A risk assessment of threats to Maui's dolphins

Rohan J.C. Currey, Laura J. Boren, Ben R. Sharp and Dean Peterson

newzealand.govt.nz
the ROYAL SOCIETY of NEW ZEALAND TE APĀRANGI
Ministry for Primary Industries Manatū Ahu Matua
Department of Conservation Te Papa Atawhai

Cover: Maui's dolphins, 2011. *Photo: R.M. Hamner, Oregon State University Marine Mammal Institute.*

This report was prepared for publication by the Publishing Team, Department of Conservation, Wellington, New Zealand. It may be cited as: Currey, R.J.C.; Boren, L.J.; Sharp, B.R.; Peterson, D. 2012: A risk assessment of threats to Maui's dolphins. Ministry for Primary Industries and Department of Conservation, Wellington. 51 p.

In the interest of forest conservation, we support paperless electronic publishing.

CONTENTS

A risk assessment of threats to Maui's dolphins

Rohan J.C. Currey[1], Laura J. Boren[2], Ben R. Sharp[1] and Dean Peterson[3]

[1] Ministry for Primary Industries, PO Box 2526, Wellington 6140, New Zealand
Email: rohan.currey@mpi.govt.nz

[2] Department of Conservation, PO Box 10420, Wellington 6143, New Zealand
Email: lboren@doc.govt.nz

[3] The Royal Society of New Zealand, PO Box 598, Wellington 6140, New Zealand, New Zealand

Summary

Maui's dolphin (*Cephalorhynchus hectori maui*) is a subspecies of Hector's and Maui's dolphin (*Cephalorhynchus hectori*) and is endemic to New Zealand. Maui's dolphin is listed as 'critically endangered' on the IUCN's Red List of threatened species and 'nationally critical' in the New Zealand Threat Classification System. Current population estimates indicate that about 55 Maui's dolphins over 1 year of age remain, and the population is exposed to a range of human- and non-human-induced threats. A risk assessment workshop was held in June 2012 with the purpose of identifying, analysing and evaluating all threats to Maui's dolphins. The risk assessment scoring was conducted by an expert panel of domestic and international specialists in marine mammal science and ecological risk assessment. The method for the risk assessment involved five key steps: defining Maui's dolphin distribution, threat identification, threat characterisation including the spatial distribution of the threat, threat scoring, and quantitative analysis.

The panel's scores combined for all identified threats suggested a broad range of plausible values for human-induced Maui's dolphin mortalities over the next 5 years (a median of 5.27 dolphins per annum with 95% of the distribution of scores being between 0.97 and 8.40 dolphins per annum). The panel attributed 95.5% of these mortalities to commercial, recreational, customary or illegal fishing-related activities combined, and the remaining 4.5% to non-fishing-related threats.

Despite this uncertainty, the panel's scores indicate high confidence that total human-induced mortality is higher than the population can sustain. Population projections based on the panel's estimated total mortalities indicate a 95.7% likelihood that the population will decline if threats remain at current levels (i.e. as at the time of the workshop and prior to the introduction of interim measures). Estimated total human-induced Maui's dolphin mortalities equate to a level of impact that is many times higher than the estimated Potential Biological Removals (PBR; a median of 75.5 times PBR, with 95% of the distribution of estimates being between 12.4 and 150.7 times PBR).

The risk assessment method assessed the cumulative impact and associated population risk posed by all threats combined and also disaggregated the impacts of the respective threats, to identify those threats that pose the greatest risk to the dolphins. It also identified several threats that may have a low likelihood, but which, given the small population size of Maui's dolphins, nonetheless may have detrimental consequences for the population.

Keywords: Maui's dolphin, *Cephalorhynchus hectori maui*, risk assessment, potential biological removal, risk ratio, cumulative impacts

1. Introduction

1.1 Purpose

In order to manage human-induced threats to Hector's and Maui's dolphins (*Cephalorhynchus hectori*), the Department of Conservation (DOC) and the then Ministry of Fisheries (MFish—now Ministry for Primary Industries, MPI) jointly developed and consulted on the Hector's and Maui's dolphin Threat Management Plan (TMP) (MFish & DOC 2007). DOC and MPI had agreed to review the TMP in 2013; however, the Minister for Conservation and the Minister for Primary Industries agreed that, in light of new information, the review of the Maui's portion of the TMP should be brought forward. This risk assessment provides an evaluation of the risks posed to Maui's dolphin to support the review of the TMP.

1.2 Background

More than 50 species or subspecies of marine mammals are found in New Zealand's EEZ (Perrin et al. 2008). Among these are the endemic Hector's and Maui's dolphins. Both are protected under the New Zealand Marine Mammals Protection Act (1978). The Hector's subspecies is listed as 'endangered' on the International Union for the Conservation of Nature's (IUCN's) Red List of threatened species, and as 'nationally endangered' in the New Zealand Threat Classification System. The Maui's subspecies is listed as 'critically endangered' by the IUCN and as 'nationally critical' in the New Zealand System (Reeves et al. 2000; Baker et al. 2010).

Maui's dolphin (*Cephalorhynchus hectori maui*) is a subspecies of Hector's and Maui's dolphin[1] which is one of 93 species in the order that contains whales, dolphins and porpoises (cetaceans) (Jefferson et al. 1993). There are currently only 44 named subspecies in this group. Only two species or subspecies of cetacean are listed as 'critically endangered' on the IUCN Red List (IUCN 2009). These are the vaquita, or Gulf of California porpoise (*Phocoena sinus*), which is a full species of porpoise with just over 200 individuals remaining (Gerrodette et al. 2011), and Maui's dolphin, which now has approximately 55 individuals over 1 year of age remaining (95% CI: 48–69; Hamner et al. 2012a). In the recent past, three species or subspecies were listed as critically endangered; however, the baiji, or Chinese river dolphin (*Lipotes vexillifer*), was recently declared extinct due to human-related mortality (Turvey et al. 2007). About 40 baiji were known to be alive in 1998, but none were found during an extensive survey in 2006 (Turvey et al. 2007). Their disappearance indicates that species with populations at low levels can become extinct over relatively short periods of time.

Maui's dolphin is a small coastal dolphin. Maui's dolphins feed opportunistically, both at the bottom and throughout the water column, and have been reported to feed on a variety of species of fish (Miller et al. in press). Some diet variation has been observed between different populations of Hector's dolphins, and the evidence from Maui's dolphins is consistent with that of Hector's dolphins; i.e. red cod (*Pseudophycis bachus*) and āhuru (*Auchenoceros punctatus*) are important in their diet, along with sole (*Peltorhamphus* sp.) (Miller et al. in press). Maui's dolphins are typically found in small groups (average group size 4.7; Oremus et al. in press). Fewer dolphins are sighted in winter and the groups tend to be more dispersed than in summer (Rayment et al. 2006). The dolphins have relatively small ranges along the coastline (average distance approx. 35 km), although movements of up to 80 km have been recorded for some individuals (Oremus et al. in press).

[1] In this document, 'Hector's dolphin(s)' refers to the South Island subspecies (*Cephalorhynchus hectori hectori*), while 'Maui's dolphin(s)' refers to the North Island subspecies (*C. hectori maui*). 'Hector's and Maui's dolphins' refers to both subspecies collectively (*C. hectori*). This approach is taken to avoid confusion and enable distinction between the South Island subspecies and the species as a whole.

The life history of Maui's dolphins makes them particularly susceptible to population decline arising from human impacts. Hector's and Maui's dolphins have a short lifespan for a cetacean, with the oldest recorded individual living to 22 years of age (Rayment et al. 2009). The dolphins mature relatively late, with females becoming sexually mature at 7–9 years of age (Slooten 1991), and they are slow breeders, giving birth to a single calf every 2 to 4 years (Dawson 2008). The resulting low reproductive rate makes them less resilient to impacts arising from anthropogenic threats, and susceptible to population decline. Assuming that Maui's dolphins survive and reproduce at rates similar to their South Island counterparts, a maximum growth of 1.8–4.9% per year can be expected, although 1.8% was deemed the most plausible 'best case' scenario (Slooten & Lad 1991). Thus, a population of 55 could be expected to add only about 1 individual each year on average. Recent capture recapture analysis indicates that the population is in decline, with a survival rate of 84% (95% Confidence Interval (CI): 75–90%) and a rate of population decline of 2.8% per year (95% CI: 10.5% decline to 5.6% increase; Hamner et al. 2012a). However, this growth rate reflects trends between 2001 and 2011 that may not fully reflect population-level effects of management measures put in place in 2008[2]. The confidence intervals reflect statistical uncertainty, but do not necessarily equate to plausible biological bounds.

A revised estimate of potential biological removal (PBR) was calculated in 2012 for Maui's dolphins (see Appendix 1). The PBR is the maximum human-induced mortality that can be sustained by a marine mammal population without preventing that population from reaching or maintaining a population level above their maximum net productivity level with high certainty (Wade 1998). One of the key parameters in the estimation of PBR is R_{max}, which is defined as the maximum net productivity rate of the population at a small size (i.e. unconstrained by density-dependent factors). The net productivity (or population growth rate) is the annual per capita rate of increase resulting from additions due to reproduction, minus losses due to natural mortality (Wade 1998). Depending on the value used for R_{max}[3], the estimated PBR for Maui's dolphins ranges from one dolphin per 10 years to one dolphin per 23 years; this implies that Maui's dolphins can sustain only one human-induced mortality every 10 to 23 years without compromising their ability to reach or maintain (with high certainty) a population level above their maximum net productivity level (see Appendix 1).

1.3 Threats

Threats are defined as any extrinsic factor or activity that may negatively affect the Maui's dolphin population, either by killing individual dolphins, i.e. direct threats, or by changing their population characteristics (e.g. resulting in reduced reproductive output), i.e. indirect threats. The actual level of the effect arising from a threat is referred to as the **impact**; in this context, easily expressed in numbers of dolphin deaths (or equivalent dolphin deaths, for indirect threats) per annum. Population-level **risk** is a function of impact and depends on the inherent biological or population-level characteristics of that population.

Maui's dolphins are exposed to a range of potential threats, both human- and non-human-induced. The non-human-induced threats include naturally occurring causes of mortality such as parasites, disease, predation, extreme weather events and small population effects (MFish & DOC 2007). The intrinsic rate of population increase (R_{max}) accounts for non-human-induced (natural) mortality such that, in the absence of other (human-induced) mortality, a population unaffected by density-dependent limits to growth could still be expected to increase at the estimated maximum population growth rate (R_{max}). Therefore, when trying to determine causes of population decline,

2 For more details on the history of management measures refer to the Maui's dolphin Threat Management Plan 2012: MPI & DOC 2012.

3 PBR calculated with R_{max} of 0.04 (the default value recommended for dolphin populations by Wade (1998)) results in an estimate of 1 dolphin in 10 years. The PBR with R_{max} of 0.018 (the value calculated for Hector's dolphins by Slooten & Lad (1991)) results in an estimate of 1 dolphin in 23 years.

the focus is on human-induced threats and their impact on population growth. In this context, the relative risk posed by specific threats is a function of the estimated level of impact, modified by inherent biological and population level considerations. Impact levels are estimated for each threat as a function of the spatial scale of the threatening activity, the intensity of the activity, and the vulnerability of Maui's dolphins to that particular threat.

Human-induced threats include fishing activities, tourism, petroleum and mineral exploration and mining, and coastal development. Each of these activities has the ability to affect the population directly or indirectly (see Wade et al. 2012).

Direct impacts are those that affect the survival of individuals directly from the activity itself (e.g. bycatch in fishing operations, physical trauma from use of seismic airguns, boat strike). These include direct mortality, but can also include physical trauma or injury that is a direct result of the activity.

Indirect impacts are those that affect the longer-term survival or the reproductive ability of the population and which result indirectly from the activity (e.g. compromised health, poor nutrition from reduced food availability, masking of biologically important behaviours, or displacement from an area). Indirect effects can result in mortality, but not as a direct result of the activity; rather, the mortality may occur much later through reduced fitness or reduced prey availability, or displacement to suboptimal habitat.

1.4 Risk assessment

When decisions need to be made about the management of natural resources, including populations of protected species, managers responsible for such decisions are generally forced to rely upon sparse data subject to considerable uncertainty. Ecological Risk Assessments (ERAs) provide a systematic framework for evaluating the potential implications of different management decisions when information is sparse, incomplete or uncertain (Burgman et al. 1993). Broadly speaking, the challenge of any risk assessment is to assemble whatever relevant knowledge is available—whether quantitative or qualitative, objective or subjective—and devise a means to utilise that knowledge in the most rigorous and objective way possible to estimate the likely consequences of actual or potential actions, while maintaining transparency about the requisite assumptions and inputs, and associated uncertainty.

Discussion of the risk assessment process is often fraught with confusion arising from vague and inconsistent use of language, and the term 'risk assessment' is commonly applied to a wide range of loosely related analytic approaches. It is important to distinguish clearly between different risk assessment approaches and to select the most appropriate approach for a particular management problem, and to be clear about that selection and its implications, taking special care to define the operative terms. The scoring framework can be qualitative, semi-quantitative, quantitative or 'model-based' (Hobday et al. 2007).

In the most common risk assessment approach, risk is calculated as a product of the expected likelihood and expected consequence of an 'event' (i.e. occurrence of the threat or activity in question), combined and assigned a numerical score in a 'likelihood-consequence matrix'. Commonly used qualitative models score various attributes, such as likelihood and consequence, as being low, medium or high. Another example is the SICA method, which scores Scale, Intensity and Consequence in a range from negligible to extreme (Hobday et al. 2007). However, with its emphasis on discrete low-frequency events, the likelihood-consequence approach is not ideally suited for the assessment of risks arising from activities that are predictable, ongoing and cumulative, such as the environmental effects of fishing. In particular, both 'likelihood' and 'consequence' are unavoidably scale-dependent in both time and space, and there is generally a mismatch between the scales at which individual fishing 'events' occur and the scales at which the ecological consequences become manifest in ways that are relevant for management. At these longer and larger scales, the assessed 'events' are certain and multiply, such that risk is a function not of their individual likelihood and consequence, but of their cumulative impact, for which an alternate 'exposure-effects' ERA approach is more suited (e.g. Sharp et al. 2009).

The 'exposure-effects' approach to risk assessment is designed to estimate risks associated with threats that are measurable and ongoing (see US EPA 1992, 1998). Because the impacts associated with those threats are generally not well-known, a two-stage assessment process is required: an impact assessment to estimate the level of the effect associated with each threat, then an evaluation of the associated ecological or population-level consequence (i.e. risk). Because the relationship between impact and risk is affected by the specific biological or population characteristics of the organism in question, this latter stage is best informed by specialist knowledge or population modelling, or may benefit from reference to established benchmarks for evaluating the consequences of impacts at different levels (e.g. PBR for marine mammals).

1.5 A risk assessment for Maui's dolphins

To inform the development of the Maui's dolphin component of the TMP review, all new information on Maui's dolphin biology and potential threats was evaluated and incorporated in a risk assessment workshop process. The purpose of the workshop was to identify, analyse and evaluate all threats to Maui's dolphins and estimate the level of impact and corresponding risk posed by these threats, individually and collectively, to the achievement of management objectives (see MFish & DOC 2007; MPI & DOC 2012). A semi-quantitative risk assessment method consistent with the 'exposure-effects' approach was chosen for this exercise. In the absence of reliable quantitative information from which to estimate impacts on Maui's dolphins arising from different threats in a systematic way, an expert panel considered available data and characterised the nature of each threat, then used their expert judgement to assess the associated impact, but expressed each estimate on a quantitative scale (i.e. dolphin deaths or equivalent dolphin deaths per annum).

An advantage of this approach is that the resulting semi-quantitative impact estimates are expressed on a common scale and are additive for all threats, and the corresponding combined population-level consequences can be expressed quantitatively and compared with empirical estimates. The risk assessment method did not conflate uncertainty with risk; rather, each expert was asked to represent their own estimated uncertainty for each impact score, by defining a triangular distribution (i.e. most likely level of impact plus upper and lower bounds).

All threat characterisations included a spatially explicit characterisation of risk by visually and mathematically representing in a Geographic Information System (GIS) the spatial overlap of the threat (e.g. spatial fishing effort distribution) and the affected population (i.e. the spatial dolphin distribution; see below). As a consequence, even estimates of impacts made by expert judgement could be subsequently disaggregated in space using available spatial data. This allows, for example, the generation of testable hypotheses about levels of impact occurring in particular areas and prediction of the extent to which impact and risk might be reduced using different management measures.

Finally, the outputs of this method are amenable to incremental improvement, such that if reliable quantitative estimates of impact for particular threats become available in the future (e.g. by the acquisition of fisheries observer data to estimate capture rates in particular fisheries), then empirically derived impact estimates can replace the expert-derived estimates for that threat without the need to repeat the risk assessment exercise for all threats.

This report summarises the methodology applied and the results of the risk assessment workshop. Note that the focus of the workshop and of this report is **risk assessment, not risk management**. Management objectives, recommended management measures informed by the outcomes of this workshop and report, and future research priorities are proposed in the Maui's dolphin Threat Management Plan (MPI & DOC 2012)[4].

[4] The Maui's dolphin Threat Management Plan 2012 will be available at www.mpi.govt.nz and www.doc.govt.nz

2. Methods

2.1 Risk assessment workshop

A risk assessment workshop was held in Wellington, New Zealand on 12–13 June 2012. The workshop was facilitated by scientists from the Royal Society of New Zealand, MPI and DOC. The risk assessment scoring was conducted by an expert panel (the panel) comprising domestic and international specialists in marine mammal science and ecological risk assessment. The panellists were selected to ensure a broad range of scientific expertise was represented, including specialists in marine mammal acoustics, ecology, genetics, population biology and taxonomy, as well as ecological risk assessment methodology and its application to fisheries. Representatives (stakeholders) from a range of sectors, including central and local government, environmental NGOs, the fishing industry, the mining industry and iwi, were present to inform the risk assessment scoring by the panel and to ensure transparency in the workshop process.

The workshop began with invited presentations on Hector's and Maui's dolphin biology, including their diet, foraging ecology, demography, population genetics and distribution[5]. Following the presentations, there was directed discussion to produce an agreed map of Maui's dolphin distribution (Fig. 1). This was followed by discussion of risk assessment methodology and then the risk assessment took place.

The method for the risk assessment involved five key steps:

- Defining Maui's dolphin spatial distribution.
- Threat identification.
- Threat characterisation.
- Threat scoring.
- Quantitative analysis.

The risk assessment steps will be discussed consecutively under these headings below. Analysis of cumulative risk combined for all threats was completed by the authors of this report subsequent to the workshop.

2.2 Defining Maui's dolphin spatial distribution

The map of Maui's dolphin[6] distribution was developed from a combination of empirical evidence and expert judgment (Fig. 1, see Appendix 2 for details). Sighting data, from various systematic surveys of Maui's dolphins off the west coast of the North Island (Ferreira & Roberts 2003; Slooten et al. 2005; Scali 2006; Rayment & du Fresne 2007; Childerhouse et al. 2008; Stanley 2009; Hamner et al. 2012a), were modelled to estimate the probability that a dolphin would be seen at a given point, averaged over time. The panel agreed that certain aspects of the resulting modelled distribution did not accurately reflect Maui's dolphin distribution due to limitations

---

5 Assoc. Prof. Liz Slooten (University of Otago) presented a primer on the biology of Hector's and Maui's dolphins, including information on diet, foraging ecology and maximum population growth rate. Rebecca Hamner (Oregon State University) presented the recent estimate of Maui's dolphin abundance (Hamner et al. 2012a) as well as the genetic test results of two recent beachcast dolphins. Dr Finlay Thompson (Dragonfly Science) presented analysis of Maui's dolphin distribution and fishing effort to provide spatial distribution layers for the spatial assessment of risk (Appendix 2).

6 The map of the distribution of Maui's dolphins was produced using a number of information sources, including sightings from aerial and boat surveys, public observations, and expert judgement. The subspecies identity of many of the sightings was unable to be confirmed. While Hector's dolphins have been detected off the North Island West Coast, they are likely to represent a relatively small proportion of the total sightings used to generate the distribution, as they comprised just 4 of the 91 animals that have been genetically sampled within the area of the agreed distribution since 2001. Given that the proportion of Hector's dolphins is likely to be small, the expert panel agreed to proceed with the map produced on the basis that it provided the best estimate of Maui's dolphin distribution available.

