449	-39.647
2013/2014	Common dolphin	Jack mackerel	Taranaki	173.471	-39.665
2013/2014	Common dolphin	Jack mackerel	Taranaki	173.464	-39.652
2013/2014	Common dolphin	Jack mackerel	Taranaki	173.458	-39.647
2013/2014	Common dolphin	Tarakihi	West Coast North Island	173.879	-36.578
2013/2014	Common dolphin	Hoki	West Coast South Island	170.594	-41.915
2013/2014	Baleen whales	Silver warehou	East Coast South Island	175.075	-43.890
2014/2015	Common dolphin	Jack mackerel	West Coast North Island	174.031	-38.047
2014/2015	Common dolphin	Jack mackerel	West Coast North Island	174.031	-37.894
2014/2015	Common dolphin	Jack mackerel	West Coast North Island	174.150	-37.233
2014/2015	Common dolphin	Jack mackerel	West Coast North Island	174.172	-37.273
2014/2015	Common dolphin	Jack mackerel	West Coast North Island	174.154	-37.247
2014/2015	Common dolphin	Jack mackerel	West Coast North Island	174.233	-37.498
2014/2015	Common dolphin	Jack mackerel	West Coast North Island	173.930	-36.861
2014/2015	Common dolphin	Jack mackerel	West Coast North Island	173.968	-36.849

2014/2015	Common dolphin	Jack mackerel	West Coast North Island	174.143	-37.739
2014/2015	Common dolphin	Jack mackerel	West Coast North Island	174.150	-37.752
2014/2015	Common dolphin	Jack mackerel	West Coast North Island	174.220	-37.616
2014/2015	Common dolphin	Jack mackerel	West Coast North Island	174.222	-37.606
2014/2015	Common dolphin	Jack mackerel	West Coast North Island	174.213	-37.617
2014/2015	Dusky dolphin	Barracouta	East Coast South Island	172.737	-44.501
2014/2015	Common dolphin	Jack mackerel	Taranaki	173.721	-40.045
2014/2015	Dusky dolphin	Barracouta	East Coast South Island	172.890	-44.422
2014/2015	Common dolphin	Jack mackerel	West Coast North Island	174.156	-37.730
2014/2015	Common dolphin	Jack mackerel	West Coast North Island	174.145	-37.756
2014/2015	Common dolphin	Jack mackerel	West Coast North Island	174.153	-37.768
2014/2015	Common dolphin	Barracouta	Taranaki	173.715	-39.811
2014/2015	Common dolphin	Jack mackerel	Taranaki	174.269	-40.466
2014/2015	Common dolphin	Jack mackerel	Taranaki	174.237	-40.472
2014/2015	Common dolphin	Tarakihi	Bay of Plenty	176.864	-37.633
2015/2016	Common dolphin	Jack mackerel	West Coast North Island	174.090	-37.998
2015/2016	Common dolphin	Jack mackerel	Taranaki	173.352	-40.216
2015/2016	Common dolphin	Tarakihi	West Coast North Island	174.046	-36.952
2015/2016	Common dolphin	John dory	Northland and Hauraki	175.260	-36.134
2015/2016	Common dolphin	John dory	Northland and Hauraki	175.259	-36.127
2015/2016	Common dolphin	Tarakihi	Northland and Hauraki	175.417	-35.773
2015/2016	Pilot whale	Tarakihi	East Coast North Island	178.264	-37.549
2015/2016	Common dolphin	Hoki	Cook Strait	174.571	-41.504
2015/2016	Common dolphin	Hoki	Cook Strait	174.593	-41.534
2016/2017	Common dolphin	Snapper	East Coast North Island	177.379	-39.078
2016/2017	Bottlenose dolphin	Snapper	Northland and Hauraki	175.096	-36.269

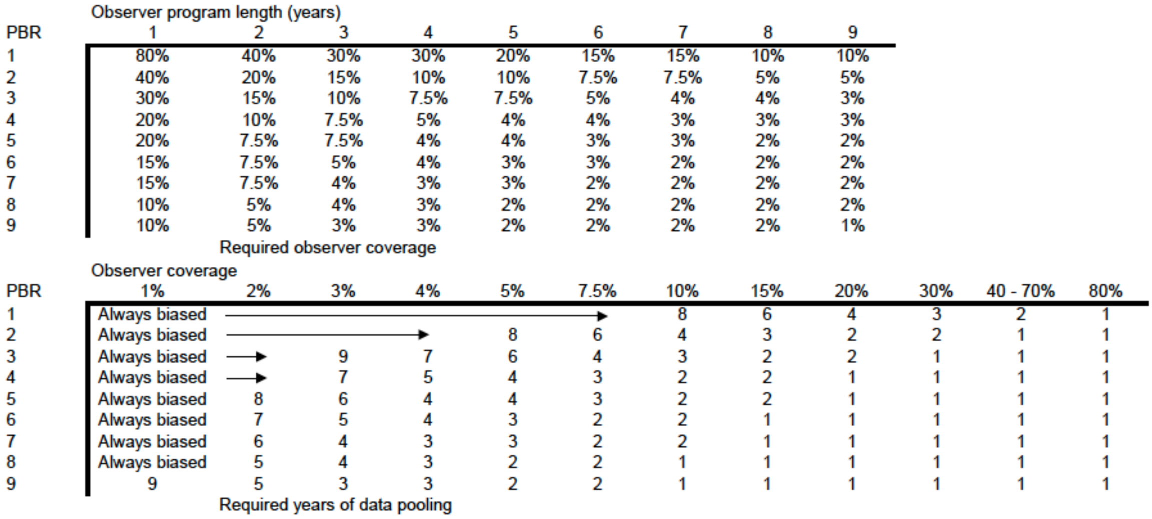
Table 2. Cetacean bycatch on trawling vessels with fisheries observers between 2002 and 2017 (Dragonfly Consulting 2019).

Year	Fishing effort (m)	Observed effort	Observer coverage
2002/2003	28,325,101	0	0.00
2003/2004	27,068,306	0	0.00
2004/2005	27,223,957	0	0.00
2005/2006	24,273,682	143,330	0.01
2006/2007	24,271,931	270,280	0.01
2007/2008	21,192,997	355,900	0.02
2008/2009	20,945,912	478,365	0.02
2009/2010	22,255,249	475,049	0.02
2010/2011	21,658,201	167,400	0.01
2011/2012	19,963,983	66,500	0.00
2012/2013	21,706,661	751,150	0.03
2013/2014	20,917,742	330,600	0.02
2014/2015	19,082,114	573,180	0.03
2015/2016	17,335,764	450,880	0.03
2016/2017	15,966,708	849,960	0.05

Table 3. Gillnet fishing effort and observer coverage between 2002 and 2017 (Dragonfly Consulting 2019).

Year	Fishing effort (m)	Observed effort	Observer coverage
2002/2003	130,165	6,840	0.05
2003/2004	120,809	6,547	0.05
2004/2005	120,465	7,713	0.06
2005/2006	109,943	6,619	0.06
2006/2007	103,308	7,932	0.08
2007/2008	89,537	9,049	0.10
2008/2009	87,550	9,769	0.11
2009/2010	92,889	9,015	0.10
2010/2011	86,089	7,450	0.09
2011/2012	84,420	9,361	0.11
2012/2013	83,837	12,398	0.15
2013/2014	85,109	13,185	0.15
2014/2015	78,766	13,564	0.17
2015/2016	78,032	12,983	0.17
2016/2017	78,170	13,723	0.18

Table 4. Trawling effort and observer coverage between 2002 and 2017 (Dragonfly Consulting 2019).