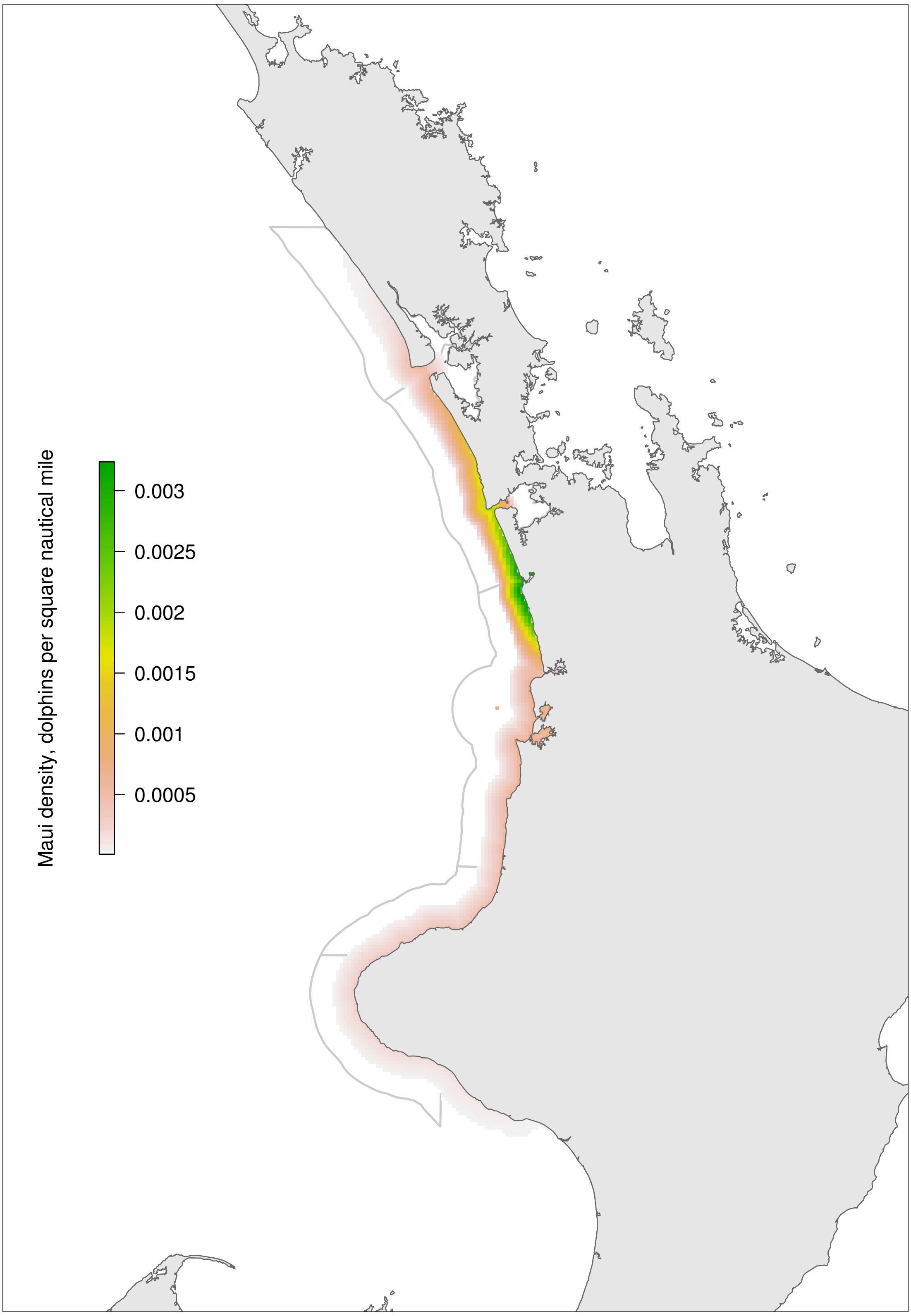

Figure 1. Maui's dolphin distribution as agreed by the expert panel. It was created mostly from the sightings and effort data from nine aerial and biopsy surveys conducted between 2000 and 2012. The distribution has been normalised to one, and so the colours represent the proportion of the dolphin population in each square nautical mile (see Appendix 2 for details). The grey outline marks the extent of the Marine Mammal Sanctuary, including the proposed southern extension.

arising from unequal survey effort, differences in sighting probability in close to shore and differences in survey methodology. Accordingly, the panel agreed that the modelled distribution should be modified to alter the shape of the offshore distribution function and extend the alongshore range further south (see Appendix 2 for details).

2.3 Threat identification

The next step in the risk assessment process was to compile a list of possible threats to Maui's dolphins. The panel worked from a list assembled for the Hector's and Maui's dolphin Threat Management Plan (MFish & DOC 2007) with the addition of tidal power generation. Given that the list of threats was originally developed 6 years ago, and includes threats to both Hector's and Maui's dolphins, the list was presented to the panel to be revised based on the applicability of each threat to Maui's dolphins. The updated list of threats (Table 1), as agreed by the panel with input from stakeholders, then formed the basis of the risk assessment.

2.4 Threat characterisation

The threat characterisation involved initial prioritisation of the threats to be included in the risk assessment followed by a description of the nature of the risk posed to the population. Based on the term of the previous Hector's and Maui's dolphin threat management plan, the risk assessment was time bounded to include threats that were assessed as likely to affect population trends within the next 5 years (Table 1). Threats for which no plausible effect on population trend was anticipated in the next 5 years (either because the threat was unlikely to affect population trends, or was unlikely to be present or occur within the next 5 years) were eliminated from further consideration. The panel undertook an evaluation of whether each threat met this criterion, taking into account feedback from stakeholders. Where a consensus was not achieved among the members of the panel, the threat was included among those subject to further consideration. As a consequence, threats that were poorly understood underwent scoring to ensure their potential impact was still considered and that the level of uncertainty around this threat could be quantified. From this process the expert panel identified 23 threats and eliminated 24 others from further consideration (Table 1).

The 23 threats evaluated by the panel as relevant for Maui's dolphins and with the potential to affect population trends in the next 5 years were then characterised to document the nature of the risk posed to the population. This included qualitative characterisation to identify, for example, the mechanism by which the threat could affect Maui's dolphins; whether the impact is direct, via removals from the population, or indirect, involving a longer-term reduction in survival or fecundity; and the specific component(s) of the population affected (e.g. fecundity, juvenile survival, or adult survival). Each characterisation also involved the use of available spatial data to examine (either visually or, where data to characterise threats was available as spatially comprehensive data layers, mathematically) the spatial overlap between the threat and the dolphin distribution produced in step 1. These spatial overlap maps were valuable during the threat scoring process to provide context for the expert panel regarding the actual intensity of threat exposure experienced by the dolphins, and will also provide a valuable resource for informing evaluation of the effects of alternate spatial risk management options.

The threat characterisation was compiled in summary form and provided to the panel for discussion. Once a consensus was reached, the resulting table (Table 2) was used as the basis for risk assessment scoring.

2.5 Threat scoring

Following the threat characterisation, each threat evaluated by the panel as relevant for Maui's dolphins and likely to affect population trends in the next 5 years was scored. Members of the panel were asked to assess the population-level impact from each of the identified threats to Maui's dolphins over the next 5 years. After discussion, the panellists agreed that the best approach would be to express estimated impact levels in terms of the expected number of Maui's dolphin mortalities (or equivalent mortalities for indirect threats) per year associated with each threat.

Table 1. A list of the threats to Hector's and Maui's dolphins. Threats were evaluated by the panel to assess whether they were applicable to Maui's dolphins and, if so, whether they were likely to affect population trends within the next 5 years.

THREAT CLASS	THREAT	APPLICABLE TO MAUI'S DOLPHINS?	LIKELY TO AFFECT POPULATION TRENDS WITHIN NEXT 5 YEARS?
Fishing	Commercial trawl	Yes	Yes
	Commercial setnet	Yes	Yes
	Commercial driftnet	No	N/A
	Recreational setnet	Yes	Yes
	Recreational driftnet	Yes	Yes
	Customary setnets	Yes	Yes
	Craypot entanglement	No	N/A
	Trophic effects	Yes	Yes
	Vessel noise: displacement, sonar	Yes	Yes
Shellfish farming	Displacement	Yes	No
	Pollution	Yes	No
Finfish farming	Displacement	Yes	No
	Pollution	Yes	No
	Entanglement	Yes	No
Tourism	Boat strike	Yes	No
	Noise	Yes	No
	Disturbance	Yes	No
	Displacement	Yes	No
Vessel traffic	Boat strike	Yes	Yes
	Disturbance	Yes	Yes
Pollution	Agricultural run-off	Yes	Yes
	Industrial run-off	Yes	Yes
	Plastics	Yes	Yes
	Oil spills	Yes	Yes
	Trophic effects	Yes	Yes
	Sewage and stormwater	Yes	Yes
Coastal development	Marinas, ports	No	N/A
	Displacement, noise, pollution, sedimentation	Yes	No
	Wave power generation	Yes	No
	Tidal power generation	Yes	No
Disease	Natural	Yes	Yes
	Stress-induced	Yes	Yes
	Domestic animal vectors	Yes	Yes
Small population effects	Stochastic and Allee effects*	Yes	Yes
Mining and oil activities	Noise (non-trauma)	Yes	Yes
	Noise (trauma)	Yes	Yes
	Pollution (discharge)	Yes	Yes
	Habitat degradation	Yes	Yes
Climate/environmental change	Temperature	No	N/A
	Prey availability	No	N/A
	Displacement	No	N/A
Shooting	Shooting	No	N/A
Research	Physical	No	N/A
	Disturbance	No	N/A
Predation	Predation	No	N/A
Inbreeding	Inbreeding	No	N/A
Military operations	Military operations	No	N/A

* Stochastic effects refers to the inherent variability in the survival and reproductive success of individuals, which can result in fluctuating population trends for small populations (Courchamp et al. 2008). These effects are distinct from depensation or Allee effects that small populations may also experience if the survival or reproduction of individuals is compromised when they are at low abundance (Stephens et al. 1999; Courchamp et al. 2008). In this report, the term 'small population effects' is used to describe both stochastic and Allee effects of small population size.

Table 2. Characterisation of threats evaluated as relevant to Maui's dolphins and likely to affect population trends within the next 5 years.

THREAT CLASS	THREAT	MECHANISM	TYPE	POPULATION COMPONENT(S) AFFECTED
Fishing	Commercial trawl	Incidental capture, cryptic mortality	Direct	Juvenile or adult survival
	Commercial setnet	Incidental capture, cryptic mortality	Direct	Juvenile or adult survival
	Recreational setnet	Incidental capture, cryptic mortality	Direct	Juvenile or adult survival
	Recreational driftnet	Incidental capture, cryptic mortality	Direct	Juvenile or adult survival
	Customary setnet	Incidental capture, cryptic mortality	Direct	Juvenile or adult survival
	Trophic effects	Competition for prey, changes in abundance of prey and predator species	Indirect	Fecundity, juvenile or adult survival
	Vessel noise: displacement, sonar	Displacement from habitat, masking biologically important behaviour	Indirect	Fecundity, juvenile or adult survival
Vessel traffic	Boat strike	Physical injury/mortality	Direct	Juvenile or adult survival
	Disturbance	Displacement from habitat, masking biologically important behaviour	Indirect	Fecundity, juvenile or adult survival
Pollution	Agricultural run-off	Compromising dolphin health, habitat degradation, trophic effects	Indirect	Fecundity, juvenile or adult survival
	Industrial run-off	Compromising dolphin health, habitat degradation, trophic effects	Indirect	Fecundity, juvenile or adult survival
	Plastics	Compromising dolphin health, ingestion and entanglement	Both	Fecundity, juvenile or adult survival
	Oil spills	Compromising dolphin health, ingestion (direct & prey) and inhalation	Both	Fecundity, juvenile or adult survival
	Trophic effects	Changes in abundance of prey and predator species	Indirect survival	Fecundity, juvenile or adult
	Sewage and stormwater	Compromising dolphin health, habitat degradation, trophic effects	Indirect survival	Fecundity, juvenile or adult
Disease	Natural	Compromising dolphin health	Both	Fecundity, juvenile or adult survival
	Stress-induced	Compromising dolphin health	Both	Fecundity, juvenile or adult survival
	Domestic animal vectors	Compromising dolphin health	Both	Fecundity, juvenile or adult survival
Small population effects	Stochastic and Allee effects	Increased susceptibility to other threats	Indirect	Fecundity, juvenile or adult survival
Mining and oil activities	Noise (non-trauma)	Displacement from habitat, masking biologically important behaviour	Indirect	Fecundity, juvenile or adult survival
	Noise (trauma)	Compromising dolphin health	Direct	Fecundity, juvenile or adult survival
	Pollution (discharge)	Compromising dolphin health	Indirect	Fecundity, juvenile or adult survival
	Habitat degradation	Displacement from habitat, reduced foraging efficiency, trophic effects	Indirect	Fecundity, juvenile or adult survival

For indirect threats, panellists elected to either estimate a mortality level equivalent to the population consequences of the threat, or to estimate the equivalent impact on population growth rate (λ), which was then transformed into a mortality estimate. Mortality estimates were based on the current level of risk posed by the threat, considering the presence and efficacy of existing risk management measures (e.g. fisheries restrictions existing at the time of the workshop). Interim fisheries restrictions introduced in the Taranaki region since the workshop was held were not considered, meaning risk was estimated as if these restrictions were not in effect. These estimates represented a judgement by the panel members, given available information and taking into account input from stakeholders and other informed workshop attendees (e.g. regional government officials with relevant local knowledge). The resulting estimates permit an assessment of population-level impact arising from each threat.

To inform the scoring process, the panel was presented with background material (du Fresne et al. 2012; Appendices 1 & 2). The background material included information specific to Maui's dolphins as well as material from research on Hector's dolphins (du Fresne et al. 2012). The panel agreed that information from Hector's dolphins could be used as a proxy in situations where information was limited for Maui's dolphins. Further, DOC and MPI staff compiled relevant spatial data to plot the spatial distribution of activities identified as threats to Maui's dolphins. The data layers were analysed in advance of the workshop and displayed by GIS experts at the workshop in real time. Based on the advice of the panel, the mortality associated with the two natural threats in the threat characterisation (natural diseases and small population effects) was not estimated separately. Instead, the level of mortality from these threats and their population consequences were considered to be incorporated within the choice of maximum population growth rate used in the quantitative analysis. The panel agreed to use the maximum population growth rate suggested for Hector's dolphins by Slooten & Lad (1991), i.e. 1.8% per annum.

Each panel member was asked to estimate the number of Maui's dolphin mortalities per year for each threat, along with an upper and lower bound representing uncertainty. The individual estimates were then presented back to the workshop. The panel was provided with an opportunity to discuss the results, and individual panel members were permitted to update their estimates following these discussions. The updated estimates, including upper and lower bounds, were then recorded.

Subsequent to the workshop, during data analysis and report preparation, estimates of cumulative impact from all combined threats were compiled by workshop facilitators and corresponding estimates of population growth rate were generated. Expert panellists were re-contacted at this time and offered the opportunity to update their scores in light of the combined population growth or decline rate implied by their threat-specific impact estimates. This was to ensure that the combined population-level consequences of cumulative impacts were considered and the combined mortality estimates were not influenced by the level of threat disaggregation. The panellists' final estimates were then used for the quantitative analysis.

2.6 Quantitative analysis

To preserve the uncertainty of individual expert scores in subsequent analysis of cumulative impacts and population-level consequences, each individual expert score for each threat was resampled using a parametric bootstrap (10 000 samples) from the distribution specified by the expert. If no alternate distribution was specified, the panel agreed to apply a default triangular distribution that peaked at the expert's best estimate of impact and tailed off linearly to zero at the lower and upper bounds. These distributions were aggregated with equal weighting to produce impact distributions representing estimated annual Maui's dolphin mortalities for each threat, for each threat class, for each expert, and combined across all threats and experts. The aggregated distributions across all experts incorporate estimates of uncertainty provided by individual panellists as well as the degree of consensus among the panellists. To summarise these distributions and reflect associated uncertainty, we reported medians[7] and 95% confidence intervals in the results.

To represent the population-level consequence associated with estimated impacts, we applied two different approaches: first, we generated a corresponding rate of population growth or change (λ); second, we estimated a risk ratio (RR), i.e. the level of estimated population mortality as a proportion of the Potential Biological Removals (PBR).

To estimate λ and RR, we bootstrap resampled (10 000 samples) using distributions (see below) for each of the parameters in the following formulae:

---

7 Medians are measures of central tendency that are robust to skewed data (when compared with arithmetic means). However, as medians are contingent on the shape of their underlying distribution, multiple medians cannot be summed.

$$\lambda = (N\lambda_{max} - MP)/N \quad (1)$$

$$RR = M/PBR \quad (2)$$

Where:

- N was the most recent abundance estimate (55 animals over 1 year of age; 95% CI: 48–69; selected from an empirical distribution applying Chao's (1989) formula for sparse data; Hamner et al. 2012a).
- λ_{max} was the maximum population growth rate fixed as agreed by the panel (1.8 % per annum; Slooten & Lad 1991).
- M was the total estimated human-induced mortalities combined across all threats as scored by the panel, with a distribution estimated from the expert score resampling.
- P was the proportion of total estimated threat-induced mortalities that were of individuals over 1 year of age (fixed at 100%).
- PBR was the level of potential biological removal provided to the panel (1 dolphin every 10 to 23 years; which was simulated as a uniform distribution between 0.1 and 0.044 to incorporate uncertainty, Appendix 1).

This approach assumed that the current population is at a proportion of carrying capacity sufficiently low as not to be subject to the density-dependent effects on population growth rate that affect populations near carrying capacity and, noting that any small population effects are reflected in the value chosen for λ_{max}. To summarise these distributions in the results, we report medians and 95% confidence intervals as well as the likelihood of threat-induced mortalities exceeding reference limits such as PBR (i.e. RR > 1) or the level of surplus production (i.e. $\lambda < 1$). These reference limits provide measures of the biological sustainability of threats individually or cumulatively.

3. Results

3.1 Estimated mortality

The panel estimated that there were likely to be 5.27 (95% CI: 0.97–8.40) Maui's dolphin mortalities per annum from all threats over the next 5 years (Fig. 2). The broad range of the confidence intervals of mortality estimates reflected the uncertainty of individual panellists as well as the degree of consensus among them in their estimated levels of mortality. The bimodal shape of the distribution resulted from differences in overall mortality estimates between panellists. While eight of nine panellists provided scores that were broadly consistent and relatively uncertain, one expert provided estimates that were significantly lower and comparatively more certain (Table 3). Subsequent analyses retain the outlying expert's estimates to ensure the findings are robust to diverging views among panellists.

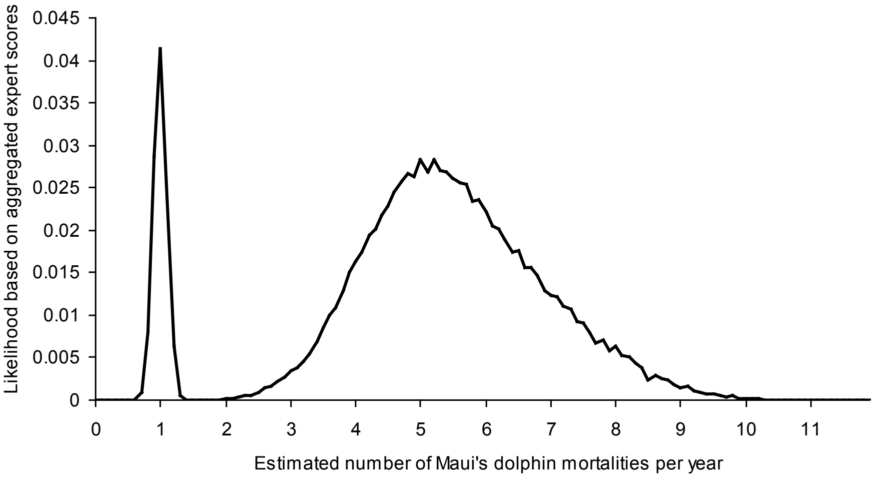

Figure 2. Distribution of estimated Maui's dolphin mortalities per year for all threats as scored by the panel. Individual scores were bootstrap resampled from distributions specified by the panel and aggregated to provide an overall distribution that incorporates uncertainty and the degree of consensus.

Table 3. Estimated number of Maui's dolphin mortalities per year arising from fishing-related threats and from all threats combined, as scored by each member of the panel. Individual threat scores were bootstrap resampled from distributions specified by the panellists and aggregated to generate medians and 95% confidence intervals.

EXPERT	FISHING-RELATED			ALL THREATS			PROPORTION FROM FISHING
	MEDIAN	95% CI LOWER	95% CI UPPER	MEDIAN	95% CI LOWER	95% CI UPPER	MEDIAN PERCENTAGE
Expert A	0.31	0.23	0.41	1.04	0.84	1.24	30.1
Expert B	4.17	2.26	6.55	4.53	2.62	6.91	92.3
Expert C	4.69	3.41	6.22	4.78	3.51	6.31	98.3
Expert D	4.77	3.34	5.94	4.86	3.43	6.03	98.3
Expert E	4.97	2.95	6.95	5.11	3.16	7.07	96.8
Expert F	4.81	3.06	6.54	5.43	3.67	7.21	88.3
Expert G	5.77	4.15	7.88	6.13	3.94	8.47	89.1
Expert H	5.91	3.69	8.19	6.48	4.83	8.54	96.4
Expert I	7.00	5.05	9.22	7.24	5.30	9.58	96.4
Total	**4.97**	**0.28**	**8.04**	**5.27**	**0.97**	**8.39**	**95.5**

The panel estimated that fishing-related threats were responsible for 4.97 (95% CI: 0.28–8.04) Maui's dolphin mortalities per annum, or 95.5% of total human-associated mortalities (Table 3). In comparison, non-fishing-related threats (of which mining and oil activities, vessel traffic, pollution and disease generated non-zero impacts) were estimated to contribute 0.27 (95% CI: 0.05–0.90) Maui's dolphin mortalities per annum, or 4.5% of total threat-associated mortalities (Table 4).

Table 4. Estimated Maui's dolphin mortalities per year, the risk ratio of mortalities to PBR and the likelihood of exceeding PBR for each threat class, as scored by the panel. Individual threat scores were bootstrap resampled from distributions specified by the panel and aggregated to generate medians and 95% confidence intervals.

THREAT CLASS	ESTIMATED MORTALITIES			RISK RATIO			LIKLIHOOD OF EXCEEDING PBR
	MEDIAN	95% CI LOWER	95% CI UPPER	MEDIAN	95% CI LOWER	95% CI UPPER	MEDIAN PERCENTAGE
Fishing	4.97	0.28	8.04	71.5	3.7	143.6	100.0
Mining and oil activities	0.10	0.01	0.46	1.5	0.1	7.4	61.3
Vessel traffic	0.07	<0.01	0.19	1.0	0.1	3.1	47.8
Pollution	0.05	<0.01	0.36	0.8	<0.1	5.9	40.2
Disease	<0.01	<0.01	0.36	<0.1	<0.1	5.5	29.5
Total	**5.27**	**0.97**	**8.39**	**75.5**	**12.4**	**150.7**	**100.0**

The estimated distributions of overall estimated mortality (Fig. 2) and fishing-related mortality (Fig. 3) were both broad and bimodal. This reflects both estimates of uncertainty by individual panellists as well as the different impact estimates among panellists. The degree of divergence between panellists was more pronounced for fishing-related mortality estimates than for overall mortality estimates, resulting in a difference in both the number and the proportion of estimated mortalities from fishing (Table 3).