Observer program length (years)

PBR	1	2	3	4	5	6	7	8	9
1	80%	40%	30%	30%	20%	15%	15%	10%	10%
2	40%	20%	15%	10%	10%	7.5%	7.5%	5%	5%
3	30%	15%	10%	7.5%	7.5%	5%	4%	4%	3%
4	20%	10%	7.5%	5%	4%	4%	3%	3%	3%
5	20%	7.5%	7.5%	4%	4%	3%	3%	2%	2%
6	15%	7.5%	5%	4%	3%	3%	2%	2%	2%
7	15%	7.5%	4%	3%	3%	2%	2%	2%	2%
8	10%	5%	4%	3%	2%	2%	2%	2%	2%
9	10%	5%	3%	3%	2%	2%	2%	2%	1%

Required observer coverage

Observer coverage

PBR	1%	2%	3%	4%	5%	7.5%	10%	15%	20%	30%	40 - 70%	80%
1	Always biased	→	→	→	→	→	8	6	4	3	2	1
2	Always biased	→	→	→	8	6	4	3	2	2	1	1
3	Always biased	→	9	7	6	4	3	2	2	1	1	1
4	Always biased	→	7	5	4	3	2	2	1	1	1	1
5	Always biased	8	6	4	4	3	2	2	1	1	1	1
6	Always biased	7	5	4	3	2	2	1	1	1	1	1
7	Always biased	6	4	3	3	2	2	1	1	1	1	1
8	Always biased	5	4	3	2	2	1	1	1	1	1	1
9	9	5	3	3	2	2	1	1	1	1	1	1

Required years of data pooling

Table 5. Recommended data levels to attain approximately unbiased estimation of average annual fisheries-related mortality and serious injury, relative to PBR (i.e., if true annual bycatch = PBR) (from Moore and Merrick 2011). "Approximately unbiased" implies median absolute bias < 25%. The top table recommends minimum observer coverage (annual average), given a certain PBR and level of data pooling (years of information combined). The bottom table recommends minimum levels of data pooling, given a certain PBR and observer coverage. If true bycatch = PBR and sampling effort is below the recommended levels, *median* bias is always negative (i.e., true bycatch > estimate), but the combination of *very* limited sampling (≤5% coverage, ≤ 5 yrs data pooling) and *very* low bycatch (e.g., 1/yr) generates bimodal estimation bias, whereby bycatch is always either underestimated (if no bycatch is observed) or overestimated (if ≥ 1 bycatch event is observed). Table reproduced from GAMMS (2016).

	0-20 nautical miles		**4-20 nautical miles**	
	PBR 4%	**PBR 1.8%**	**PBR 4%**	**PBR 1.8%**
West Coast North Island	0.12	0.05		
North Coast South Island	0.18	0.08	0.18	0.08
West Coast South Island:				
Hector	2.84	1.28		
Greymouth	2.04	0.92	0.07	0.03
Okarito Lagoon	3.24	1.46	0.75	0.34
Jackson Bay	0.19	0.09		
Milford Sound	0.05	0.02		
East Coast South Island:				
Cloudy/Clifford	1.60	0.72	0.77	0.35
Kaikoura	0.51	0.23		
Clarence	0.19	0.09		
Pegasus	1.65	0.74	0.81	0.37
Bank Peninsula north	4.14	1.86	2.34	1.05
Bank Peninsula south	4.47	2.01	1.40	0.63
Timaru	2.50	1.13	1.34	0.60
South Coast South Island	0.35	0.16		

Table 6. Potential Biological Removal (PBR) for regional populations of Maui (west coast North Island) and Hector's dolphins (all other populations), estimated following the methods of Wade (1998). We used two offshore ranges: Shoreline to 20 nautical miles offshore (full offshore range for which population estimates are available) and 4-20 nautical miles (proportion of the population outside protected areas) and two levels of Rmax, the default value of 4% for cetaceans and the 1.8% Rmax estimate for Hector's and Maui dolphins.

FIGURES:

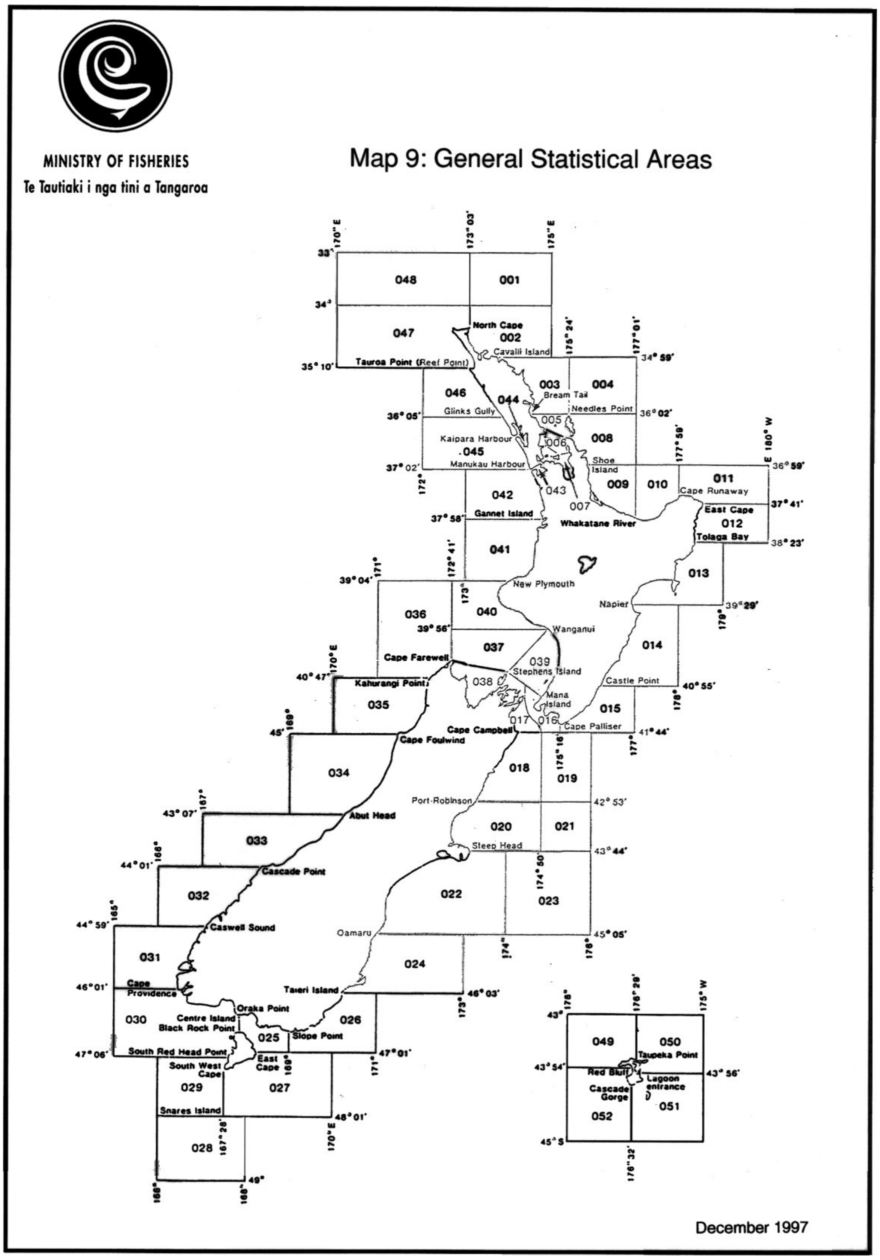


Figure 1. Fisheries statistical areas for which fishing effort data are available from 1983 onwards.