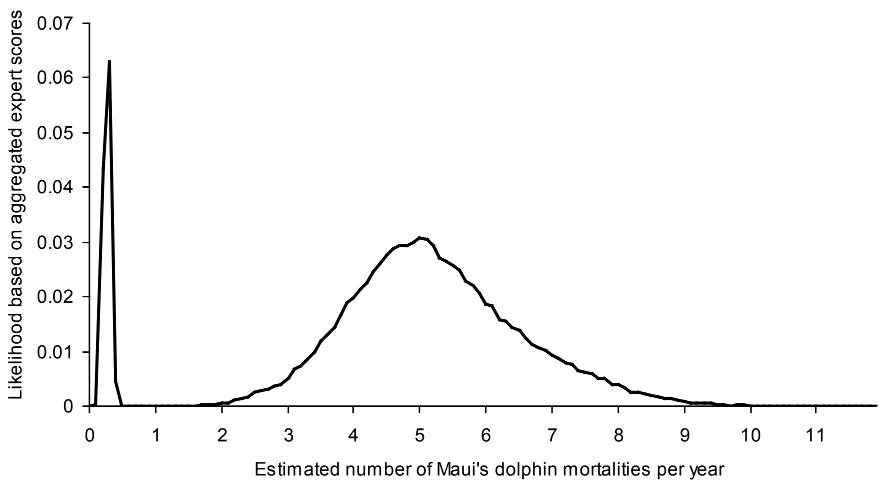

Figure 3. Distribution of estimated Maui's dolphin mortalities per year from all fisheries-related threats, as scored by the panel. Individual scores were bootstrap resampled from distributions specified by the panel and aggregated to provide an overall distribution that incorporates uncertainty and the degree of consensus.

Commercial setnet, commercial trawl and recreational/customary setnet fisheries were the threats estimated to have the greatest impact on Maui's dolphins (Fig. 4). The median estimated numbers of Maui's dolphin mortalities from commercial setnet, commercial trawl and recreational/ customary setnet fisheries were 2.33 (95% CI: 0.02–4.26), 1.13 (95% CI: 0.01–2.87) and 0.88 (95% CI: 0.02–3.14) dolphins per year respectively (see Appendix 3 for a complete list of threats and associated estimated mortalities). Despite the lack of consensus among panellists about the impact of fishing-related activities, the relative importance of commercial setnet, commercial trawl and recreational/customary setnet fisheries was unchanged whether the one outlying expert's estimates were included or not (see Appendix 3).

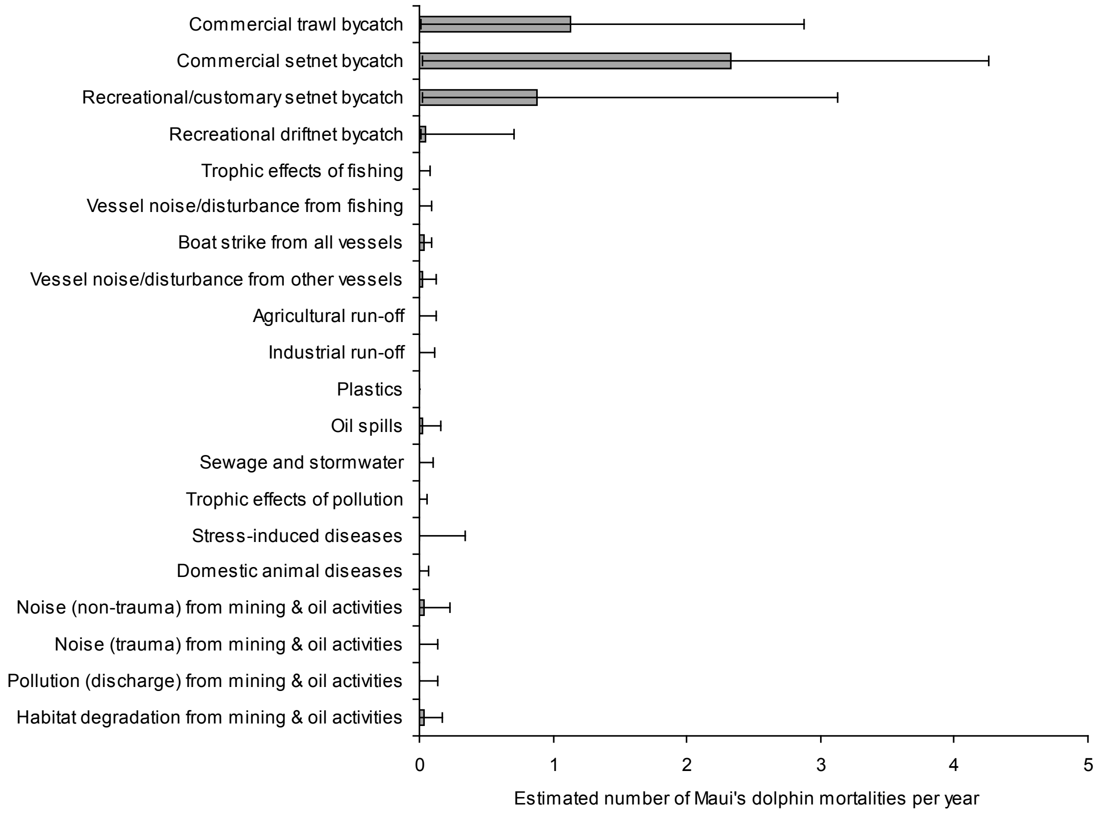

Figure 4. Estimated Maui's dolphin mortalities per year for each threat, as scored by the panel. Individual threat scores were bootstrap resampled from distributions specified by the panel and aggregated to generate medians (shaded bars) and 95% confidence intervals (error bars).

3.2 Population level impact

The level of combined impact from all threats as estimated by the expert panel is considerably higher than the population can sustain, given a maximum population growth rate of 1.8% per annum. Population projections based on the panel's estimated total mortalities suggest that there is a 95.7% likelihood of population decline in the population of Maui's dolphins over the next 5 years. The population projections suggest that, at the current rate of human-induced mortality, the population will decline at 7.6% per annum (95% CI: 13.8% decline to 0.1% increase); Fig. 5. The panel's scores suggest a rate of population change that is more negative than, but broadly consistent with, a recent empirical estimate (Hamner et al. 2012a; Fig. 6). Total estimated Maui's dolphin mortalities equate to a risk ratio of 75.5 (95% CI: 12.4–150.7) times the level of the PBR (Table 4; see Appendix 3 for a complete list of threats and associated risk ratios). Each threat class had at least a 30% chance of exceeding the PBR in the absence of other threats (Table 4).

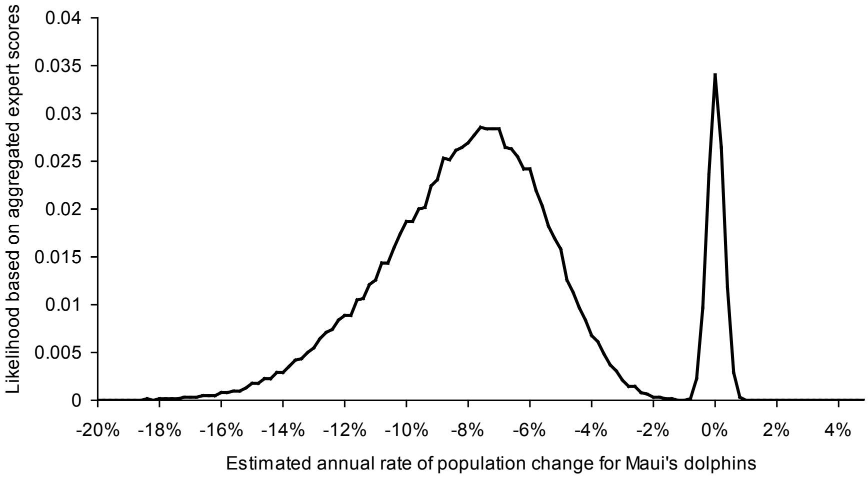

Figure 5. Estimated annual rate of population growth or decline for Maui's dolphins given the estimated mortalities per year across all threats scored by the panel. Estimates were generated via bootstrap resampling of mortality and abundance estimates to provide an overall distribution that incorporates uncertainty and the degree of consensus.

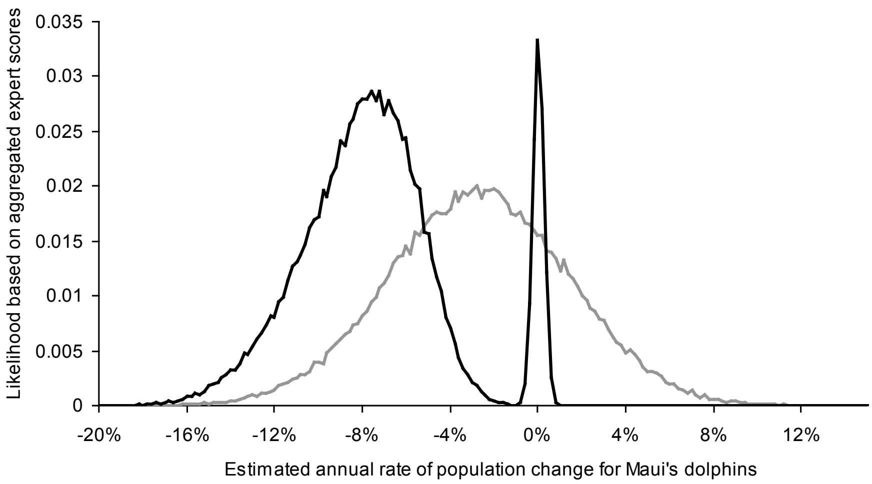

Figure 6. Estimated annual rate of population growth or decline for Maui's dolphins given the estimated mortalities per year across all threats scored by the panel (black) compared with an empirical estimate (grey) generated via bootstrap resampling the estimate of Hamner et al. (2012a).

3.3 Spatial distribution

In the initial characterisation of specific threats, the panel characterised the spatial overlap between the dolphin distribution and the spatial distribution of each threat, as a proxy for the overall threat intensity experienced by the dolphins.

Following threat scoring, these spatial overlap maps were examined in greater detail for the two threats estimated to pose the greatest level of risk to Maui's dolphins, i.e. commercial setnet and trawl fisheries. For these threats, the spatial overlap maps were generated empirically by multiplying the average annual fishing intensity under the current spatial management regime (i.e. 2008–2011 for setnets and 2008–2011 for trawls) by the relative dolphin density in each spatial cell on a fine scale (cell size = 1 nautical mile (n.m.)). The resulting maps (Figs 7 & 8) provide an empirically derived representation of the spatial distribution of impact and risk arising from each of these threats; the total impact estimates generated by the expert panel can be disaggregated and assigned quantitatively to each cell proportional to their relative values in Figs 7 & 8.

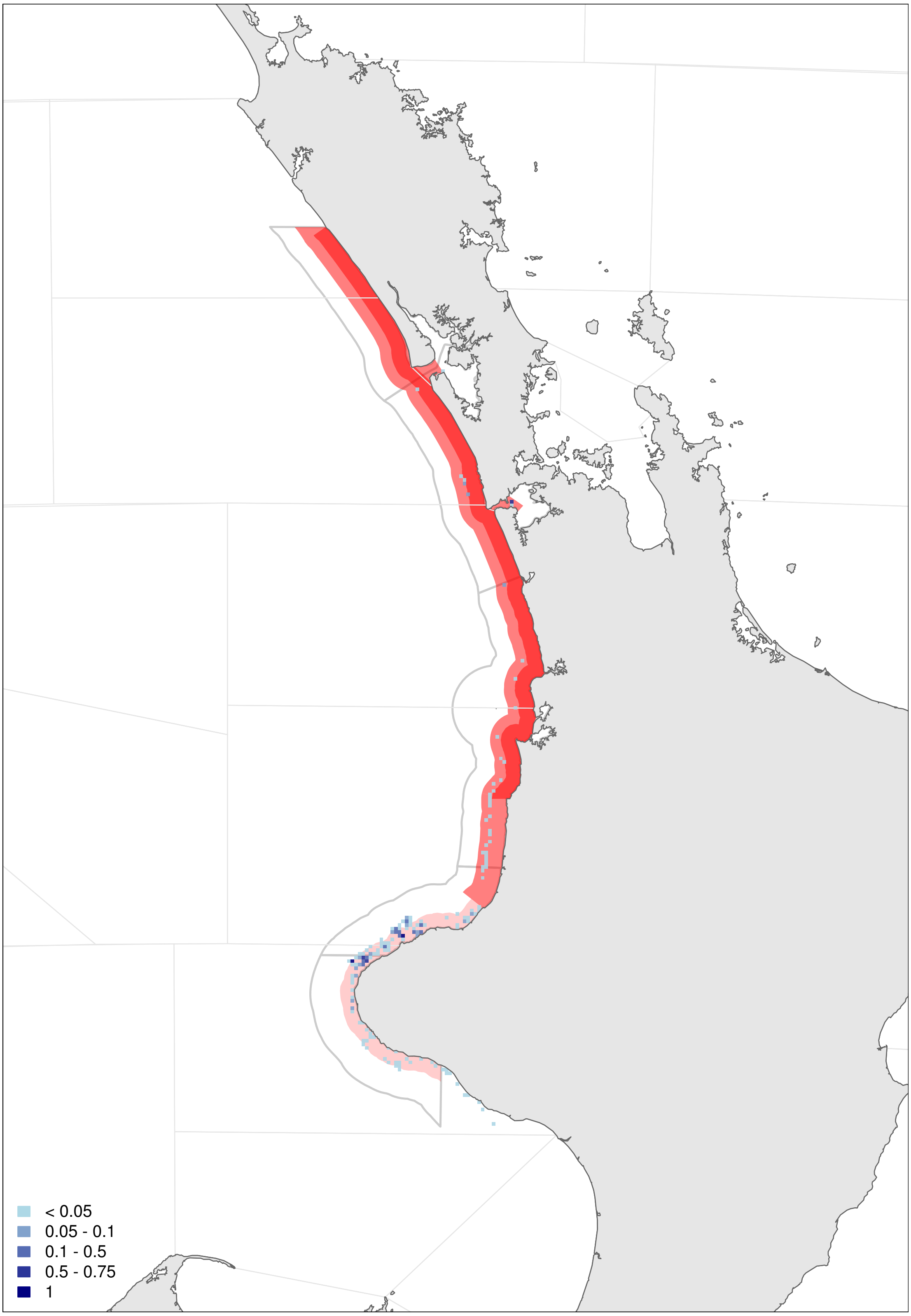

Figure 7. Intersection of Maui's dolphin distribution (Fig. 1) with all setnet effort between 2008 and 2011. The intersection is calculated by multiplying the fishing effort with the dolphin distribution value in each cell (as shown in blue). The values have been scaled to indicate relative intensity, with the maximum intersection having a value of 1. The existing and proposed areas closed to setnet fishing are indicated in shades of red[8]. The marine mammal sanctuary is outlined in grey, including the proposed extension to the sanctuary in southern Taranaki (see Appendix 2 for further details).

[8] Not all fisheries closures displayed in this map were in effect throughout the 2008–2011 period. The palest red region around Taranaki was the area proposed for closure under interim measures at the time of the workshop.

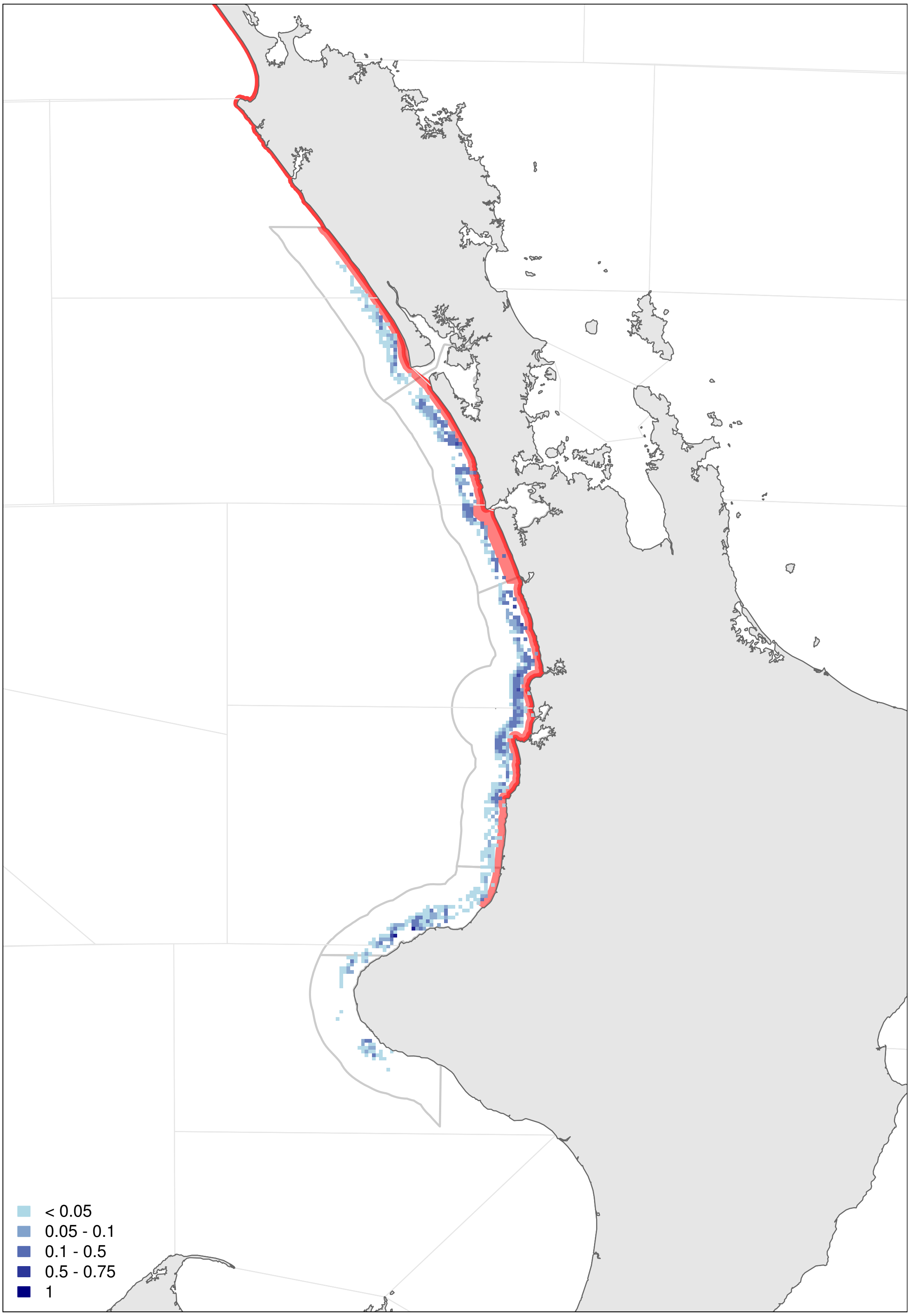

Figure 8. Intersection of Maui's dolphin distribution (Fig. 1) with all trawl effort between 2008 and 2011. The intersection (shown in blue) is calculated by multiplying the fishing effort with the dolphin distribution value in each cell. The values have been scaled to indicate relative intensity, with the maximum intersection having a value of 1. The areas closed to trawl fishing are indicated in red. The marine mammal sanctuary is outlined in grey, including the proposed extension to the sanctuary in southern Taranaki (see Appendix 2 for further details).

Figure 7 reveals that Maui's dolphins are exposed to the greatest level of risk from setnet fisheries in the area of the northern Taranaki coastline out to 7 n.m. offshore, and at the entrance to the Manukau Harbour. Figure 8 reveals that Maui's dolphins are exposed to the greatest level of risk from inshore trawl fisheries between the boundary of the trawl fishery closures areas (that extend 2 or 4 n.m. offshore) and 7 n.m. offshore, particularly in the core region of dolphin distribution (from Raglan Harbour entrance to the Kaipara Harbour entrance).

These maps, in combination with the expert-panel-derived estimates of total fisheries-associated impact from these methods, can be used to generate testable hypotheses of expected impact levels in particular locations, which could be tested or updated in future using actual data, e.g. from deploying fisheries observers (as in Richard et al. 2011). The absence of spatial information for recreational and customary setnet effort at comparable spatial resolution prevented the workshop from generating similarly precise spatial estimates of relative risk, but the application of lower-resolution spatial estimates of the relative prevalence of these threats (e.g. regional-level data from local compliance or fisheries officials) may prove valuable.

4. Discussion

4.1 Risk assessment for Maui's dolphins

The risk assessment process indicates that the long-term viability of the Maui's dolphin population remains at risk from human-induced mortality. Cumulative mortality estimates of 5.27 dolphins per year (95% CI: 0.97–8.40) cannot be sustained by a population with only 55 individuals over 1 year of age (95% CI: 48 to 69; Hamner et al. 2012a) with a maximum rate of increase of 1.8% per year. The present estimates of mortality are 76 times greater than the PBR, a level that would allow Maui's dolphins to reach or maintain a population level above their maximum net productivity level with high certainty (Wade 1998). This means that, exposed to the current level of threat, the population is highly unlikely to recover. Indeed, quantitative analysis using the panel's estimates of mortality (with associated uncertainty) indicated a 95.7% likelihood of ongoing population decline, with a median rate of population decline of 7.6% per annum.

Fishing-related threats were assessed by the panel as posing greatest risk to Maui's dolphins, particularly bycatch in commercial setnets, commercial trawl nets and recreational or customary setnets. Fishing-related activities accounted for 95.5% of total Maui's dolphin mortalities as estimated by the panel, and mortalities associated with fishing were assessed as having a 100% likelihood of exceeding the PBR, even in the absence of other threats. This is consistent with the conclusions of the Hector's and Maui's dolphin Threat Management Plan (2007; p. 12) that *it is believed that the effects of fishing are the greatest cause of human-induced mortality on the dolphins and the effect of fishing related mortality is likely to be greatest on populations that are small because the level of mortality they can sustain will be less*. The panel's estimates are also broadly consistent with a number of studies that have assessed the risk posed by commercial setnet fisheries to population trends for Hector's and Maui's dolphins (Slooten 2007; Davies et al. 2008; Slooten & Dawson 2010; Slooten & Davies 2012). Their general conclusion that setnet bycatch is likely to be driving ongoing population decline is consistent with the findings of this study. Similar findings have been made for similar small cetacean populations, including vaquita in the Gulf of California (Jaramillo-Legorreta et al. 2007; Gerrodette et al. 2011), and harbour porpoises (*Phocoena phocoena*) in the Baltic Sea (Berggren et al. 2002). Marine mammal bycatch in setnet fisheries is a global issue. In the 1990s, 84% of cetacean bycatch in the USA and most of the world's cetacean bycatch occurred in setnet fisheries (Read et al. 2006).

Among the non-fishing-related threats considered by the panel, mining and oil activities, vessel traffic, pollution and disease were all assessed as posing risk to Maui's dolphins over the next 5 years. Collectively, they represented 4.5% of total Maui's dolphin mortalities as estimated by the panel. However, impacts arising from each of these threats were identified as having between a 30% and 60% likelihood of exceeding the PBR, even in the absence of other threats, suggesting that non-fisheries threats may be expected to delay or prevent the recovery of the population even if all fishing-related mortality was eliminated. The different components of prospecting, exploration and active mining for petroleum and minerals have the ability to impact the Maui's dolphin population in a number of ways, both direct and indirect, through noise, increased vessel traffic, pollution, degradation of habitat and trophic interactions (Thompson 2012). Since the workshop, new research has identified the protozoan *Toxoplasma gondii* as the cause of death for 7 of 28 Hector's and Maui's dolphins in fresh enough condition to be examined since 2007 (a total of 54 were submitted for necropsy) (W. Roe, Massey University, unpubl. data, 31 July 2012). Land-based runoff containing cat faeces is believed to be the means by which *Toxoplasma gondii* enters the marine environment (Hill & Dubey 2002), potentially putting inshore coastal dolphin species at risk of infection. The panel's assessment of the risk posed by disease did not include this information, because it was not available at the time of the workshop.

The panel chose to include or exclude individual threats from this assessment based on their judgement of the likelihood of each threat having an impact on the Maui's dolphin population in the next 5 years. As a consequence, the risk assessment focused on current levels of risk arising from activities that are already occurring within the Maui's dolphin range or can be anticipated to occur with some level of regularity. It was noted, though, that some threats may increase in the future and that these activities should not be ignored. Threats that were considered likely to have a minimal impact on the population were not assessed, but where consensus was not reached, or the panel considered the potential consequence of an unlikely event to be high (e.g. oil spill), they were assessed. However, such threats generally resulted in low median estimates with quite wide confidence intervals. This probably reflects, in part, the low likelihood of the event occurring, but may not adequately represent the high consequence of an event should one occur. For these reasons, the panel and the stakeholders present at the workshop recommended that these potential threats be monitored and considered in future risk assessments for Maui's dolphins. Panel experts emphasised that this assessment of current risks does not replace the need for forward-looking impact assessments associated with proposed new activities.

4.2 Application of the semi-quantitative methodology

The semi-quantitative methodology developed and applied for this risk assessment provides a useful template for risk assessments for other threatened, endangered or protected species or for ecosystem-based risk assessments. The following discussion highlights the strengths and weaknesses of the method and provides suggestions for its future use.

The mortality estimates provided by the panel are analogous to a severity or consequence score in a more traditional ecological risk assessment process. However, a notable difference is that the semi-quantitative approach provides an absolute estimate of population-level impact arising from each threat, such that each impact is expressed in a common currency for all threats, making it possible to generate estimates of combined impact and risk and corresponding expected population trajectories. Moving from a relative measure of risk (as in more traditional approaches) to an absolute measure of impact makes the results more biologically meaningful, more amenable to empirical validation and incremental improvement using new sources of data, and more informative for risk management.

The semi-quantitative method used here was designed to be able to incorporate change. For example, as new information becomes available, including empirical impact estimates (e.g. from independent fisheries observers), the scores can be updated or selectively replaced, and the resultant estimate of combined impact and risk will change in a logical and transparent way. This ease of modification and repeatability with new information also enables trends in risk over time to be compared. The method can be used for other protected species, such as the South Island Hector's dolphin subspecies, and would allow for comparisons between populations and species for a given threat. Several new approaches to fisheries risk assessment estimate the impact of a particular fishing method across a range of species, and the environment (Milton 2001; Stobutzki et al. 2001; Griffiths et al. 2006; Sharp et al. 2009; Zhou et al. 2009; Fillipi et al. 2010; Sharp et al. 2011; Richard et al. 2011). Using spatial data and scoring based on the number of mortalities per year or the proportion of habitat modified by the given threat, this method could likewise be applied in other contexts.

Another valuable tool that the semi-quantitative method offers is the ability to disaggregate the level of impact each of the individual threats has on the population, as well as to assess the cumulative risk posed by all threats combined. Threats do not act on a population in isolation, so it is important to consider all threats having an effect on the population as well as the potential interaction of threats.

Another benefit of using a semi-quantitative method for assessing risk is the treatment of uncertainty. More qualitative risk assessments tend to conflate uncertainty and risk on the same scale, thereby making it difficult to detect the difference between the two (Hobday et al. 2007). The present method reflects and enables visualisation of two key forms of uncertainty—individual expert uncertainty and the degree of consensus between experts (equivalent to parameter uncertainty, and model uncertainty, Burnham & Anderson 2002). This approach also enables estimation of the likelihood of specific outcomes (e.g. the likelihood of mortality exceeding the PBR, the likelihood of population decline) in a way that explicitly acknowledges the uncertainties involved. Future applications of this approach would benefit from disaggregating individual expert uncertainty further to separate variability (naturally occurring, unpredictable change in the circumstances leading to mortalities) from uncertainty (lack of data upon which to make more confident estimates of mortality).

One issue with qualitative assessments is the potential for human bias to influence the experts' scores. To avoid this, a quantitative approach similar to that used for assessing trawl fisheries risk to sea snakes in Australia's Northern Prawn Fishery (Milton 2001) could be used. However, where data are sparse or don't exist, a semi-quantitative approach that utilises expert judgement can be employed. The semi-quantitative method employed for the Maui's dolphin assessment was more complex than simple categorical scoring of low, medium, high, and required the expert panel to have knowledge and understanding of a number of factors, including:

- The biology of the dolphins.
- Their distribution.
- The frequency and area of operation of the potential threats.
- How the threats might impact on the dolphin population.

Where data are lacking, judgements can draw on information and experiences gained in other locations or with other species.

When a risk assessment method that is dependent on expert judgement is used, it is important to bear in mind the many factors that can affect an expert's perception of risk. These include overconfidence, bias, anchoring (deferral to other expert judgements), beliefs and values, and the level of comfort with the elicitation method. Although it is impossible to completely remove human bias, the effect of bias can be mitigated. The present method aimed to minimise human bias in a number of ways, including:

- Using a series of presentations at the beginning of the workshop to make background information available to everyone at the start of the process.

- Circulating information (such as the Maui's dolphin bibliography and draft PBR report) to the expert panel members prior to the workshop.
- Having invited stakeholders present at the workshop and allowing the panel to ask for clarification from the stakeholders about some of the processes (e.g. mining methods and risk assessment, safety procedures).
- Presenting spatial data on pre-prepared maps and diagrams.
- Having all expert panel members present and then discussing their respective mortality estimates during the workshop.
- Providing individual panellists the opportunity to rescore in light of the population-level effects of their estimates of cumulative impact.

To address the lack of observational data for Maui's dolphins in general and the impacts of threats on them in particular, spatial data were collated from as many activities or proxies for threats (e.g. human settlements, river mouths, discharge points etc. for pollution and coastal development) as possible. This information was displayed by GIS experts in real time, providing a visual representation of where the dolphins and the threats occur. This allowed the workshop to assess the spatial overlap between the threats and the dolphins and to judge what they believed the likelihood and consequence of areas of overlap would be in terms of number of dolphin mortalities per year. Mapping made it possible for the workshop to focus on what was known about each threat while stakeholders were present, which aids quality assurance (people can point out problems or omissions with the data) and provides context to the other data presented. This meant that, even where data on the actual impacts of an activity on Maui's dolphins were sparse, occurrence data combined with knowledge of the species in question could be used to formulate expert judgements while minimising human bias (Macguire 2004; Kerns & Ager 2007).

Another potential issue with use of this semi-quantitative approach is time constraints. The proposal to utilise a novel risk assessment method required agreement from the expert panel on how the method would work. This, together with addressing all potential threats to Maui's dolphins, resulted in the workshop being time constrained. However, the panel was able to score all threats prioritised for scoring during the workshop, and the panellists were then provided with their aggregate scores and overall estimate of mortality and rate of population decline following the workshop and given the opportunity to adjust their scores in this follow-up process. The authors therefore consider it unlikely that time constraints compromised the final outcome.

Another benefit of the semi-quantitative approach is that it generated testable hypotheses about how impacts associated with different threats are likely to affect the Maui's dolphin population. This can assist with planning subsequent research aimed at improving our understanding of the risks to the dolphins.

4.3 Possible improvements for future risk assessments

Other work that would have been valuable to do as part of the risk assessment for Maui's dolphins included determining the area of impact for point source threats, such as vessel discharge, or from mining activities, and determining the spatial overlap between all potential threatening activities and dolphin distribution. This would have allowed identification of the areas where the combined risk to the dolphins is greatest.

It would be advantageous for future assessments to obtain as much quantitative and spatially explicit analysis of priority threats as possible prior to the workshop. The most reliable (and therefore defensible) way of estimating the impacts of any threat is to observe those impacts directly. However, it is not possible to observe all threatening processes (e.g. recreational/customary fishing, or pollution). In addition, the low abundance of Maui's dolphins and the consequent low likelihood of their presence (let alone actual injury or capture) being observed means considerable resources could be invested for minimal return of data. For these reasons it is important to focus effort on observing and collating data for those activities believed to be of greatest threat to the dolphins and to use a range of methods to quantify effects. In the case of fisheries-related threats it may be more productive to design research to generate empirical estimates of vulnerability for Hector's dolphins, for which capture events are expected to be more observable, and apply those estimates also to Maui's dolphins (e.g. using the method used by Richard et al. 2011 for seabirds).

4.4 Implications for the Maui's dolphin population

The current status of Maui's dolphin has raised concern about the population's chances for recovery even with the removal of human-induced mortality. However, the panel judged that the population can recover, based on their selection of a maximum population growth rate of 1.8% per annum; a positive number that reflects an increasing population in the absence of human impacts. Further, there is evidence, both within the Maui's dolphin population and in cetacean examples globally (see Jenner et al. 2008; Carroll et al. 2011), to suggest that, if human-induced mortalities are adequately reduced, the population does stand a chance of recovery.

Although genetic diversity is low for Maui's dolphin compared with their subspecies counterpart the South Island Hector's dolphin, their level of genetic diversity was found to be higher than expected for a population of about 55 animals over the age of 1 year (Hamner et al. 2012a). The sex ratio was also found to be near even but with slightly more females, which is also beneficial to the potential recovery of the population (Hamner et al. 2012a). The average along-shore home range of about 35 km and extreme movements of up to 80 km exhibited by Maui's dolphins will support gene flow through the population (Oremus et al. in press).

Also positive for Maui's dolphins is the presence of two female Hector's dolphins in the Maui's range. One of the two was sampled in the core of the Maui's dolphin range in two consecutive years (Hamner et al. 2012a). In addition, two *Cephalorynchus* dolphins found beachcast along the West Coast of the North Island in the last year were also found to be Hector's dolphins, providing further evidence for the overlap between Hector's and Maui's dolphins (DOC 2012; R. Hamner, Oregon State University, unpubl. data, 12 June 2012). This overlap provides the potential for interbreeding between the subspecies. Although there is currently no evidence of interbreeding, should it happen it would increase the population's genetic diversity and reproductive potential (Hamner et al. 2012b).

Globally, a number of whale and dolphin species have been hunted to quite low numbers in the past and there are a number of examples of marine mammal populations recovering from low numbers once protection has been implemented (e.g. southern right whales, Carroll et al. 2011; Antarctic blue whales, Jenner et al. 2008). Even in the absence of human-induced threats, however, population recovery for cetaceans will be slow. Antarctic blue whales have been recovering at approximately 8.2% per annum, resulting in numbers increasing from approximately 360 in the 1970s to approximately 2300 in 2007 (representing less than 10% of their pre-whaling population, Jenner et al. 2008). In the absence of all human-induced threats, Maui's dolphins are likely to increase at less than 2% per annum (Slooten & Lad 1991). At their current population size, this equates to an average of about one dolphin a year.

The vaquita, another critically endangered small cetacean, provides another example of a declining population where the largest contribution to human-induced mortality is bycatch in setnet fisheries (Jaramillo-Legorreta et al. 2007). Based on the 1997 population estimate and estimated bycatch, it was concluded that the vaquita population could be as low as 150 individuals by 2007 and that the rate of population decline meant there was a window of only 2 years before the population declined below the number needed to retain reproductive fitness (50 adults, Franklin 1980). While the midpoint of the most recent population estimate (in 2008) was not as low as that predicted (245—95% CI: 68–884), it still suggests a population decline of about 57% since 1997 and a rate of about 7.6% per year (Gerrodette et al. 2011). This is similar to the estimated rate of population decline for Maui's dolphin agreed on by the panel in this assessment. Although this estimate is larger than the 3% decline per annum estimated by Hamner et al. 2012a (see also Appendix 1), it is within the confidence intervals that those authors estimated (95% CI: 10.5% decline to 5.6% increase).

There are numerous challenges in studying rare species like Maui's dolphin. Estimates of abundance are typically imprecise because sighting rates are generally low, especially at the extremes of the population range (Jaramillo-Legorreta et al. 2007). The small body size of Maui's dolphins, inconspicuous surfacing, small group size and preference for murky inshore waters all affect the ability of observers to detect them. This lack of precision is also reflected in the large confidence intervals around estimates of population change and the probability of decline for a population. For example, Wade and colleagues estimated a 75.3% probability that the Maui's dolphin population is declining (See Appendix 1). Jaramillo-Legorreta et al. 2007 suggest that, when dealing with small populations, detecting population change will take several years. They estimated that reliably detecting a 4% increase in population size for vaquita through annual surveys would take 25 years. Thus, for a small population, a further population decline may go undetected for several years.

5. Conclusions

The Maui's dolphin risk assessment indicates that the current level of human-induced impact on this population cannot be sustained. The key points resulting from the risk assessment process are:

1. The expert panel agreed that a spatially-based, semi-quantitative method could be used to estimate current human-induced impacts on Maui's dolphins.
2. The panel estimated that there were likely to be 5.27 (95% CI: 0.97–8.40) human-induced Maui's dolphin mortalities per annum from all threats.
3. The broad confidence intervals for this estimate reflect uncertainty within and between panellists; 8 of 9 panellists had broadly consistent scores, whereas one panellist estimated mortalities to be much lower.
4. Fishing-related threats accounted for about 95% of total estimated impact compared with 5% from mining and oil activities, vessel traffic, pollution and disease combined.
5. The estimated level of impact on Maui's dolphins is 75.5 (95% CI: 12.4–150.7) times the level of PBR. All classes of threat had a 30% or greater probability of exceeding the PBR in the absence of other threats.
6. The panellists' estimates indicate a 95.7% likelihood of population decline over the next 5 years, assuming the agreed maximum population growth rate of 1.8% per annum.
7. Population projections assuming the current rate of human-induced mortality (i.e. as at the time of the workshop and prior to the introduction of interim measures) indicate that the population will decline at 7.6% per annum (95% CI: 13.8% decline to 0.1% increase).
8. Residual risk to Maui's dolphins from setnet fisheries is greatest off the northern Taranaki coastline out to 7 n.m. offshore and close to the entrance of the Manukau Harbour.
9. Residual risk from inshore trawl fisheries remains between the boundary of the trawl fishery closures areas (that extend 2 or 4 n.m. offshore) and 7 n.m. offshore, particularly towards the centre of dolphin distribution (from Raglan Harbour entrance to the Kaipara Harbour entrance.

6. Acknowledgements

We would like to thank all the workshop participants, particularly the expert panellists: Dr Rochelle Constantine (University of Auckland), Assoc. Prof. Steve Dawson (University of Otago), Alistair Dunn (NIWA), Rebecca Hamner (Oregon State University), Dr David Middleton (New Zealand Seafood Industry Council), Assoc. Prof. Liz Slooten (University of Otago), Dr Barb Taylor (National Marine Fisheries Service), Dr Leigh Torres (NIWA) and Dr Anton van Helden (Te Papa Tongarewa). The report was improved by the helpful comments of Chris Francis (NIWA), Prof. Andy Read (Duke University) and Richard Stoklosa (E-Systems). Finally, we would like to acknowledge the many DOC and MPI staff that assisted with the workshop and the preparation of this report.

7. References

Baker, C.S.; Chilvers, B.L.; Constantine, R.; Du Fresne, S.; Mattlin, R.H.; van Helden, A.; Hitchmough, R. 2010: Conservation status of New Zealand marine mammals (suborders Cetacea and Pinnipedia), 2009. *New Zealand Journal of Marine and Freshwater Research 44(2)*: 101–115.

Berggren, P.; Wade, P.R.; Carlströma, J.; Read, A.J. 2002: Potential limits to anthropogenic mortality for harbour porpoises in the Baltic region. *Biological Conservation 103*: 313–322

Burgman, M.A.; Akçakaya, H.R.; Ferson, S. 1993: Risk assessment in conservation biology. Chapman and Hall, London. 314 p.

Burnham, K.P.; Anderson, D.R. 2002: Model selection and multi-model inference: a practical information-theoretic approach (Second ed.). Springer-Verlag, New York. 496 p.

Carroll, E.L.; Childerhouse, S.J.; Fewster, R.M.; Patenaude, N.J.; Steel, D.; Dunshea, G.; Boren, L.; Baker, C.S. 2011: Updated abundance and estimate of rate of increase for the New Zealand southern right whale. Report to the International Whaling Commission. SC/S11/RW20.

Chao, A. 1989: Estimating population size for sparse data in capture-recapture experiments. *Biometrics 4*: 126–135.

Childerhouse, S.; Rayment, W.; Webster, T.; Scali, S.; du Fresne, S.D. 2008: Offshore aerial survey of Maui's dolphin distribution 2008. Department of Conservation, Auckland Conservancy Office, New Zealand (unpublished). 6 p.

Courchamp, F.; Berec, L.; Gascoigne, J. 2008: Allee effects in ecology and conservation. Oxford University Press, Oxford, U.K. 256 p.

Dawson, S.M. 2008: *Cephalorhynchus* dolphins *C. heavisidii*, *C. eutropia*, *C. hectori*,and *C. commersonii*. Pp. 191–196 in Perrin, W.F.; Wursig, B.; Thewissen, J.G.M. (Eds): Encyclopedia of marine mammals. Academic Press, San Diego.

Davies, N.M.; Bian, R.; Starr, P.; Lallemand, P.; Gilbert, D.; McKenzie, J. 2008: Risk analysis for Hector's dolphin and Maui's dolphin subpopulations to commercial set net fishing using a temporal-spatial age-structured model. Ministry of Fisheries, Wellington. 113 p.

Del Bianco, D.; De Albernaz, J.R.; Tavares, D.; Fernandes, H.; Jardim, P.G.; Da Silva, L.G.P.; Neto, A.A.d.; Neto, D.D.; Beltrane, D. Jr 2011: Semi-quantitative risk analysis. United States Patent: 8050933 B2.

DOC (Department of Conservation) 2012: Hector's and Maui's dolphins incident database. Department of Conservation, Wellington.

Du Fresne, S.; Burns, D.; Gates, E. 2012: An updated, annotated bibliography for Hector's (*Cephalorhynchus hectori hectori*) and Maui's (*C. hectori maui*) dolphins. *DOC Research and Development Series 332*. Department of Conservation, Wellington. 47 p.

Ferreira, S.M.; Roberts, C.C. 2003: Distribution and abundance of Maui's dolphins (*Cephalorhynchus hectori maui*) along the North Island west coast, New Zealand. *DOC Science Internal Series 93*. Department of Conservation, Wellington. 19 p.

Filippi, D.; Waugh, S.; Nichol, S. 2010; Revised spatial indicators for seabird interactions with longline fisheries in the western and central pacific. Unpublished report (WCPFC-SC6-2010-EB-IP-01) prepared for the Western and Central Pacific Fisheries Commission.

Franklin, I.R. 1980: Evolutionary change in small populations. Pp. 135–150 in Soulé, M.E.; Wilcox, B.A. (Eds): Conservation biology: an evolutionary-ecological perspective. Sineauer Associates, Sunderland, Massachusetts.

Gerrodette, T.; Taylor, B.L.; Swift, R.; Rankin, S.; Jaramillo-Legorreta, A.M.; Rojas-Bracho, L. 2011: A combined visual and acoustic estimate of 2008 abundance, and change in abundance since 1997, for the vaquita, *Phocoena sinus*. *Marine Mammal Science 27(2)*: e79–e100.

Griffiths, S.P.; Brewer, D.T.; Heales, D.S.; Milton, D.A.; Stobutzki, I.C. 2006: Validating ecological risk assessments for fisheries: assessing the impacts of turtle excluders devices on elasmobranch bycatch populations in an Australian trawl fishery. *Marine and Freshwater Research 57(4)*: 395–401.

Hamner, R.M.; Oremus, M.; Stanley, M.; Brown, P.; Constantine, R.; Baker, C.S.