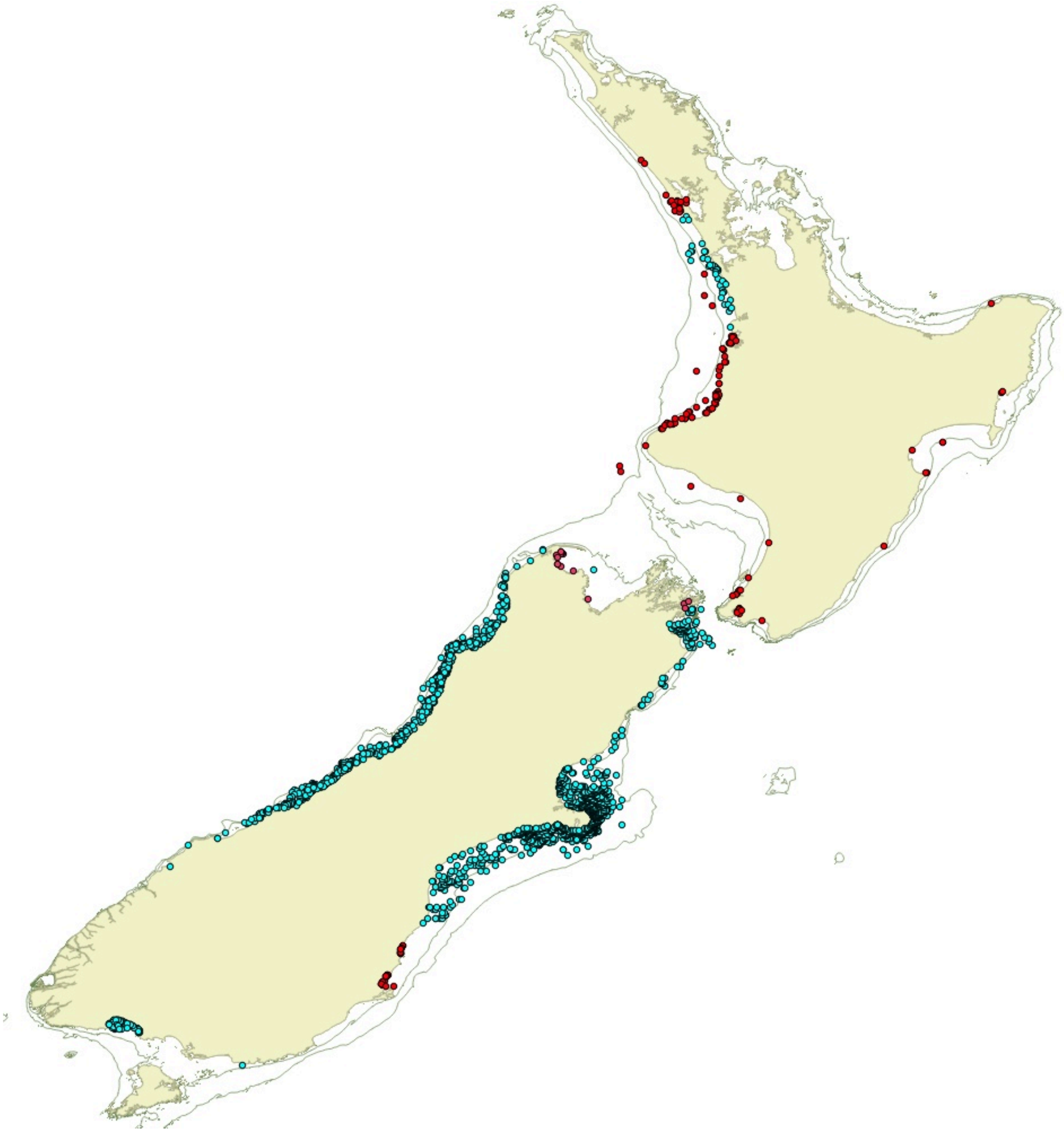


Figure 2. Map of NZ dolphin sightings: Blue dots indicate sightings from line-transect surveys carried out by MPI (MacKenzie and Clement 2014, 2016) and Otago University (Dawson et al. 2004; Slooten et al. 2004). Red dots off the South Island coastline indicate sightings from small boat surveys carried out by Otago University (Dawson and Slooten 1988; Turek et al. 2013). Red dots off the North Island indicate public sightings. The 20, 50 and 100 m depth contours are shown.

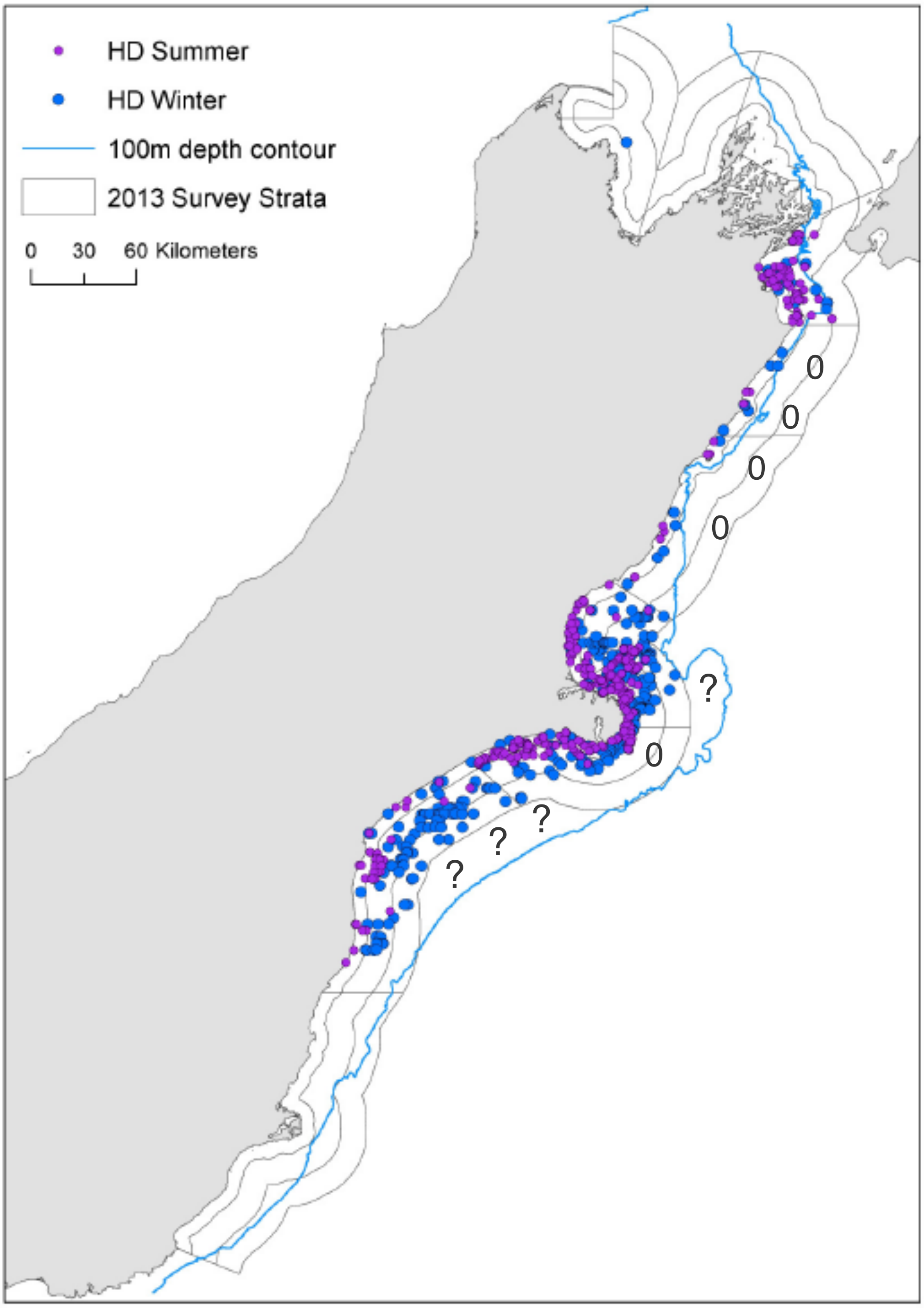


Figure 3. Map of survey sightings off the east coast of the South Island (MacKenzie and Clement 2014). Survey effort extended to 20 nmi offshore. Areas where survey effort extended beyond the 100 m depth contour, and no sightings were made are indicated with a “0”. Areas where the survey effort did not extend as far offshore as the 100 m depth contour are indicated with a “?”.