2012a: Estimating the abundance and effective population size of Maui's dolphins using microsatellite genotypes in 2010–11, with retrospective matching to 2001–07. Department of Conservation, Auckland. 44 p.

Hamner, R.M.; Pichler, F.P.; Heimerier, D.H.; Constantine, R.; Baker, C.S. 2012b: Genetic differentiation and limited gene flow among fragmented populations of New Zealand endemic Hector's and Maui's dolphins. *Conservation Genetics*. DOI 10.1007/s10592-012-0347-9.

Hill, D.; Dubey, J.P. 2002: *Toxoplasma gondii*: transmission, diagnosis and prevention. *Clinical Microbiology and Infection 8(10)*: 634–640.

Hobday, A.J. 2004: Ecological risk assessment for Australian Commonwealth Fisheries final report stage 1 hazard identification and preliminary risk assessment. Report R01/0934 for the Australian Fisheries Management Authority, Canberra: 172 pp.

Hobday, A.J.; Smith, A.; Webb, H.; Daley, R.; Wayte, S.; Bulman, C.; Dowdney, J.; Williams, A.; Sporcic, M.; Dambacher, J.; Fuller, M.; Walker, T. 2007: Ecological risk assessment for effects of fishing: Methodology. Report R04/1072 for the Australian Fisheries Management Authority, Canberra: 174 p.

IUCN (International Union for the Conservation of Nature) 2012: The IUCN Red List of threatened species. Version 2012.1. <http://www.iucnredlist.org>. Downloaded on 22 August 2012.

Jaramillo-Legorreta, A.; Rojas-Bracho, L.; Brownell, R.L. Jr; Read, A.J.; Reeves, R.R.; Ralls, K.; Taylor, B.L. 2007: Saving the vaquita: immediate action, not more data. *Conservation Biology 21(6)*: 1653–1655.

Jefferson, T.A.; Leatherwood, S.; Webber, M.A. 1993: FAO species identification guide: marine mammal species of the World. Food and Agriculture Organization of the United Nations, Rome. 320p. http://www.fao.org/

Jenner, C.; Jenner, M.; Burton, C.; Sturrock, V.; Salgado Kent, C.; Morrice, M.; Attard, C.; Moller, L.; Double, M.C. 2008: Mark recapture analysis of pygmy blue whales from the Perth Canyon, Western Australia 2000–2005. Paper submitted for consideration by the IWC Scientific Committee SC/60/SH16. SC/60/SH16. 9 p.

Kerns, B.K.; Ager, A. 2007: Risk assessment for biodiversity conservation planning in Pacific Northwest forests. *Forest Ecology and Management 246*: 38–44.

Macguire, L.A. 2004: What can decision analysis do for invasive species management? *Risk Analysis 24*: 859–868.

MFish (Ministry of Fisheries); DOC (Department of Conservation) 2007: Hector's dolphin threat management plan. Ministry of Fisheries and Department of Conservation. 154 p.

Miller, E.; Lalas, C.; Dawson, S.; Hiltrun, R.; Slooten, E. in press: Hector's dolphin diet: the species, sizes and relative importance of prey eaten by *Cephalorhynchus hectori*, investigated using stomach content analysis. *Marine Mammal Science*.

Milton, D.A. 2001: Assessing the susceptibility to fishing of populations of rare trawl bycatch: sea snakes caught by Australia's Northern Prawn Fishery. *Biological Conservation 101*: 281–290.

MPI (Ministry for Primary Industries); DOC (Department of Conservation) 2012: Maui's dolphin Threat Management Plan discussion document. Ministry for Primary Industries and Department of Conservation, Wellington. 217 p.

Oremus, M.; Hamner, R.M.; Stanley, M.; Brown, P.; Baker, C.S.; Constantine, R. in press: Distribution, group characterisitics and movements of the critically endangered Maui's dolphin (*Cephalorhynchus hectori maui*). *Endangered Species Research*.

Perrin, W.F.; Würsig, B.; Thewissen, J.G.M. (Eds) 2008: Encyclopedia of marine mammals. Second Edition. Academic Press, San Diego.

Rayment, W.; du Fresne, S.D. 2007: Offshore aerial survey of Maui's dolphin distribution 2007. Auckland Conservancy, Department of Conservation (unpublished). 6 p.

Rayment, W.; Dawson, S.; Slooten, E.; Childerhouse, S. 2006: Off shore distributionof Hector's dolphin at Banks Peninsula. *DOC Research & Development Series 232*. Department of Conservation, Wellington. 23 p.

Rayment, W.; Dawson, S.; Slooten, L.; Brager, S.; du Fresne, S.; Webster, T. 2009: Kernel density estimates of alongshore home range of Hector's dolphins at Banks Peninsula, New Zealand. *Marine Mammal Science 25(3)*: 537–556.

Read, A.J.; Drinker, P.; Northridge, S. 2006: Bycatch of marine mammals in U.S. and global fisheries. *Conservation Biology 20(1)*: 163–169.

Reeves, R.R.; Dawson, S.M.; Jefferson, T.A.; Karczmarski, L.; Laidre, K.; O'Corry-Crowe, G.; Rojas-Bracho, L.; Secchi, E.R.; Slooten, E.; Smith, B.D.; Wang, J.Y.; Zhou, K. 2000: *Cephalorhynchus hectori* ssp. *maui*. In: IUCN 2012. IUCN Red List of threatened species. Version 2012.1. <www.iucnredlist.org>. Downloaded on 22 August 2012.

Richard, Y.; Abraham, E.R.; Filippi, D. 2011: Assessment of the risk to seabird populations from New Zealand commercial fisheries. Final Research Report for Ministry of Fisheries projects IPA2009/19 and IPA2009/20 (unpublished report held by the Ministry for Primary Industries, Wellington). 66 p.

Scali, S. 2006: Use of harbours by the critically endangered species Maui's dolphin (*Cephalorhynchus hectori maui*). Department of Conversation, Auckland Conservancy Office, New Zealand (unpublished). 28 p.

Sharp, B.R.; Parker, S.J.; Smith, N. 2009: An impact assessment framework for bottom fishing methods in the CAMLR Convention area. *CCAMLR Science 16*: 195–210.

Sharp, B.R.; Waugh, S.M.; Walker, N.A. 2011. A risk assessment framework for incidental seabird mortality associated with New Zealand fishing in the New Zealand EEZ. Unpublished report held by the Ministry for Primary Industries, Wellington.

Slooten, E. 1991: Age, growth, and reproduction in Hector's dolphins. *Canadian Journal of Zoology 69*: 1689–1700.

Slooten, E.; Lad, F. 1991: Population biology and conservation of Hector's dolphin. *Canadian Journal of Zoology 69*: 1701–1707.

Slooten, E. 2007: Conservation management in the face of uncertainty: effectiveness of four options for managing Hector's dolphin bycatch. *Endangered Species Research 3*: 169–179.

Slooten, E.; Dawson, S.M. 2010: Assessing the effectiveness of conservation management decisions: likely effects of new protection measures for Hector's dolphin. *Aquatic Conservation: Marine and Freshwater Ecosystems 20*: 334–347.

Slooten, E.; Davies, N. 2012: Hector's dolphin risk assessments: old and new analyses show consistent results. *Journal of the Royal Society of New Zealand 42(1)*: 49–60.

Slooten, E.; Dawson, S.M.; Rayment, W.J.; Childerhouse, S.J. 2005: Distribution of Maui's dolphin, *Cephalorhynchus hectori maui*. New Zealand Fisheries Assessment Report, 2005/28.

Slooten, E.; Dawson, S.M.; Rayment, W.J.; Childerhouse, S.J. 2006: A new abundance estimate for Maui's dolphin: what does it mean for managing this critically endangered species? *Biological Conservation 128(4)*: 576–581.

Smith, A.D.M.; Fulton, E.J.; Hibday, A.J.; Smith, D.C.; Shoulder, P. 2007: Scientific tools to support the practical implementation of ecosystem-based fisheries management. *ICES Journal of Marine Science 64*: 633–639.

Stanley, M. 2009: Maui's winter offshore aerial survey June/July 2009. Auckland Conservancy, Department of Conservation, (unpublished). 10 p.

Stephens, P.A.; Sutherland, W.J.; Freckleton, R.P. 1999: What is the Allee effect? *Oikos 87*: 185–190.

Stobutzki, I.; Miller, M.; Brewer, D. 2001: Sustainability of fishery bycatch: a process for assessing highly diverse and numerous bycatch. *Environmental Conservation 28(2)*: 167–181.

Thompson, K. 2012: Maui's and mining: a review of marine mineral mining activity on the west coast of New Zealand and its potential impacts. Unpublished report prepared for Auckland Conservancy, Department of Conservation. 43 p.

Turvey, S.T. et al. 2007: First human-caused extinction of a cetacean species? *Biology Letters 3*: 537–540.

US EPA (US Environmental Protection Agency) 1992: A framework for ecological risk assessment. Document EPA/630/R-92/001. Risk Assessment Forum, U.S. Environmental Protection Agency, Washington, DC. 41 p.

US EPA (US Environmental Protection Agency) 1998: Guidelines for ecological risk assessment. Document EPA/630/R-95/002F. Risk Assessment Forum, U.S. Environmental Protection Agency, Washington, DC. 188 p.

Wade, P.R. 1998: Calculating limits to the allowable human-induced mortality of cetaceans and pinnipeds. *Marine Mammal Science 14*: 1–37.

Wade, P.R.; Reeves, R.R.; Mesnick, S.L. 2012: Social and behavioural factors in cetacean responses to overexploitation: are odontocetes less 'resilient' than mysticetes? *Journal of Marine Biology*: doi: 10.1155/2012/567276.

Zhou, S.; Griffiths, S.P.; Miller, M. 2009: Sustainability assessment for fishing effects (SAFE) on highly diverse and data-limited fish bycatch in a tropical prawn trawl fishery. *Marine and Freshwater Research 60*: 563–570.

Appendix 1

The Potential Biological Removal (PBR) and probability of decline for Maui's dolphin

Paul R. Wade[1], Rebecca M. Hamner[2], Rochelle Constantine[3] and C. Scott Baker[2,3]

[1] National Marine Mammal Laboratory, Alaska Fisheries Science Center, National Marine Fisheries Service, 7600 Sand Point Way NE, Seattle, WA 98155 USA
Email: Paul.Wade@noaa.gov

[2] Marine Mammal Institute and Department of Fisheries and Wildlife, Oregon State University, Hatfield Marine Science Center, 2030 SE Marine Science Drive, Newport, OR 97365 USA

[3] Molecular Ecology and Evolution Laboratory, School of Biological Sciences, University of Auckland, Auckland, New Zealand

Background

Maui's dolphin (*Cephalorhynchus hectori maui*; a subspecies of Hector's and Maui's dolphin, *Cephalorhynchus hectori*) is classified as 'critically endangered' by the International Union for the Conservation of Nature (IUCN 2009) and 'nationally critical' under the New Zealand Threat Classification Scheme (Baker et al. 2010). Maui's dolphins are thought to once have been widely distributed along the west coast of the North Island (du Fresne 2010). Based on records of strandings and sightings (Dawson et al. 2001), this distribution has apparently contracted over the last 100 years. Since 1970, when systematic collection of stranding records began, the distribution of strandings has been concentrated along the northwestern coast from Dargaville in the north to Whanganui in the south. Within this limited range, the distribution has contracted further over the last three decades (Dawson et al. 2001). Surveys of Maui's dolphins since the late 1990s have reported the large majority of sightings along only 40 km of coastline from the Manakau Harbour to Port Waikato (Slooten et al. 2006; du Fresne 2010). Previous estimates of abundance from small-boat and aerial surveys vary from 75 to 140 individuals, with relatively large confidence intervals (Table 1; Dawson & Slooten 1988; Martien et al. 1999; Ferreira & Roberts 2003; Slooten et al. 2006).

Here we present a calculation of the Potential Biological Removal (PBR) and probability of decline based on estimates of abundance from genotype capture-recapture models using biopsy samples from living dolphins collected from 2001 to 2011 and previous estimates from aerial and vessel surveys. Unlike the previous sighting surveys of Maui's dolphins, the biopsy-based genotyping allowed for the accumulation of capture records over time, providing estimates of trends in abundance through open-population models. As reported in detail in Hamner et al. (2012), biopsy samples collected by the University of Auckland during surveys in 2001 to 2006 were augmented with samples collected during more intensive surveys in 2010 and 2011, conducted in collaboration between the New Zealand Department of Conservation (DOC), the University of Auckland and the Marine Mammal Institute of Oregon State University. Based on the intensive sampling in 2010 and 2011, the abundance of Maui's dolphins was estimated to be 55 (95% CL: 48 to 69), using a two-sample, closed-population model. Across the entire 10 year study (i.e. 2001–11), annual survival was estimated to be 84% (95% CL: 75% to 90%) and population decline was estimated to be −2.8% per year (95% CL: −10.5% to +5.6%), based on a Pradel Survival and Lambda model (Hamner et al. 2012).

Potential Biological Removal

Wade (1998) developed a method for calculating a threshold for human-related mortality for marine mammal populations. This development was driven, in large part, by amendments to the US Marine Mammal Protection Act (MMPA) in 1994. These specified the use of a Potential Biological Removal (PBR) scheme for managing human-related mortality, particularly incidental mortality ('by catch') in commercial fisheries (Wade & Angliss 1997). The PBR scheme calculates a threshold for the number of allowable takes using an estimate of abundance for the population subject to the mortality and a standard 'recovery factor' developed through population simulations. The 'standard' PBR is calculated to achieve the management goal of allowing populations to stay above, or recover to, their Maximum Net Productivity Level (generally taken to be between 50% and 80% of carrying capacity). Wade (1998) also proposed an alternative take threshold based on a more conservative recovery factor chosen to allow populations to recover (increase) at a rate close to their intrinsic (or biological) maximum (R_{max}). This lower threshold has been adopted in the US as the PBR for populations listed as Endangered under the US Endangered Species Act (ESA).

The Endangered Species PBR (using a recovery factor of 0.1) was calculated based on the criterion that time to recovery (to the Maximum Net Productivity Level) should not be delayed by more than 10%. However, the model used for the PBR calculations is implicitly deterministic and thus does not account for the increased threat of extinction through stochastic processes that could be caused by human-related mortality in very small populations. Additionally, the model used for the PBR calculations does not incorporate depensation or 'Allee' effects, which can increase extinction risk in very small populations (Stephens et al. 1999). For these reasons, in the case of small populations, Wade (1998) notes that a Population Viability Analysis (PVA) should be used to model very small populations and evaluate extinction risk from human-related mortality and stochastic factors. In the US, some ESA-listed species have human-related mortality limits that are set to lower values than those calculated by the PBR for endangered species, based on consideration of the stochastic extinction risk and other risk factors. Therefore, it should be understood that the PBR can be used to set limits for human-related mortality that should have a minimal impact on a population of an endangered species, all other factors being equal. In other words, such a population will have a similar probability of growth or decline as a comparable population in which there is no human-related mortality. Because of stochastic risks, however, the Endangered Species PBR does not represent a threshold above which extinction is certain, or below which survival is assured, and it should not be interpreted in that way.

With these caveats in mind, we have revised the PBR previously calculated by Slooten et al. (2006) from the 2004 aerial surveys. From the estimate of N = 111, Slooten et al. (2006) calculated a PBR of 0.16 (or one dolphin every 6.4 years). For the genotype capture-recapture analysis, 2010–11 abundance was estimated to be N = 55, with a CV of 0.152 (Hamner et al. 2012, Table 1). Using a value of 0.04 for R_{max} (the default value recommended for dolphin populations by Wade (1998) and the value used under the US MMPA) and a recovery factor value of 0.1, the Endangered Species PBR was calculated to be 0.10, or 1 dolphin every 10 years. Further, Slooten & Lad (1991) estimated R_{max} for Hector's dolphins as 0.018, considerably lower than the default R_{max} value of 0.04. Using this lower value of 0.018, the Endangered Species PBR for Maui's dolphin is 0.044, or 1 dolphin every 23 years.

Probability of decline

Trend from the Pradel model

Hamner et al. (2012) fit a Pradel Survival and Lambda model to the capture histories for Maui's dolphin for the years 2001–11. From this, the rate of growth (referred to as Lambda) was estimated to be 0.972 (SE: 0.041), which represents a population decline of –2.8% per year (95% CI: –10.5% to +5.6%). The decline is not significant at the p = 0.05 level, which is not

Table A1.1. Estimates of abundance (*N*), and associated 95% confidence limits (CL), for Maui's dolphins, based on small-boat surveys, aerial sighting surveys and genotype capture-recapture (GCR)

REFERENCE	SURVEY METHOD	APPLICABLE YEAR(S)	*N*	CI LOWER	CI UPPER
Dawson & Slooten 1988	Small boat strip transect	1985	134	n.a.	n.a.
Martien et al. 1999	Small boat strip transect	1985*	140	46	280
Russell 1999	Small boat	1998	80	n.a.	n.a.
Ferreira & Roberts 2003	Aerial line transect	2001/02	75	48	130
Baker et al. 2012	Small boat GCR	2002†	69	52	100
Slooten et al. 2006	Aerial line transect	2004	111	48	252
Hamner et al. 2012	Small boat GCR	2010/11‡	55	48	69

* The estimate and confidence intervals in Martien et al. (1999) were recalculated from the sightings reported in Dawson & Slooten (1988); i.e. these are not independently derived.

† Calculated here with a two-sample, closed-population model using genotype capture-recapture from samples collected in the years 2001 and 2003, as reported by C.S. Baker et al. (unpubl. data).

‡ The estimate and confidence intervals do not include two individuals identified as migrant Hector's dolphins, based on genotype population assignment.

surprising given the relatively sparse capture-recapture records data (e.g. there were more than 10 identifications in only 4 years) and the short length of time available to establish a trend. However, these results, and independent evidence from the apparent contraction of the Maui's dolphin range (Dawson et al. 2001), suggest the population was declining during this period and over the previous several decades. A Bayesian interpretation of the results for Lambda (assuming an uninformative prior distribution) from the 2001–11 capture-recapture analysis would be that there is a 75.3% probability the population is declining. This probability was calculated from the cumulative probability of Lambda being < 1.0, under the assumption of a normal distribution with a mean of 0.972 and a SE of 0.041.

Trend from all available abundance estimates, 1985–2011

Given that there was an abundance survey in 1985 (Dawson & Slooten 1988; Martien et al. 1999), it is possible to examine the trend in the population from 1985 until 2011, providing a much longer time-period over which to potentially document a trend. Hamner et al. (2012) provide a two-sample Lincoln-Petersen estimate of abundance for 2010–11. Examining the genotype capture histories for 2001–06, as reported in Baker et al. (in press), there are two other years that have more than 10 identifications in a year—2001 and 2003. In these 2 years there were 21 identifications in 2001, 18 in 2003, with 5 individuals seen in both years. Using the same methods as Hamner et al. (2012), the two-sample estimate for 2001–03 is $N = 69$ (95% CI: 52–100). Other surveys that estimated abundance occurred in 1998 (Russell 1999), 2001–02 (Ferreira & Roberts 2003), and 2004 (Slooten et al. 2006) (Table A1.1). The various surveys were conducted using different methods. However, all of the surveys covered the current longitudinal range of Maui's dolphins.

A trend analysis was conducted using abundance estimates assigned to the years 1985 (Martien et al. 1999), 1998 (Russell 1999), 2001.5 (a midpoint chosen to reflect data collection spanning multiple years, in this case data from 2001–02, Ferreira & Roberts 2003), 2002 (data from 2001–03, as reported by Baker et al. (2012), recalculated here with Lincoln-Petersen genotype capture-recapture), 2004 (Slooten et al. 2006), and 2010.5 (midpoint for data collected from 2010–11, Hamner et al. 2012). Using a linear regression on the natural logarithm of abundance, the trend from these six abundance estimates is –3.2% per year (90% CL: –5.7% to –0.6%) for the time period 1985 to 2011. This estimated trend is significantly different from 0.0 at the alpha = 0.05 level (p-value = 0.029, one-sided test). A Bayesian linear regression with uninformative conjugate prior distributions on the parameters gives identical results to a maximum likelihood linear regression analysis. Therefore, in a Bayesian framework, this can be interpreted as a 97.1% probability that the trend from these abundance estimates was less than zero. This suggests that the population may have been declining over a longer time period (since 1985) than documented by the genotype capture-recapture analysis (2001 to 2011).

Given that aerial surveys went further offshore than the small boat surveys, it is conceivable that the aerial survey estimates could include more animals and, therefore, not be strictly comparable to the boat-based estimates (sighting and capture-recapture). Therefore, we repeated the analysis above to re-calculate the trend using only the four abundance estimates from boat surveys, in the years 1985, 1998, 2002, and 2010.5. The estimated trend from those four estimates is −3.7% per year (90% CI: −4.2% to −3.2%) for the time period 1985 to 2011. The probability that the trend is less than 0.0 is ~1.0. This is very similar to the estimate that included the aerial surveys, suggesting the population has been declining over this time period. Despite differences in methods between the surveys the trend appears consistent to that from Hamner et al (2012) where survey methodology was consistent, therefore the results here are broadly indicative of a declining population irrespective of differences in methodology.

Acknowledgements

We sincerely thank Rohan Currey, Ministry for Primary Industries; Phil Brown and Laura Boren, Department of Conservation, for helpful comments and suggestions.

Literature cited

Baker, C.S.; Chilvers, B.L.; Constantine, R.; du Fresne, S.; Mattlin, R.H.; van Helden, A.; Hitchmough, R. 2010. Conservation status of New Zealand marine mammals (suborders Cetacea and Pinnipedia), 2009. *New Zealand Journal of Marine and Freshwater Research 44*: 101–115.

Baker, C.S.; Hamner, R.M.; Cooke, J.; Heimeier, D.; Vant, M.; Steel, D.; Constantine, R. (2012): Low abundance and probable decline of the critically endangered Maui's dolphin estimated by genotype capture–recapture. *Animal Conservation*. doi:10.1111/j.1469-1795.2012.00590.x.

Dawson, S.; Russell, K.; Pichler, F.B.; Slooten, L.; Baker, C.S. 2001: The North Island Hector's dolphin is vulnerable to extinction. *Marine Mammal Science 17*: 366–371.

Dawson, S.M.; Slooten, E. 1988: Hector's dolphin: *Cephalorhynchus hectori*: distribution and abundance. Pp. 315–324 in: Brownell, R.L. Jr; Donovan, G.P. (Eds): Biology of the genus *Cephalorhynchus*. Reports of the International Whaling Commission, Cambridge.

du Fresne, S. 2010: Distribution of Maui's dolphins (*Cephalorhynchus hectori maui*), 2000–2009. *DOC Research and Development Series 322*, Department of Conservation, Wellington. 47 p.

Ferreira, S.M.; Roberts, C.C. 2003: Distribution and abundance of Maui's dolphins (*Cephalorhynchus hectori maui*) along the North Island West Coast, New Zealand. *DOC Internal Series 93*, Department of Conservation, Wellington.

Hamner, R.M.; Oremus, M.; Stanley, M.; Brown, P.; Constantine, R.; Baker, C.S. 2012. Estimating the abundance and effective population size of Maui's dolphins using microsatellite genotypes in 2010–11, with retrospective matching to 2001–07. Auckland Conservancy, Department of Conservation, Auckland. Available at http://www.doc.govt.nz/upload/documents/conservation/native-animals/marine-mammals/mauis-dolphin-abundance-estimate-report.pdf.

IUCN (International Union for the Conservation of Nature) 2009: The IUCN Red List of Threatened Species. http://redlist.org/apps/redlist/details/2475/0

Martien, K.K.; Taylor, B.L.; Slooten, E.; Dawson, S. 1999: A sensitivity analysis to guide research and management for Hector's dolphin. *Biological Conservation 90*: 183–191.

Russell, K. 1999: The North Island Hector's dolphin: a species in need of conservation. Unpublished MSc thesis, School of Environmental and Marine Sciences, University of Auckland, Auckland. 136 p.

Slooten, E.; Dawson, S.; Rayment, W.; Childerhouse, S. 2006: A new abundance estimate for Maui's dolphin: what does it mean for managing this critically endangered species? *Biological Conservation 128*: 576–581.

Slooten, E.; Lad, F. 1991: Population biology and conservation of Hector's dolphin. *Canadian Journal of Zoology 69*: 1701–1707.

Stephens, P.A.; Sutherland, W.J. 1999: Consequences of the Allee effect for behaviour, ecology and conservation. *Trends in Ecology and Evolution 14*: 401–405.

Wade, P.R. 1998: Calculating limits to the allowable human-caused mortality of cetaceans and pinnipeds. *Marine Mammal Science 14*: 1–37.

Wade, P.R.; Angliss, R.P. 1997: Guidelines for assessing marine mammal stocks: report of the GAMMS Workshop, April 3–5, 1996. NOAA Technical Memorandum NMFS-OPR-12. 93 p.

Appendix 2

Maui's dolphin distribution and fishing effort

Finlay N. Thompson and Yvan Richard

Dragonfly Science, PO Box 27535, Wellington 6141, New Zealand
www.dragonfly.co.nz

Introduction

Maui's dolphins (*Cephalorhynchus hectori maui*) are endemic to the west coast of the North Island, and share the space with inshore fishers, both commercial and recreational. The dolphins live close to shore and have been observed along the whole west coast, although most recently, only between Raglan and Kaipara harbours. Most inshore commercial fishing uses setnets and small trawl nets, and Maui's dolphins have been observed caught in setnets.

This appendix includes information presented to the Maui's dolphin risk assessment workshop's expert panel on Maui's dolphin distribution, and commercial fishing effort in the area they occupy.

Maui dolphin distribution

A map of Maui's dolphin distribution was developed using information from sightings made during various systematic surveys of Maui's dolphins on the west coast of the North Island (Ferreira & Roberts 2003; Slooten et al. 2005; Scali 2006; Rayment & du Fresne 2007; Childerhouse et al. 2008; Stanley 2009; Hamner et al. 2012). The distribution was intended to describe current knowledge of the dolphin's range and patterns of movement. The surveys used to develop the distribution are listed in Table A2.1.

Table A2.1. Surveys used to develop the distribution of Maui's dolphins described in this Appendix.

SURVEY	SIGHTINGS ON	SIGHTINGS OFF	TOTAL SIGHTINGS
Ferreira 2000/2001	25		25
Ferreira 2001/2002	34		34
Slooten 2004—summer	20	4	24
Slooten 2004—winter	9	4	13
Scali 2006	7	7	
Rayment 2007	13	4	17
Childerhouse 2008	6	3	9
Biopsies 2010	37		37
Biopsies 2011	28		28

The distribution was developed by incorporating sightings data into a model. The model estimated the probability (π) that a dolphin would be seen at a given point. This probability was decomposed into an alongshore function, d_a, describing the north-south density, and an offshore function, d_o, describing the density of Maui's dolphins from the shore out to sea.

$$\pi(x,y) = d_o(x), d_a(y)$$

A generalised additive model was used to estimate these functions from the survey sightings using semi-parametric methods (Wood 2004). The survey areas were derived from published records and from some survey shape files provided (L. Boren, DOC, unpubl. data). A one-n.m. grid was applied to an area that included all the survey areas and, for each grid cell that overlapped a survey, a record was included in data used to fit the model. The number of sightings in each cell,

Y_i, was assumed to follow a Poisson distribution with a rate, μ_i, that varied between cells, indicated by *i*. Because the extent of the observations was published as part of survey reporting, we were able to include cells with zero sightings.

A factor, λ_s, was added to the model to account for unknown differences between the various surveys. In some cases, the observation effort was not uniform. In these cases, a term, $E_{s,i}$, was added to account for differences in this effort between areas.

$$Y_i \sim Poisson\ (\mu_i)$$

$$\log(\mu_i) = d_o(x_i) + d_a(x_i) + \log(E_{s,i}) + \lambda_s$$

The model was fit using the MGCV package developed for the R statistical methods system (Wood, 2004). The resulting offshore distribution function is plotted in Fig. A2.1. To test for sensitivity to the models used, data with each of the surveys omitted one by one was also used. It is clear that the general shape does not change when individual surveys are dropped. In Fig. A2.2, the alongshore distribution shows that the peak area in which Maui's dolphins have been seen is around Port Waikato. This peak is also visible in Figs A2. 3 to A2.5. These figures show the derived Maui's dolphin distribution.

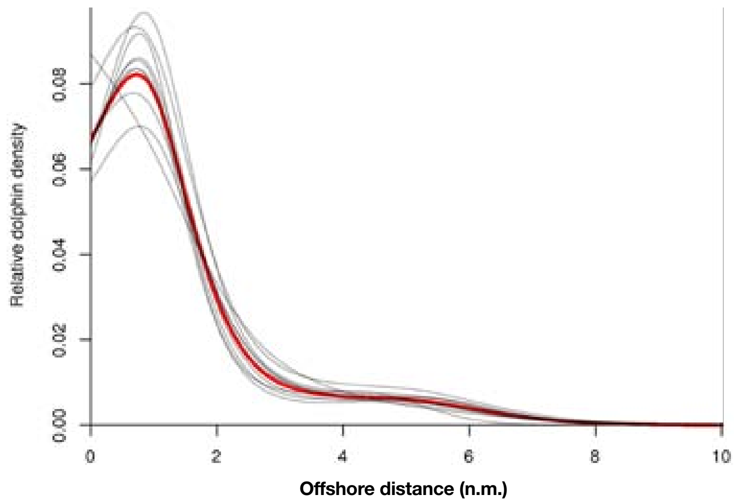

Figure A2.1. The relationship between distance offshore and Maui's dolphin abundance, created from the survey data. The grey lines on the plot report are the results from a cross validation of the model. Each line is created by running the model with one of the surveys omitted

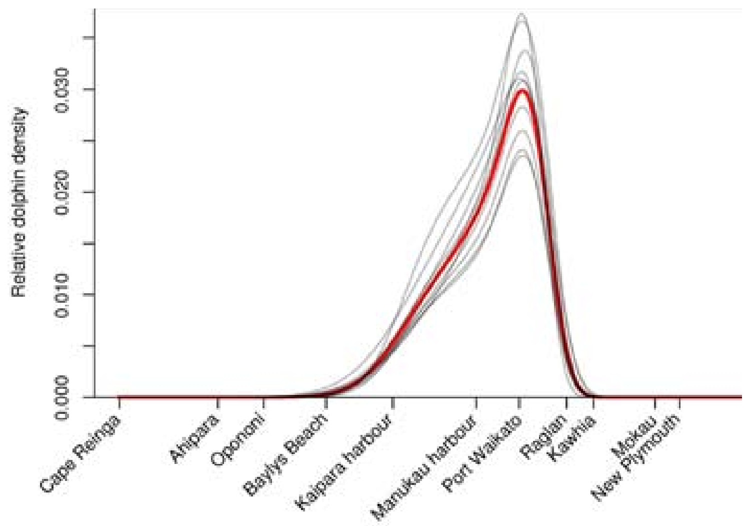

Figure A2.2. The relationship between the distance alongshore and Maui's dolphin abundance, created from the survey data. The grey lines in the plot report results from cross validation of the model. Each line is created by running the model with one of the surveys omitted.

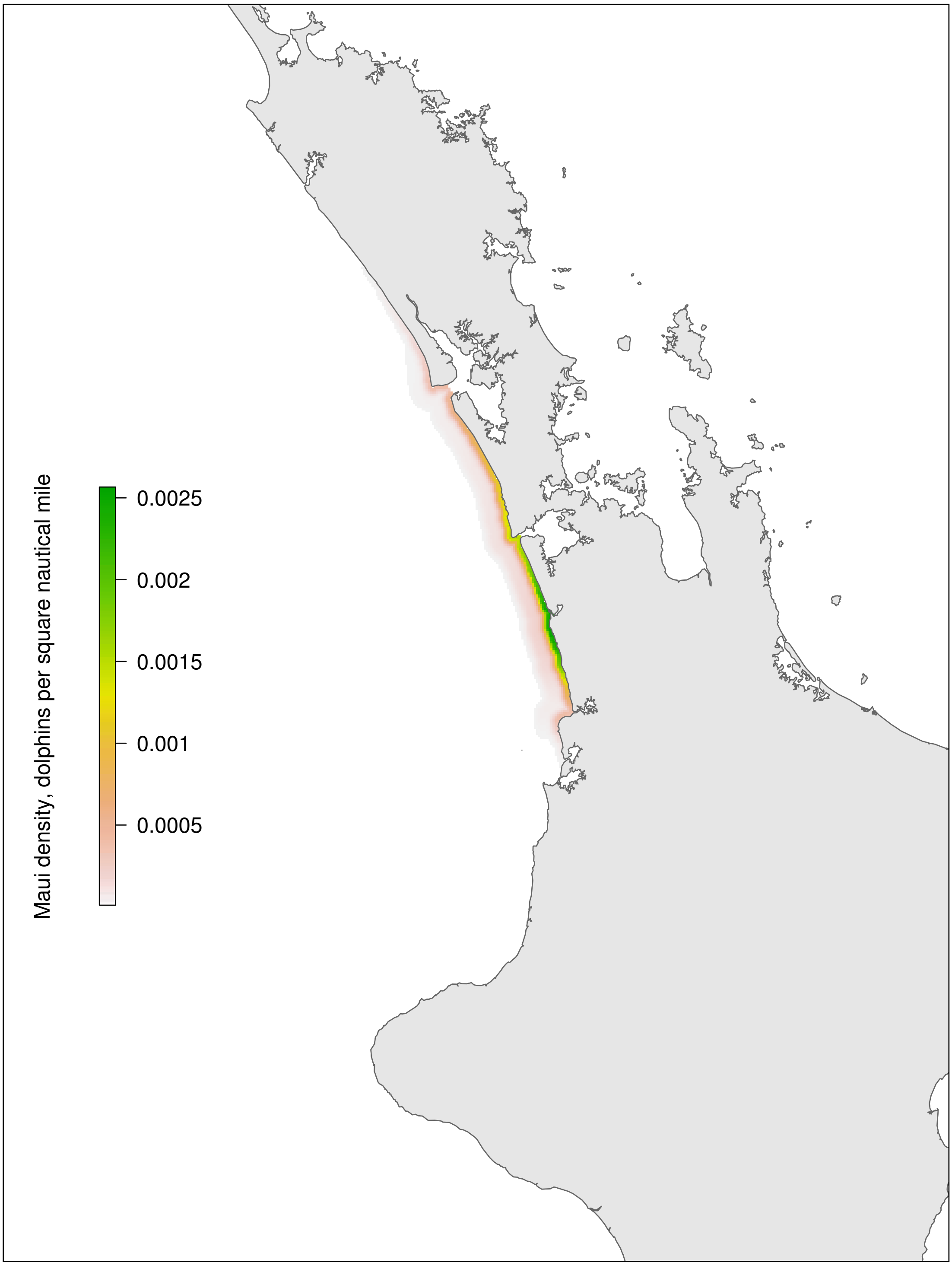

Figure A2.3. Maui's dolphin distribution, created from the sightings and effort data from nine aerial and biopsy surveys conducted between 2000 and 2012. The distribution has been normalised to one, and so the colours represent the expected number of dolphins per square nautical mile.

Modifications suggested by the risk assessment workshop

The expert panel agreed on two modifications to the Maui's dolphin distribution. These relate to the shape of the offshore distribution and the southerly extent of the alongshore distribution.

The expert panel considered that the shape of the offshore distribution derived from the survey data was unreliable. Instead, a triangular distribution was decided, based on survey data from the west coast of the South Island. The shape imposed was defined by a triangle with maximum density at the coast, going to zero at 7 n.m. (see figs 6 and 7 in Slooten et al. 2005).

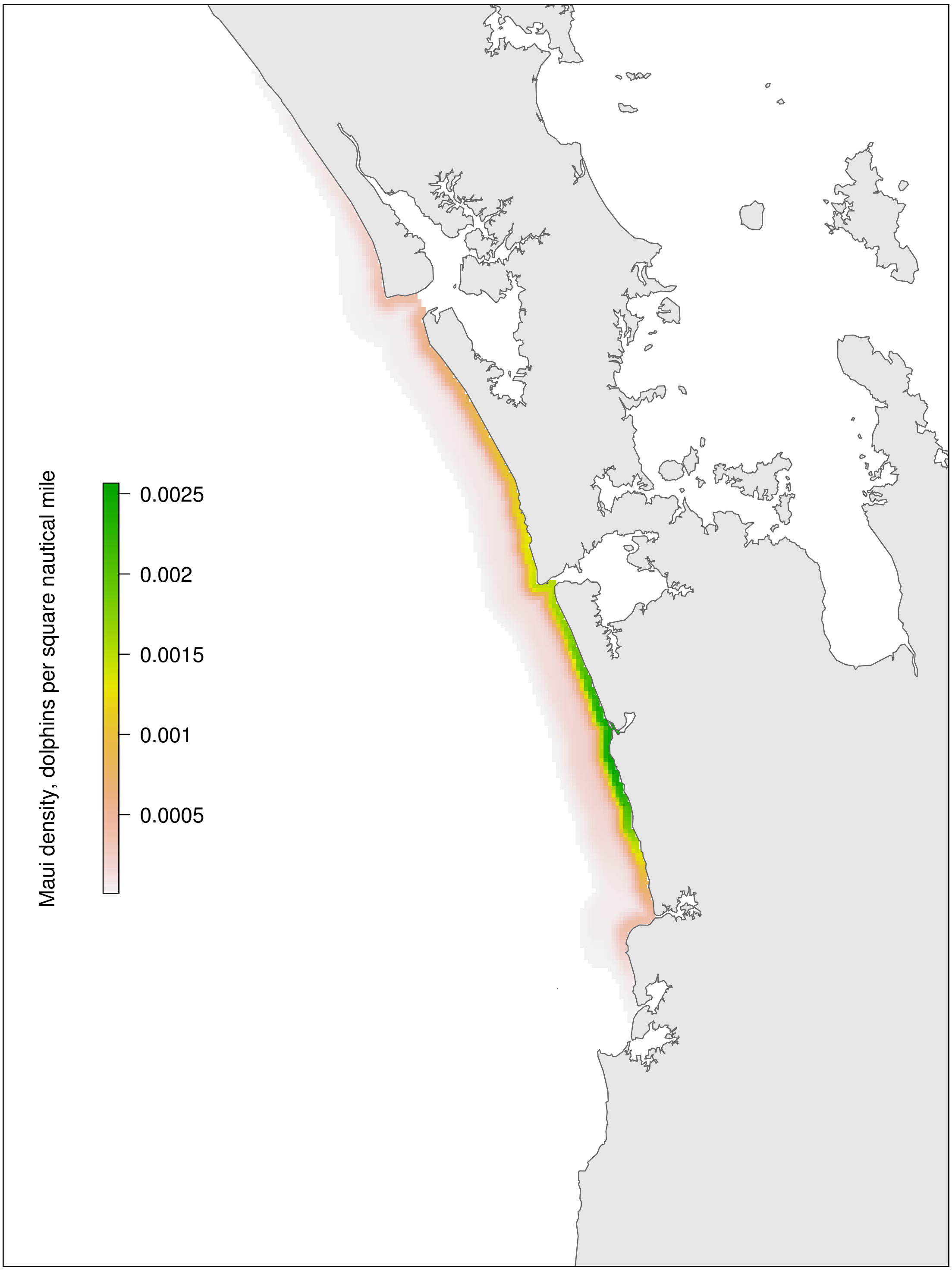

Figure A2.4. A close-up of the core area of the Maui's dolphin distribution created from the sightings and effort data from nine aerial and biopsy surveys conducted between 2000 and 2012. The distribution has been normalised to one, and so the colours represent the expected number of dolphins per square nautical mile.

The expert panel considered that the range of the distribution derived from survey sightings was quite restricted, and prone to being underestimated. The panel agreed that various non-survey sightings suggested that the distribution should be expanded, especially towards Taranaki. The final decision to extend the distribution south was based on decisions made by the expert panel members. A linear ramp from Port Waikato to Whanganui was defined, with a linear decrease alongshore, reaching zero at Whanganui. Similarly, expert panel discussions informed the decision to define the distribution of Maui's dolphins in the various harbours by a linear ramp decreasing with distance from the entrance of the harbour.

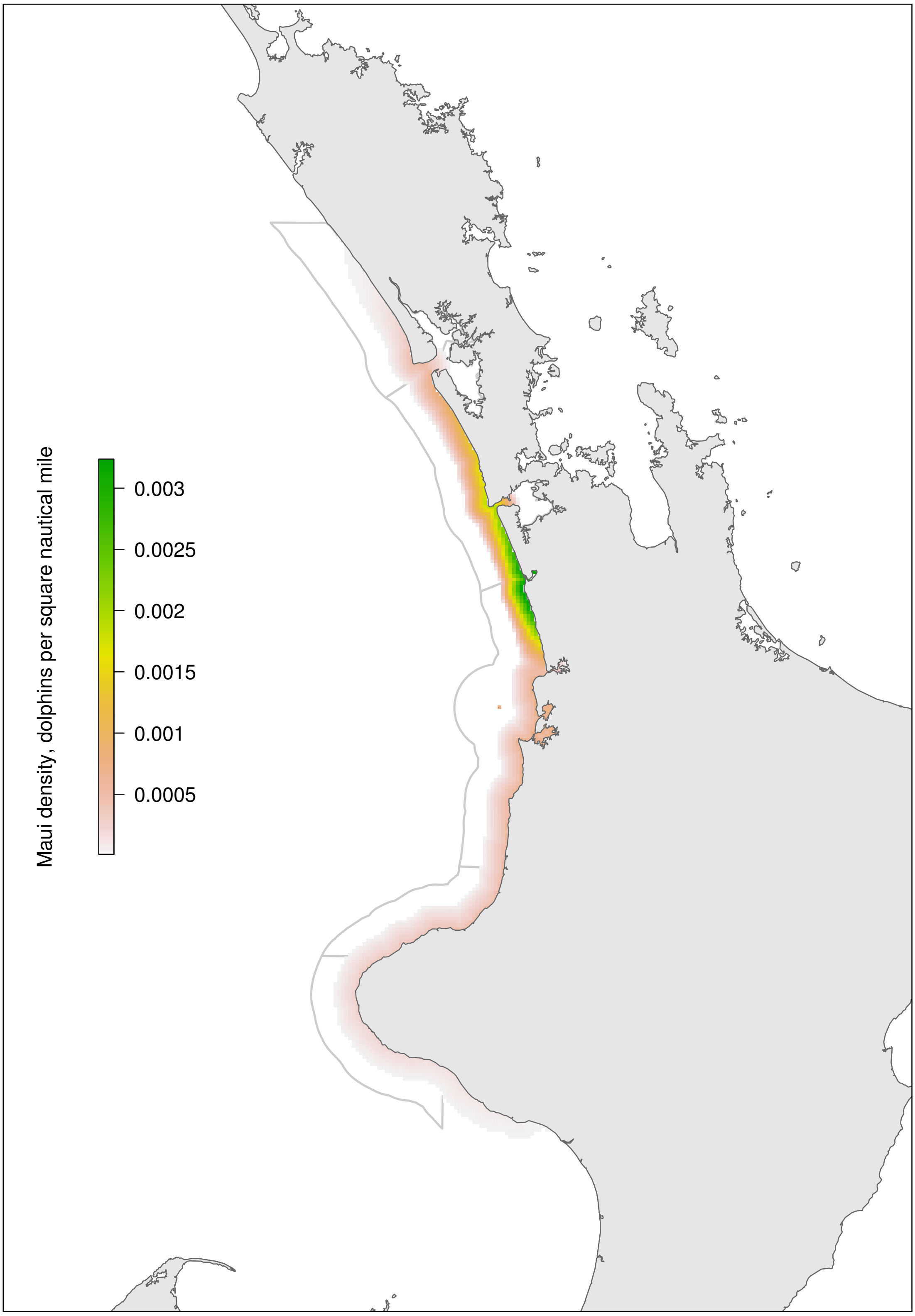

Figure A2.5. Maui's dolphin distribution as agreed by the expert panel, using the distribution from research findings and effort data for the core range and applying a ramp to identify the extent of the southern range and into harbours. The distribution has been normalised to one, and so the colours represent the expected number of dolphins per square nautical mile. The grey outline marks the extent of the Marine Mammal Sanctuary, including the proposed southern extension.