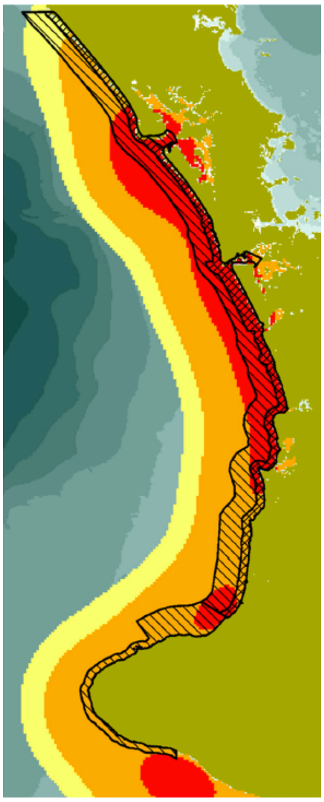


Figure 4a. Kernel density plot of Maui dolphin distribution off the west coast of the North Island, based on an individual based model calibrated to field data on movements and depth preference (de Jager et al. 2019). K50 (red), K95 (orange) and K99 (yellow) are shown.

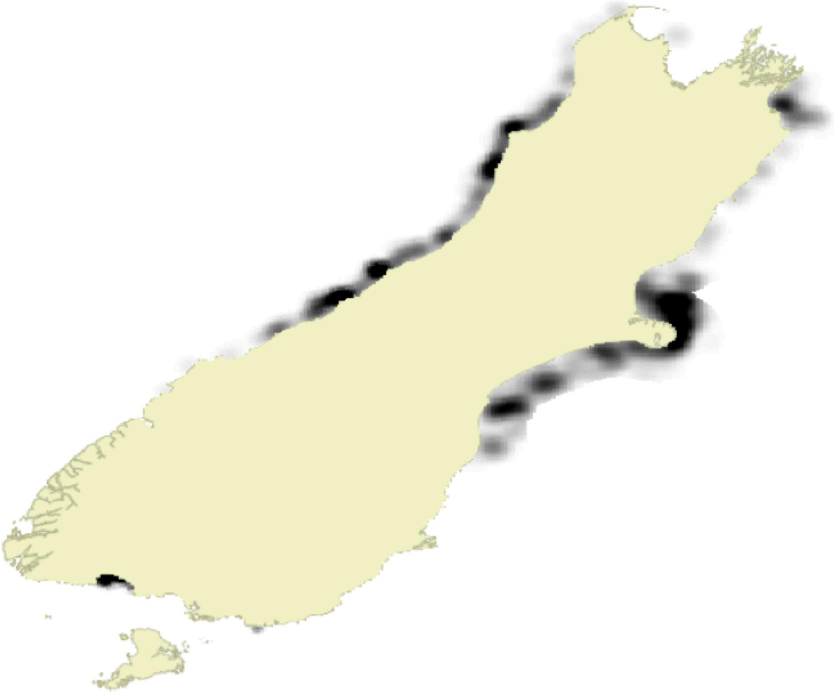


Figure 4b. Kernel density plot of Hector’s dolphin distribution around the South Island, using sightings from the two most recent line transect surveys (MacKenzie and Clement 2014,2016; Dawson et al. 2004; Slooten et al. 2004).

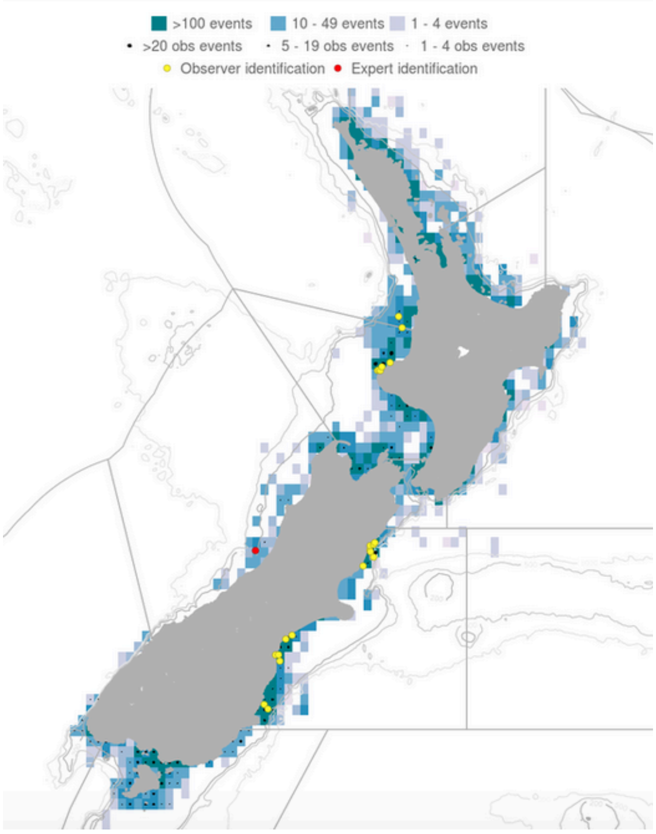


Figure 5. Gillnet fishing effort, observed effort and observed cetacean captures from 2002 to 2017, mapped in 0.2-degree cells. Fishing effort is shown in blue. Fishing is only shown if the effort could be assigned a latitude and longitude, and if there were three or more vessels and three or more companies or persons fishing within a cell. In this case, 91.1% of the effort is shown. Observed fishing events are indicated by black dots. Cetacean bycatch is shown as coloured dots, with yellow dots indicating the species was identified by a fisheries observer and red dots indicating a cetacean expert was consulted to identify the species caught (Dragonfly 2019).

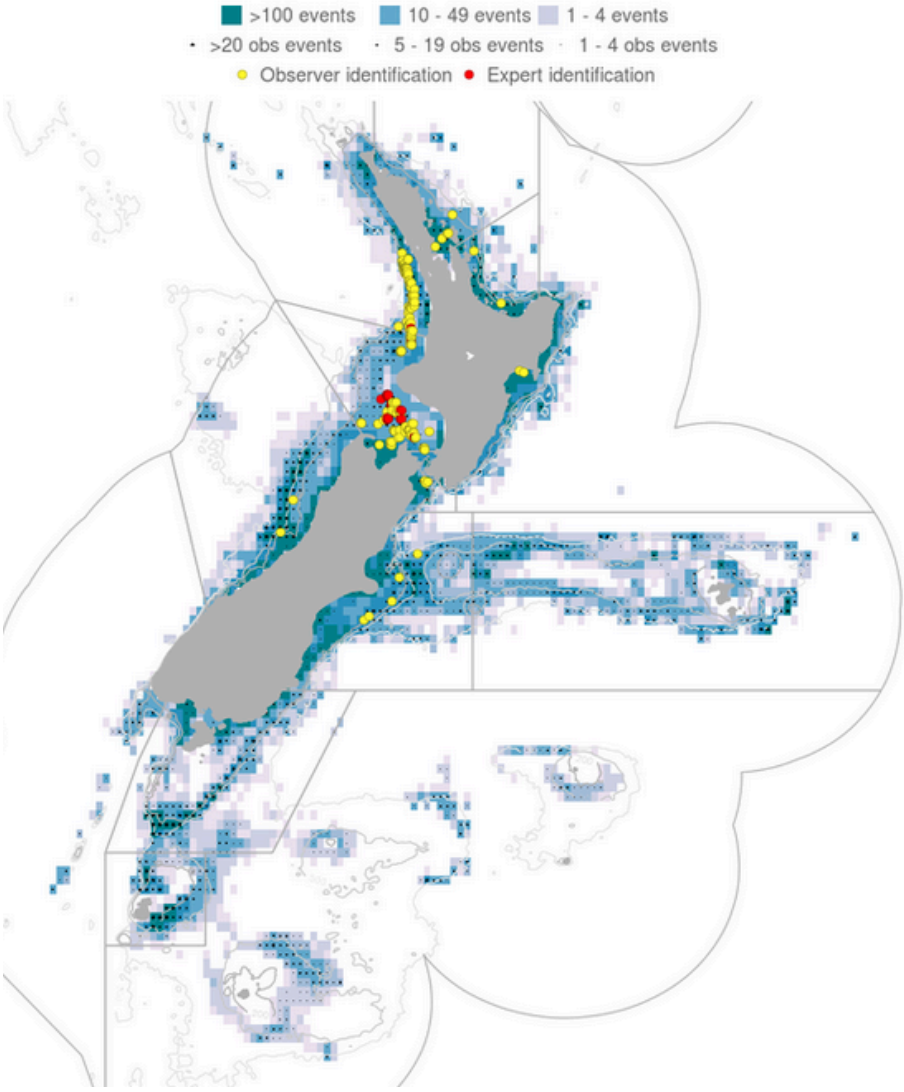


Figure 6. Trawl fishing effort, observed effort and observed cetacean captures from 2002 to 2017, mapped in 0.2-degree cells. Fishing effort is shown in blue. Observed fishing events are indicated by black dots. Cetacean bycatch is shown as coloured dots, with yellow dots indicating the species was identified by a fisheries observer and red dots indicating a cetacean expert was consulted to identify the species caught (Dragonfly 2019).

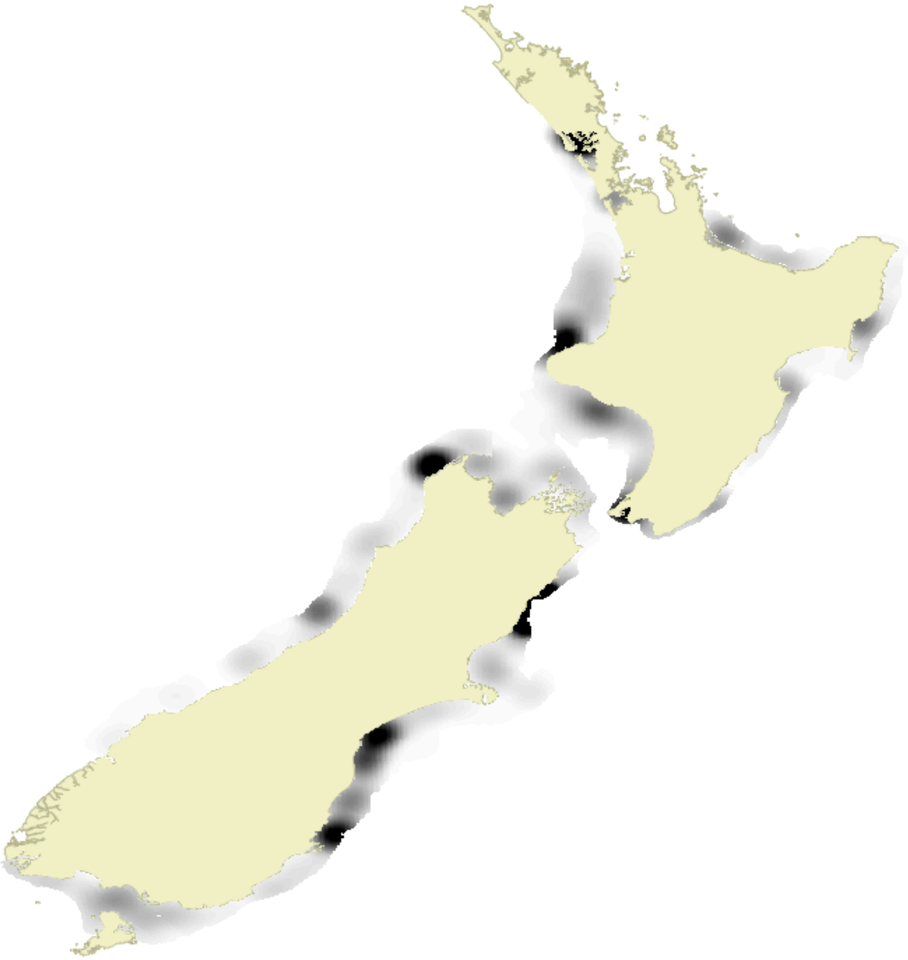


Figure 7. Kernel density plot of gillnet fishing effort from 2009 to 2017 (data provided by MPI).

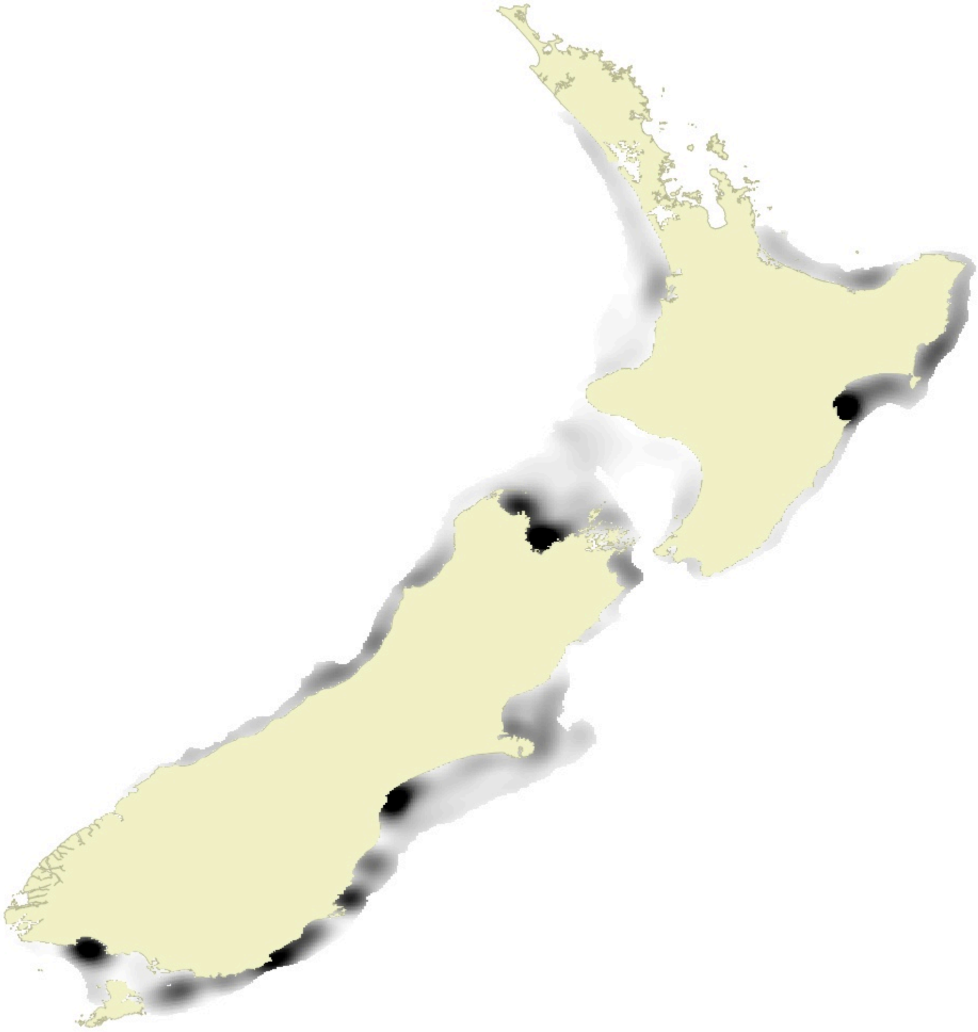


Figure 8. Kernel density plot of trawl fishing effort from 2009 to 2017, based on data provided by MPI.