The final Maui's dolphin distribution map (Fig. 1) was created by combining the alongshore distribution derived from the survey data with modifications suggested by the expert panel. The different parts of the distribution were combined together by matching probabilities at boundaries, and then renormalised so that the overall distribution integrated into one.

Fishing effort

Commercial fishers are required to report all fishing effort to the MPI on various paper forms (MFish 2008). The older Catch Effort Landing Return form (CELR) has one record per day, and does not (generally) include latitude and longitude information. More detailed forms were introduced for trawl fisheries (TCER) in October 2007, and for setnet fishing (NCELR) in October 2006. These forms include one record per fishing event, trawl tow or net set, and capture the latitude and longitude.

Since its introduction, almost all of the trawl effort has been reported on the new TCER form. However, setnet fishers on vessels less than 6 m in length are not required to use the new NCELR form. The smaller vessels operate almost entirely inside the harbours; consequently, there is no quantitative information about the location of fishing effort in these areas. The coastal setnet fishery is assumed to have been accurately reported since the introduction of the NCELR form in October 2006.

Trawl effort is measured in number of tows. Setnet effort records include number of nets set, the length of nets set, and the duration of time in the water. After grooming the data we found that the most reliable measure is the total length of nets set, which we report in kilometres.

All fishing effort is reported to a statistical area. In Tables A2.2–A2.5, the fishing effort is divided into the six statistical areas from Whanganui to north of Kaipara Harbour. In Fig. A2.6, the statistical areas are given names to make them easier to interpret. Figures A2.7–A2.14 show setnet and trawl fishing effort, plus the intersection of fishing effort and Maui's dolphin distribution.

References

Childerhouse, S.; Rayment, W.; Webster, T.; Scali, S.; du Fresne, S.D. 2008: Offshore aerial survey of Maui's dolphin distribution 2008. Auckland Conservancy, Department of Conservation (unpublished). 6 p.

Ferreira, S.M.; Roberts, C.C. 2003: Distribution and abundance of Maui's dolphins (*Cephalorhynchus hectori maui*) along the North Island west coast, New Zealand. *DOC Science Internal Series 93*. 19 p.

MFish (Ministry of Fisheries) 2008: Research database documentation. Retrieved from http://tinyurl.com/fdbdoc

Hamner, R.M.; Oremus, M.; Stanley, M.; Brown, P.; Constantine, R.; Baker, C.S. 2012: Estimating the abundance and effective population size of Maui's dolphins using microsatellite genotypes in 2010–11, with retrospective matching to 2001–07. Auckland Conservancy, Department of Conservation. 44 p.

Rayment, W.; du Fresne, S.D. 2007: Offshore aerial survey of Maui's dolphin distribution 2007. Auckland Conservancy, Department of Conservation (unpublished). 6 p.

Scali, S. 2006: Use of harbours by the critically endangered species Maui's dolphin (*Cephalorhynchus hectori maui*). Auckland Conservancy, Department of Conversation (unpublished). 28 p.

Slooten, E.; Dawson, S.M.; Rayment, W.J.; Childerhouse, S.J. 2005: Distribution of Maui's dolphin, *Cephalorhynchus hectori maui*. New Zealand Fisheries Assessment Report, 2005/28.

Slooten, E.; Dawson, S.M.; Rayment, W.J.; Childerhouse, S.J. 2006: A new abundance estimate for Maui's dolphin: what does it mean for managing this critically endangered species? *Biological Conservation 128(4)*: 576–581.

Stanley, M. 2009: Maui's winter offshore aerial survey June/July 2009. Auckland Conservancy, Department of Conservation (unpublished). 10 p.

Wood, S.N. 2004: Stable and efficient multiple smoothing parameter estimation for generalized additive models. *Journal of the American Statistical Association 99*: 673–687.

Table A2.2. Number of fisher reported records, by fishing method group, and statistical area, for the two fishing years, 2009–10 and 2010–11.

YEAR	METHOD	RECORDS					
		EGMONT	TARANAKI	WAIKATO	MANUKAU	KAIPARA	HELENSVILLE
2009–10	Setnet	317	1072	485	1868	3832	21
	Trawl	658	1813	836			803
	Troll	19	265	173	1		333
	Bottom longline	53	184	79	2		84
	Purse or beach seine		9	38			28
	Ring net		12	10	49	41	
	Lines, gathering, or diving	68	12	4	3	14	4
	Surface longline		1	8			29
	Potting	13	4				
	Fish traps		3				
2010–11	Setnet	240	922	527	2034	4157	5
	Trawl	545	1397	818		1	749
	Troll	20	153	131		1	131
	Bottom longline	59	308	131	1	1	151
	Purse or beach seine	2	157	55		33	7
	Ring net		9	3	69	49	
	Lines, gathering, or diving	61	23		4	15	3
	Surface longline		1	14			35
	Potting	10	1				

Table A2.3. Fisher-reported setnet fishing effort reported between 1992–93 and 2010–11, reported as number of vessels, records, nets set, and kilometres of net set broken down by statistical areas 040–045. The 'located %' column provides the percentage of total effort that has been reported with a latitude and longitude.

YEAR*	VESSELS	RECORDS	SETS	KILOMETRES OF NET SET						TOTAL	LOC'D†
				EGMONT	TARANAKI	WAIKATO	MANUKAU	KAIPARA	H'VILLE‡		
1992–93	209	10349	44012	1749	1508	354	1718	3446	372	9147	0.0
1993–94	179	9683	29100	1621	965	350	2365	3310	342	8952	0.1
1994–95	181	9906	39044	1521	1452	505	2020	3259	452	9209	0.0
1995–96	179	9425	52539	1238	1293	397	1858	3179	353	8317	0.0
1996–97	184	10705	46535	1180	1382	934	1824	3798	437	9555	0.0
1997–98	171	11755	65908	800	1358	753	2052	4671	336	9969	0.0
1998–99	158	11042	33087	1010	1133	368	2087	5320	283	10202	0.3
1999–00	162	12513	30959	860	958	528	2356	5370	152	10224	0.0
2000–01	171	13115	24930	893	850	574	2469	6083	136	11004	0.0
2001–02	175	11296	18174	909	731	587	2175	5176	284	9862	0.0
2002–03	160	10098	15446	853	977	437	1958	4235	106	8566	0.0
2003–04	147	9557	15843	960	774	517	1961	3790	14	8016	0.0
2004–05	138	9245	16522	930	1012	468	1749	3473	56	7688	0.0
2005–06	128	8554	23446	585	965	350	1666	3137	55	6759	0.0
2006–07	136	9015	42579	757	1002	308	1978	2698	70	6814	29.4
2007–08	123	8322	41725	742	1060	320	1581	2716	120	6538	32.4
2008–09	120	8283	46742	815	1260	399	1146	3104	99	6823	35.0
2009–10	122	7921	45257	797	1244	290	1135	3088	20	6573	35.4
2010–11	124	8130	55501	633	1178	357	1244	3102	5	6520	33.6

* Fishing year

† Located %

‡ Helensville

Table A2.4. Fisher-reported trawl effort between 1992–93 and 2010–11, reported as number of vessels, records, number of tows by statistical areas, total number of tows. The 'located' column provides the percentage of total effort that has been reported with a latitude and longitude.

YEAR*	VESSELS	RECORDS	TOWS						TOTAL	LOC'D†
			EGMONT	TARANAKI	WAIKATO	MANUKAU	KAIPARA	H'VILLE‡		
1992–93	61	4325	647	2807	1728	2	20	2221	7425	39.82
1993–94	57	3356	574	2176	1646	49	11	2086	6542	29.88
1994–95	60	2893	446	1547	1448	1	20	1611	5073	37.69
1995–96	67	3217	288	1379	1450	28	9	1760	4914	50.43
1996–97	64	3887	325	1831	1690	5	26	1529	5406	63.06
1997–98	67	4448	472	1679	2005	26	25	1823	6030	62.6
1998–99	64	4229	345	2251	1911	34	22	1735	6298	54.45
1999–00	53	3792	719	1815	1526	10	5	1583	5658	49.75
2000–01	54	4582	875	1515	1731		7	1663	5791	68.42
2001–02	55	4508	1085	1618	1562	4	8	1252	5529	71.48
2002–03	48	4391	1055	1729	754	1	5	1422	4966	81.09
2003–04	50	5238	662	1700	1820		3	1424	5609	89.09
2004–05	48	5540	725	1820	1626	2	4	1655	5832	91.34
2005–06	41	4038	838	1646	897		4	1086	4471	82.93
2006–07	42	3714	714	1543	940		4	948	4149	81.83
2007–08	36	4516	702	1817	1010	1	1	1022	4553	98.57
2008–09	35	3945	579	1568	867	3	4	940	3961	99.8
2009–10	37	4116	673	1833	837	1	1	804	4149	99.95
2010–11	36	3516	546	1401	819		1	749	3516	99.91

* Fishing year

† Located %

‡ Helensville

Table A2.5. Fisher-reported trawl effort, from vessels less than 43 m long, between 1992–93 and 2010–11, reported as number of vessels, records, number of tows by statistical areas, total number of tows. The 'located' column provides the percentage of total effort that has been reported with a latitude and longitude.

YEAR*	VESSELS	RECORDS	TOWS						TOTAL	LOC'D†
			EGMONT	TARANAKI	WAIKATO	MANUKAU	KAIPARA	H'VILLE‡		
1992--93	44	2783	163	1785	1700	2	20	2213	5883	24.14
1993--94	41	2138	180	1360	1638	49	11	2086	5324	13.86
1994--95	43	2206	166	1142	1446	1	20	1611	4386	27.95
1995--96	56	3002	150	1315	1437	28	9	1760	4699	48.16
1996--97	54	3625	215	1699	1671	5	26	1528	5144	61.18
1997--98	59	4001	250	1565	1896	26	25	1821	5583	59.61
1998--99	55	4124	254	2246	1910	34	22	1727	6193	53.67
1999--00	46	3674	623	1803	1516	10	5	1583	5540	48.68
2000--01	43	4056	414	1454	1730		7	1660	5265	65.26
2001--02	40	3829	516	1525	1549	4	8	1248	4850	67.48
2002--03	39	3021	214	1336	631	1	5	1409	3596	73.92
2003--04	43	3232	342	940	1011		3	1307	3603	83.04
2004--05	36	3624	342	1007	1112	2	4	1449	3916	87.10
2005--06	32	2546	313	953	683		4	1026	2979	74.39
2006--07	32	2259	217	824	755		4	894	2694	72.01
2007--08	25	2933	198	896	875	1	1	999	2970	97.85
2008--09	24	2768	252	859	749	3	4	917	2784	99.71
2009--10	26	2650	222	1027	636	1	1	796	2683	99.93
2010--11	28	2425	255	855	574		1	740	2425	99.88

* Fishing year

† Located %

‡ Helensville

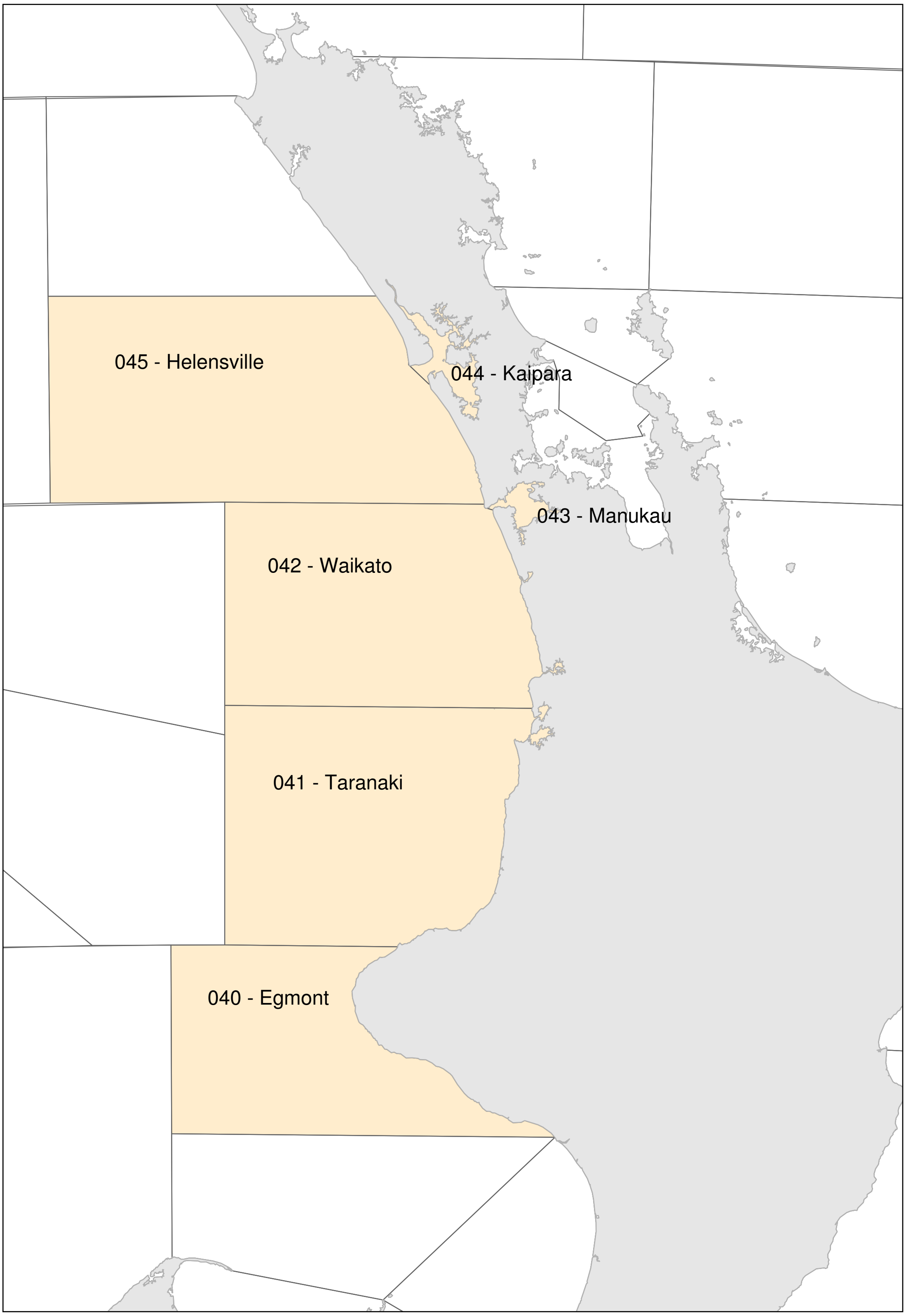

Figure A2.6. Labelled fisheries statistical areas which show the areas included in the tables of fishing effort.

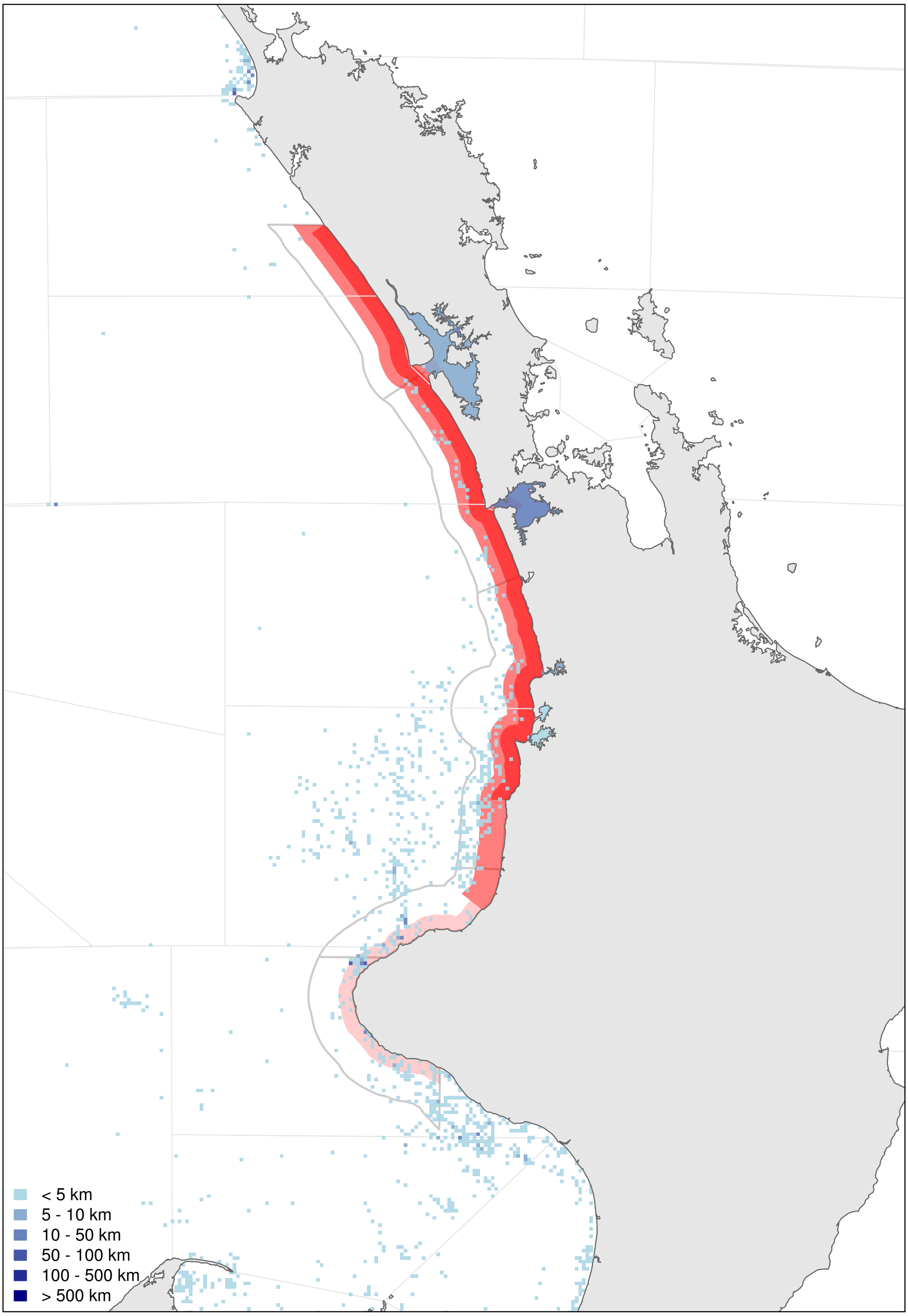

Figure A2.7. Setnet effort, measured in kilometres of net set per year, per 1 square nautical mile, for the years 2006 to 2008. The various existing and proposed areas closed to setnet fishing are indicated in red. The grey outline marks the extent of the Marine Mammal Sanctuary, including the proposed southern extension.

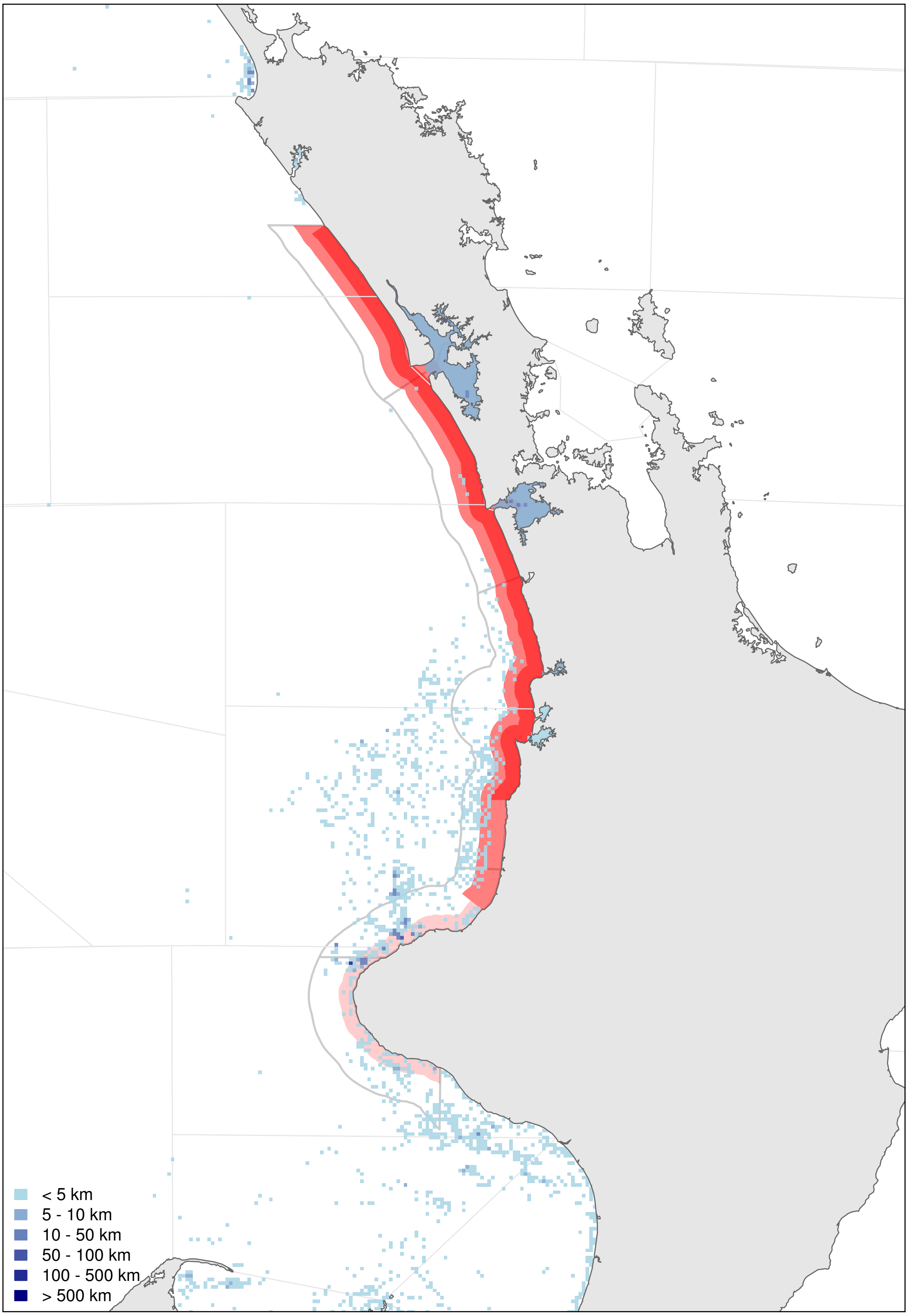

Figure A2.8. Setnet effort, measured in kilometres of net set per year, per 1 square nautical mile, for the years 2008 to 2011. The various existing and proposed areas closed to setnet fishing are indicated in red. The grey outline marks the extent of the Marine Mammal Sanctuary, including the proposed southern extension.