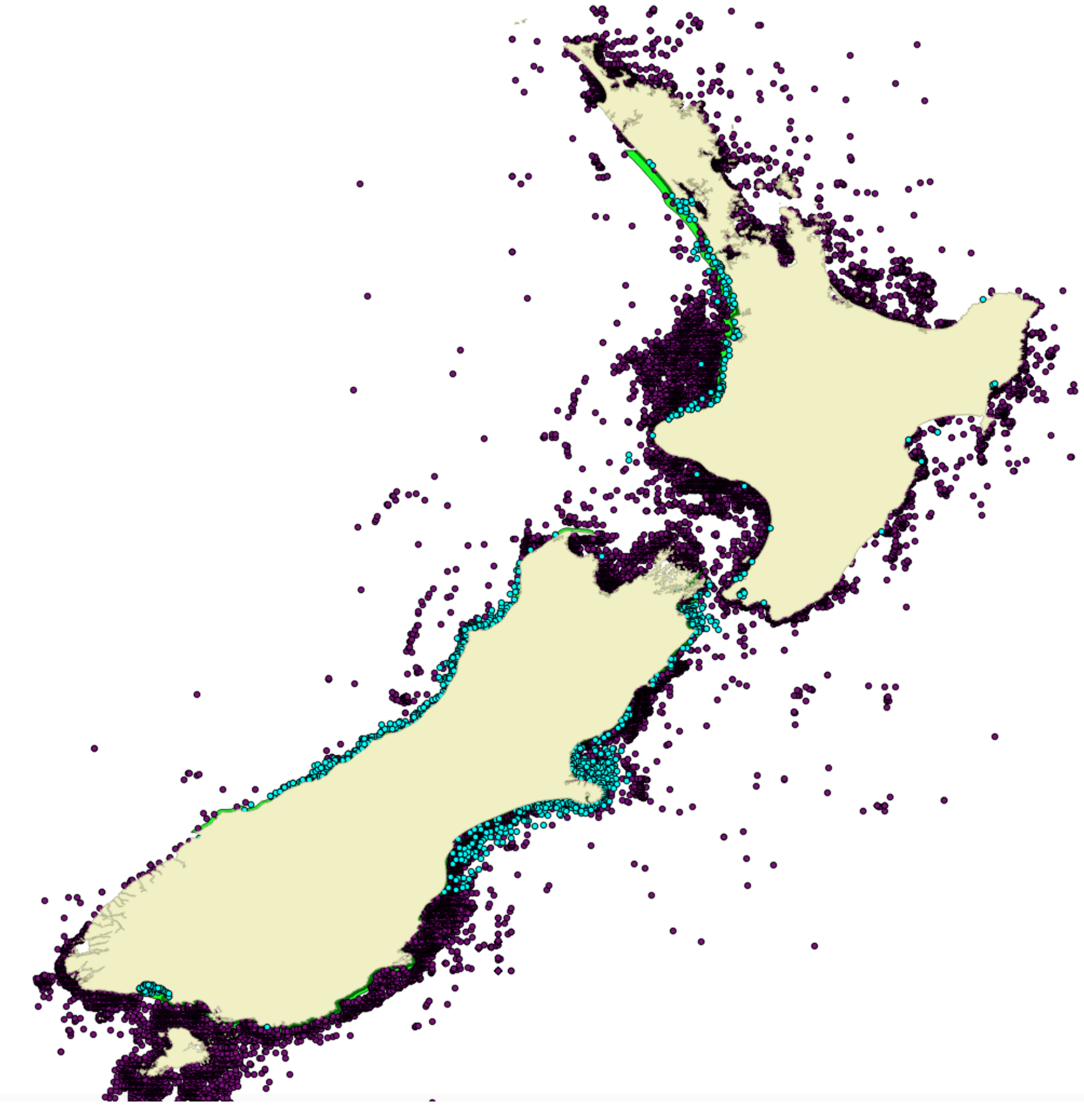


Figure 9. NZ dolphin sightings (blue) and gillnet fishing effort during 2009-2017 (purple). Areas where gillnets (light green) or both gillnets and trawling (dark green) are banned are largely obscured by fishing effort.

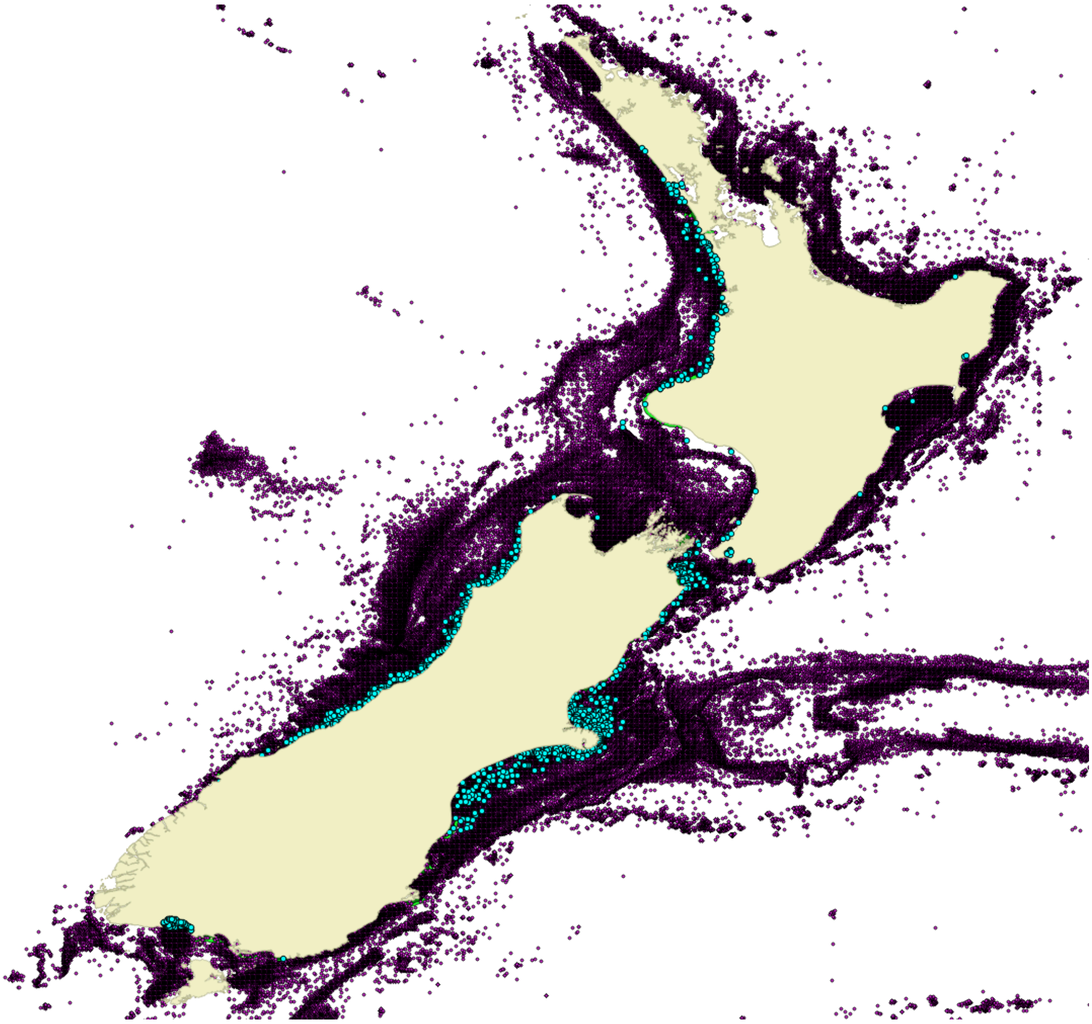
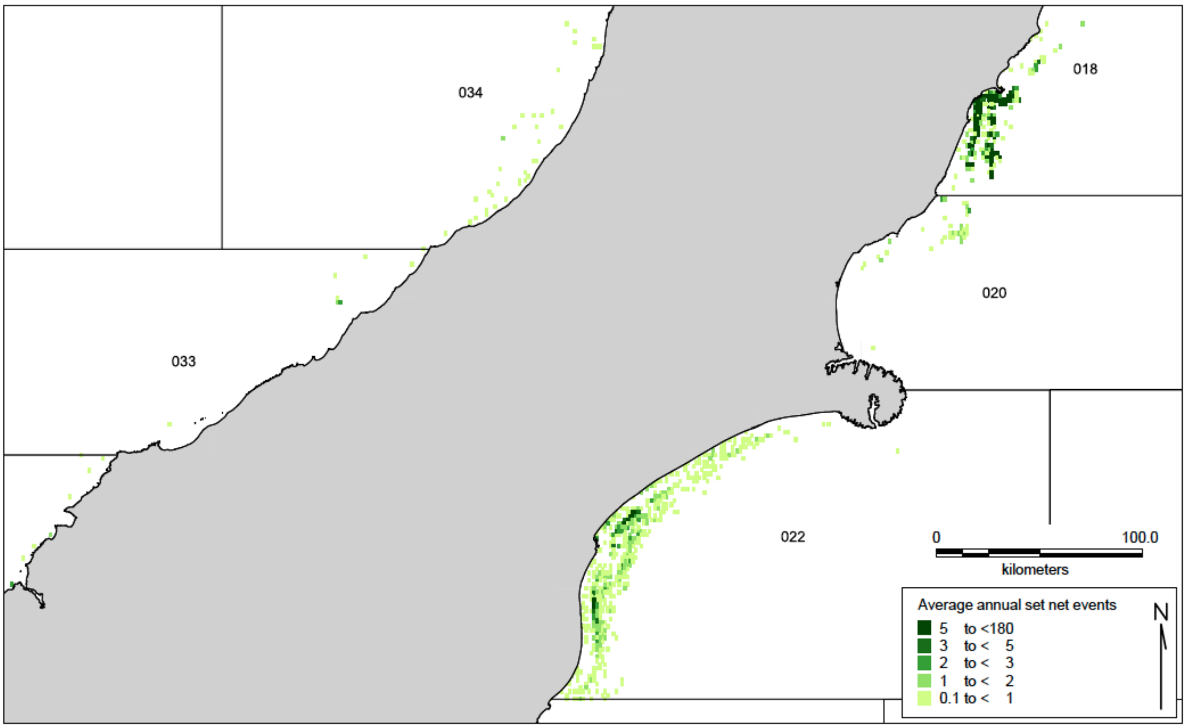
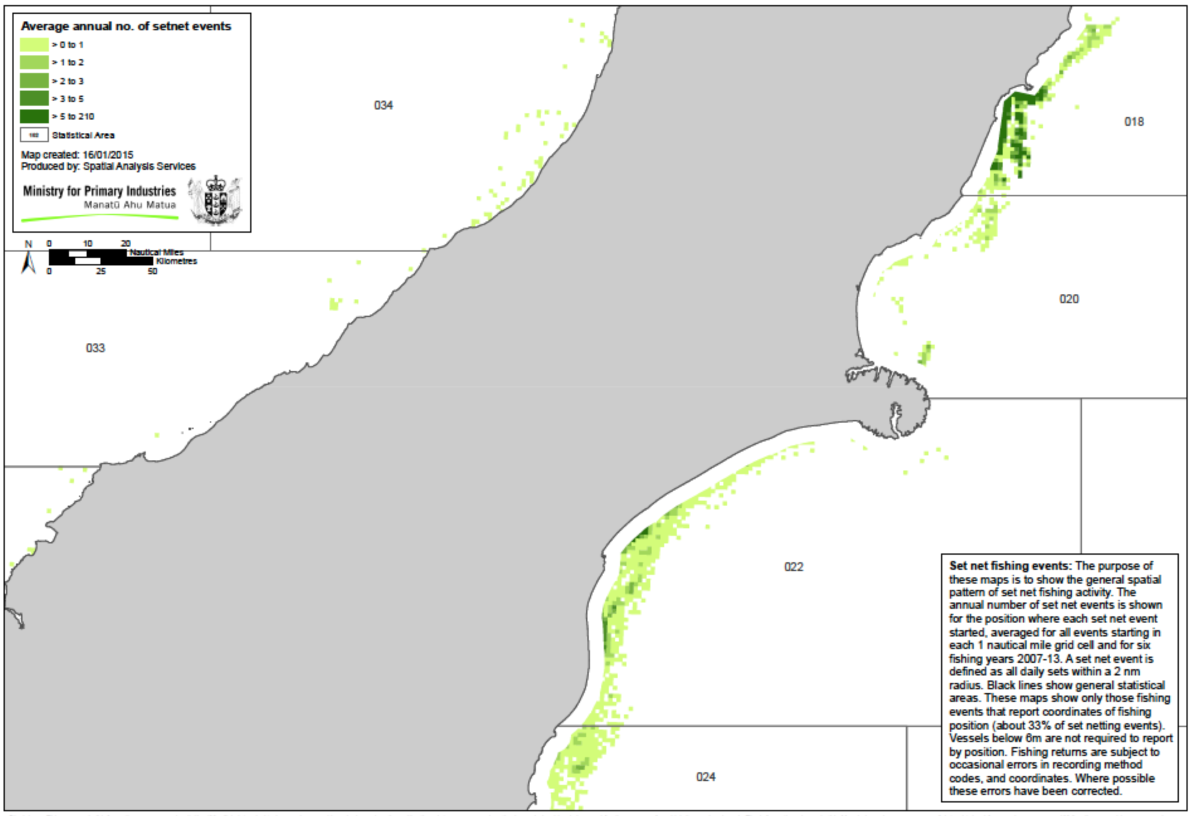


Figure 10. NZ dolphin sightings (blue) and trawl fishing effort during 2009-2017 (purple). Areas where gillnets (light green) or both gillnets and trawling (dark green) are banned are obscured by fishing effort.



Set net fishing events: The purpose of these maps is to show the general spatial pattern of set net fishing activity. The annual number of set net events is shown for the position where each set net event started, averaged for all events starting in each 1 nautical mile grid cell and for three fishing years 2007-10. A set net event is defined as all daily sets within a 2 nm radius. Black lines show general statistical areas. These maps show only those fishing events that report coordinates of fishing position (about 33% of set netting events). Vessels below 6m are not required to report by position. Fishing returns are subject to occasional errors in recording method codes, and coordinates. Where possible these errors have been corrected.

Figure 11. Gillnet fishing effort for 2007-2010 (MPI 2013a).



Set net fishing events: The purpose of these maps is to show the general spatial pattern of set net fishing activity. The annual number of set net events is shown for the position where each set net event started, averaged for all events starting in each 1 nautical mile grid cell and for six fishing years 2007-13. A set net event is defined as all daily sets within a 2 nm radius. Black lines show general statistical areas. These maps show only those fishing events that report coordinates of fishing position (about 33% of set netting events). Vessels below 6m are not required to report by position. Fishing returns are subject to occasional errors in recording method codes, and coordinates. Where possible these errors have been corrected.

Figure 12. Gillnet fishing effort for 2007-2013 (MPI 2019).

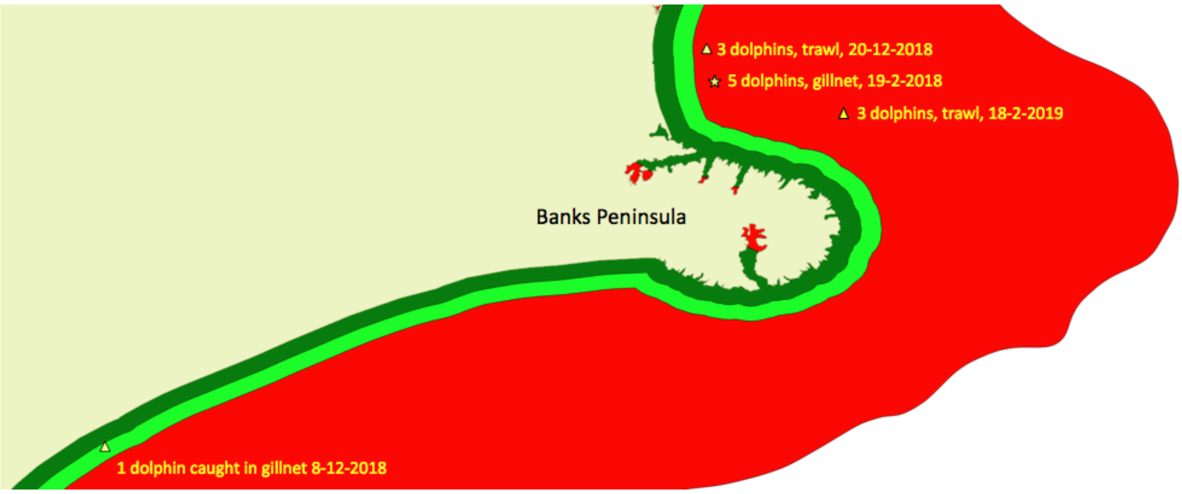


Figure 13. Recent bycatch events around Banks Peninsula, reported by fishermen (DOC 2019 – incident database).

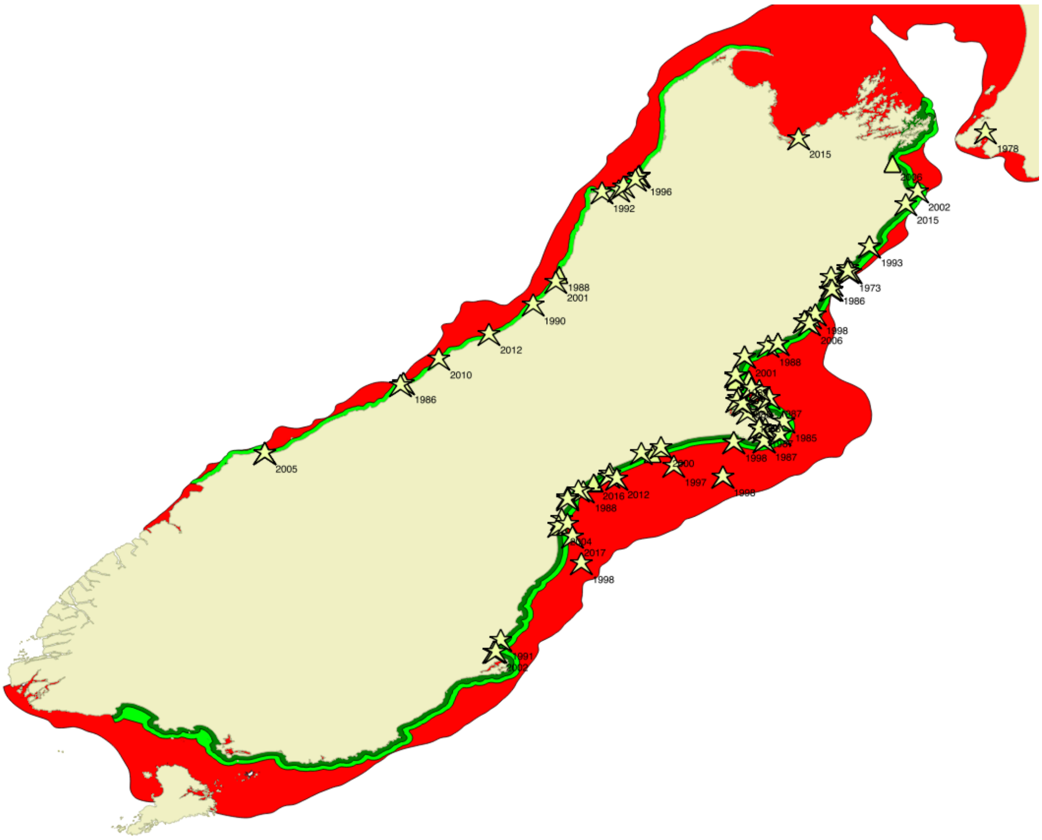


Figure 14. Locations of bycatch events from the DOC incident database (DOC 2019). Stars indicate dolphins caught in gillnets. Triangles indicate dolphin bycatch in trawl fisheries.

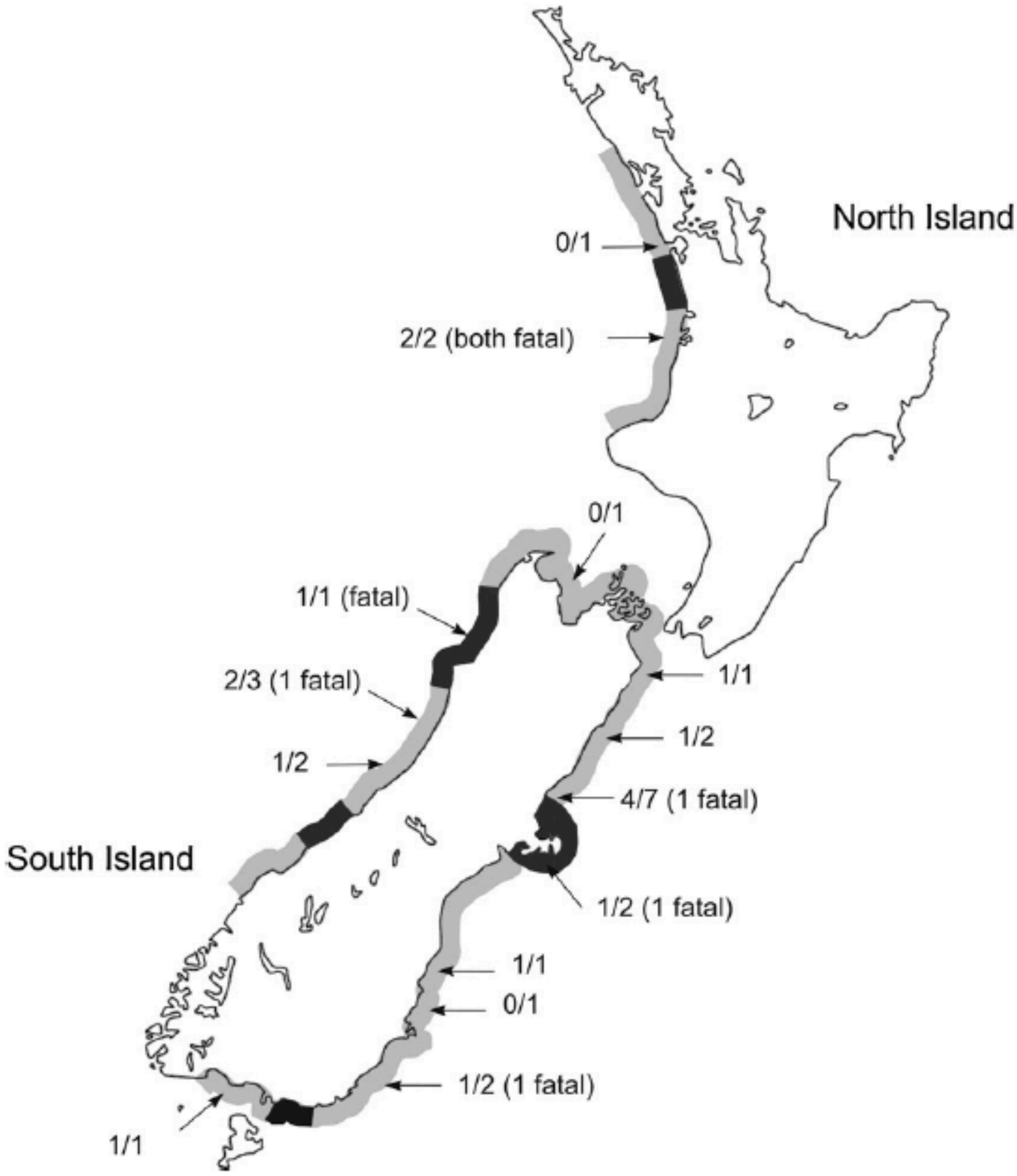


Figure 15. Locations of beachcast NZ dolphins with toxoplasma, as a proportion of the total number sampled, with cases where the cause of death was thought to be toxoplasma indicated in brackets. For example, 2/3 (1 fatal) indicates that 3 dolphins were tested, two carried toxoplasma and in one case the disease was thought to be the cause of death Cases (Roe et al. 2013).