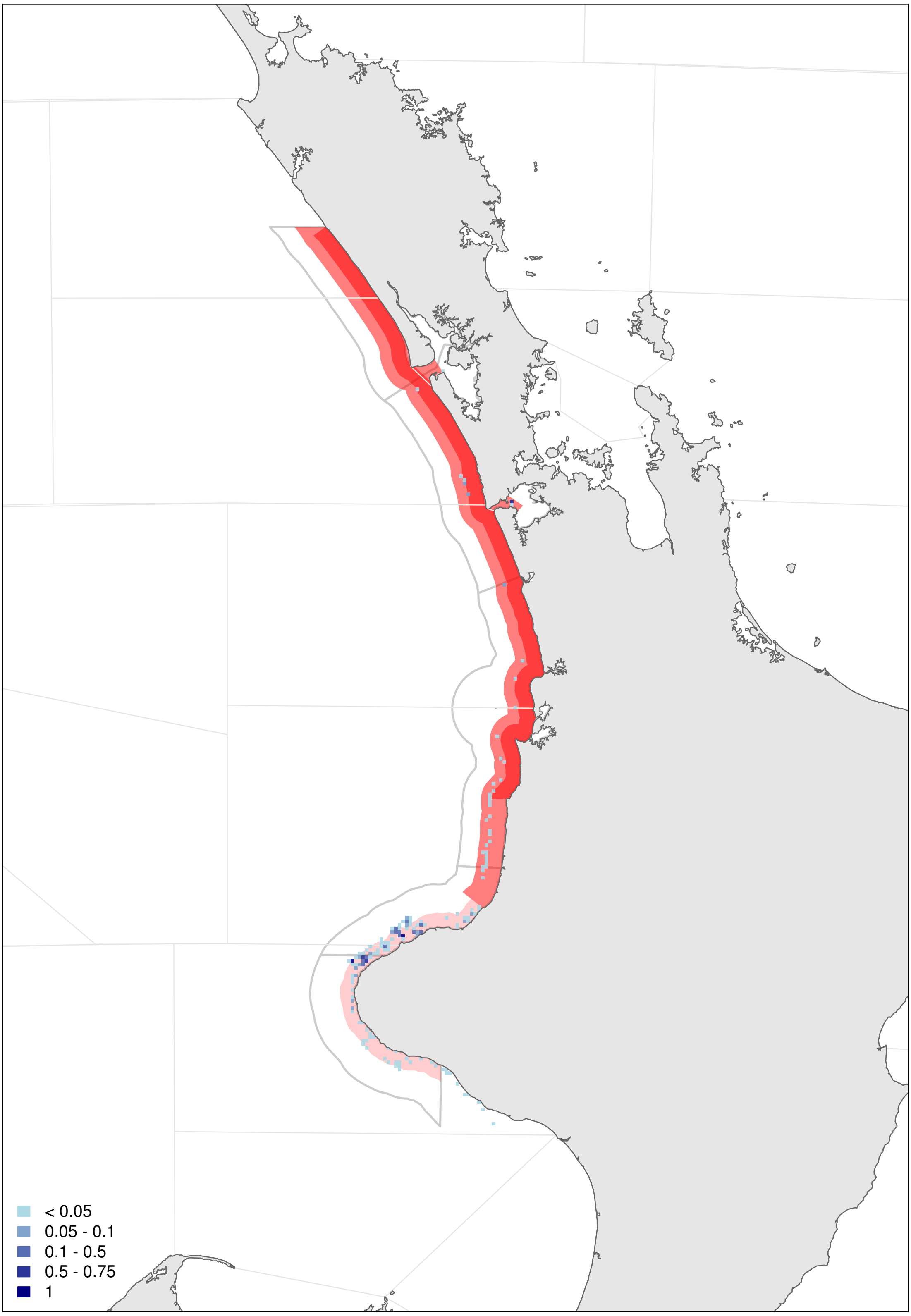

Figure A2.9. Intersection of Maui's dolphin distribution with all setnet effort between 2008 and 2011. The intersection is calculated by multiplying the fishing effort with the dolphin distribution value in each cell (as shown in blue). The values have been scaled so that the maximum value is 1. The various existing and proposed areas closed to setnet fishing are indicated in red. The grey outline marks the extent of the Marine Mammal Sanctuary, including the proposed southern extension.

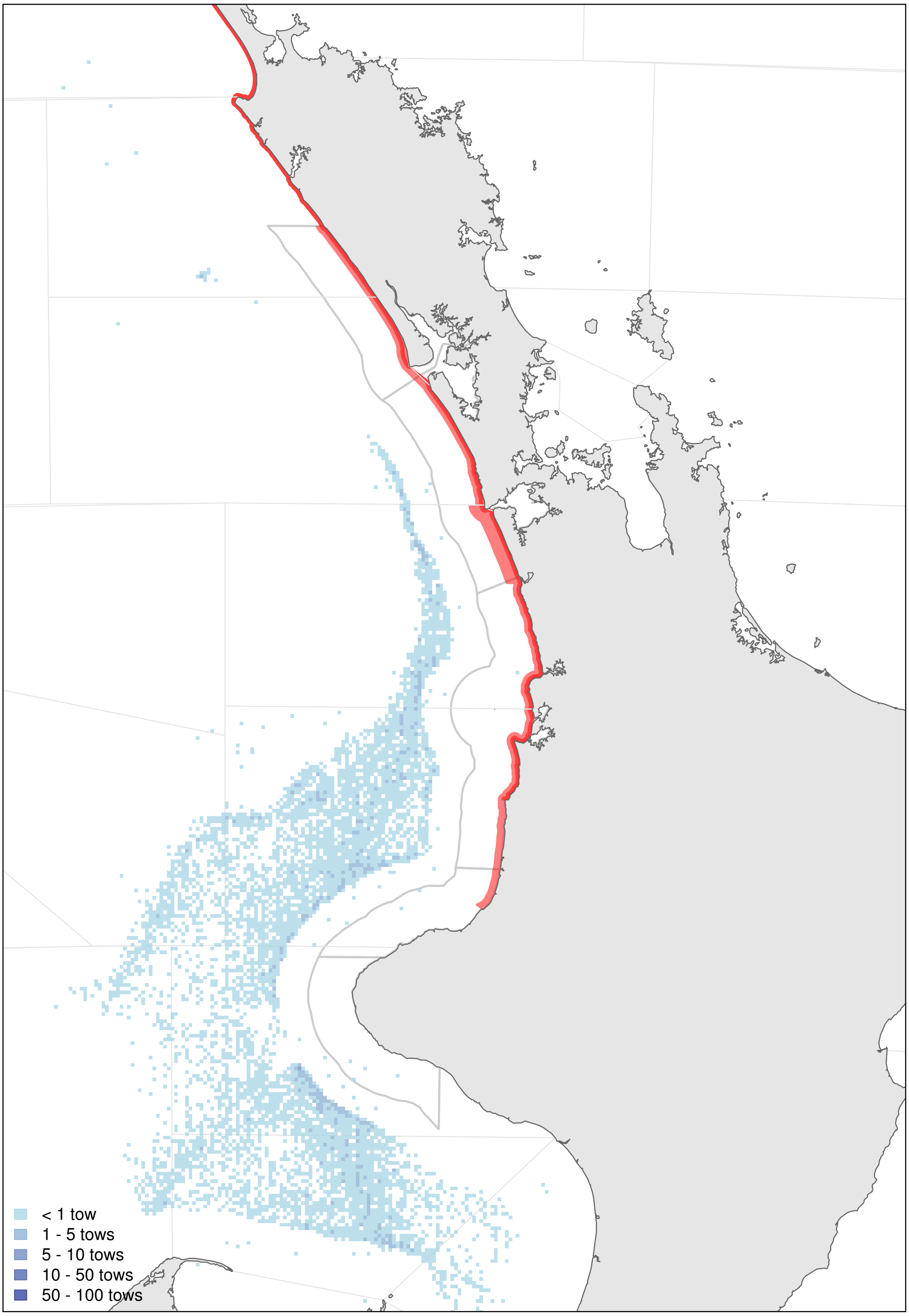

Figure A2.10. Trawl effort from vessels greater than 43 m long measured in tows per year, per square nautical mile, for the years 2006 to 2011. The various existing areas closed to trawl fishing are indicated in red. The grey outline marks the extent of the Marine Mammal Sanctuary, including the proposed southern extension.

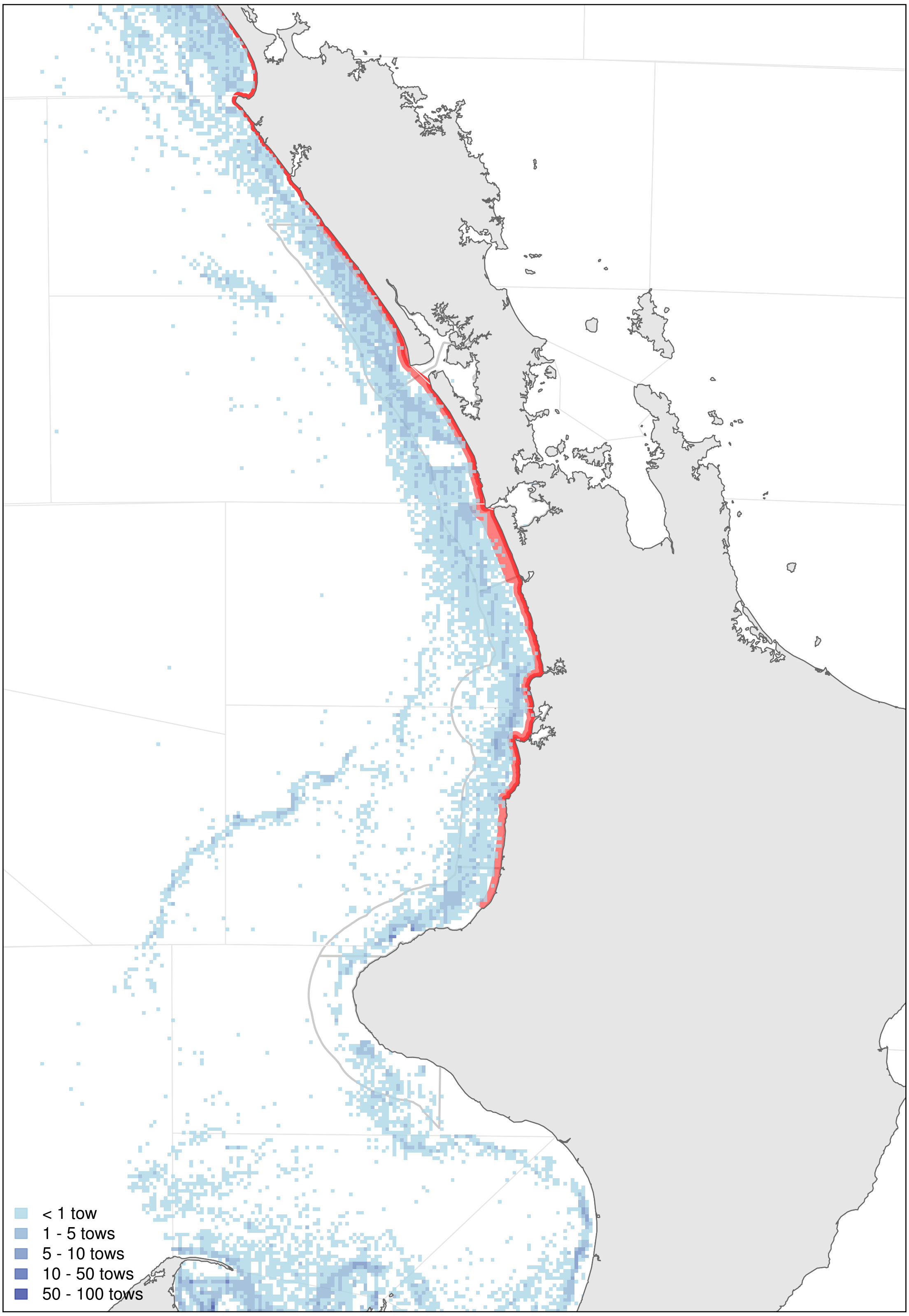

Figure A2.11. Trawl effort from vessels less than 43 m long, measured in tows per year, per square nautical mile, for the years 2006 to 2011. The various existing areas closed to trawl fishing are indicated in red. The grey outline marks the extent of the Marine Mammal Sanctuary, including the proposed southern extension.

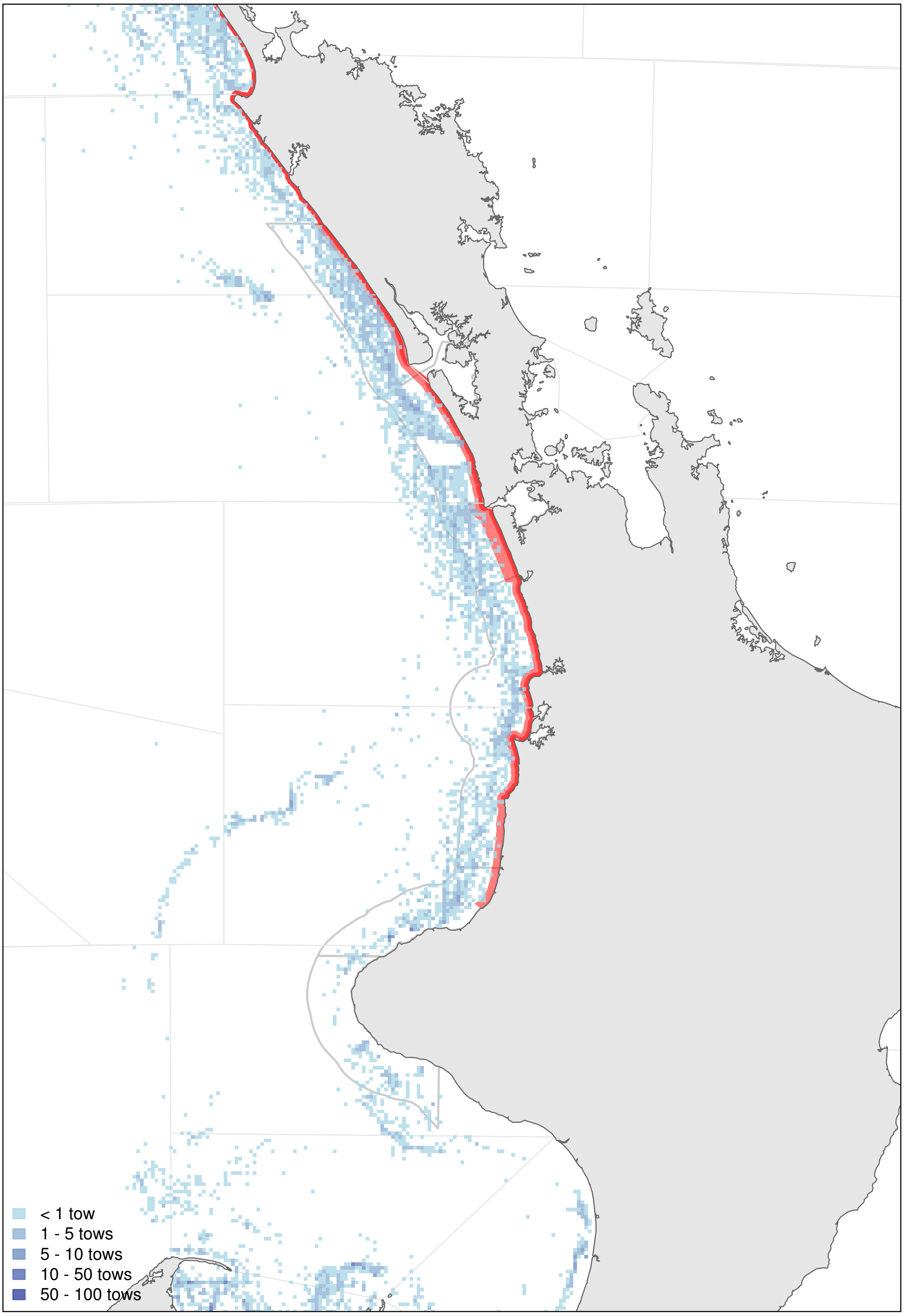

Figure A2.12. Trawl effort from vessels less than 43 m long, measured in tows per year, per square nautical mile, for the years 2006 to 2008. The various existing areas closed to trawl fishing are indicated in red. The grey outline marks the extent of the Marine Mammal Sanctuary, including the proposed southern extension.

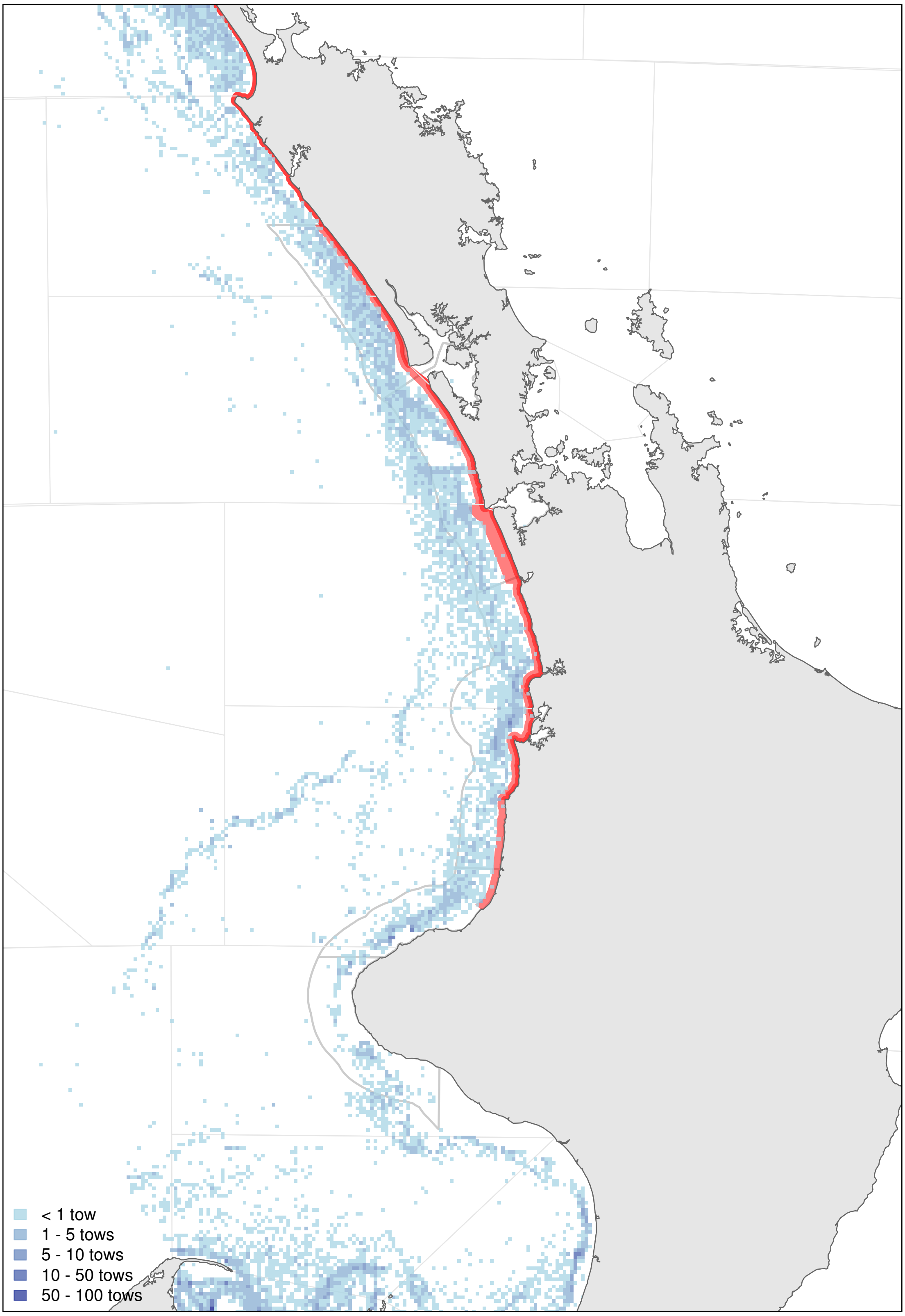

Figure A2.13. Trawl effort from vessels less than 43 m long, measured in tows per year, per square nautical mile, for the years 2008 to 2011. The various existing areas closed to trawl fishing are indicated in red. The grey outline marks the extent of the Marine Mammal Sanctuary, including the proposed southern extension.

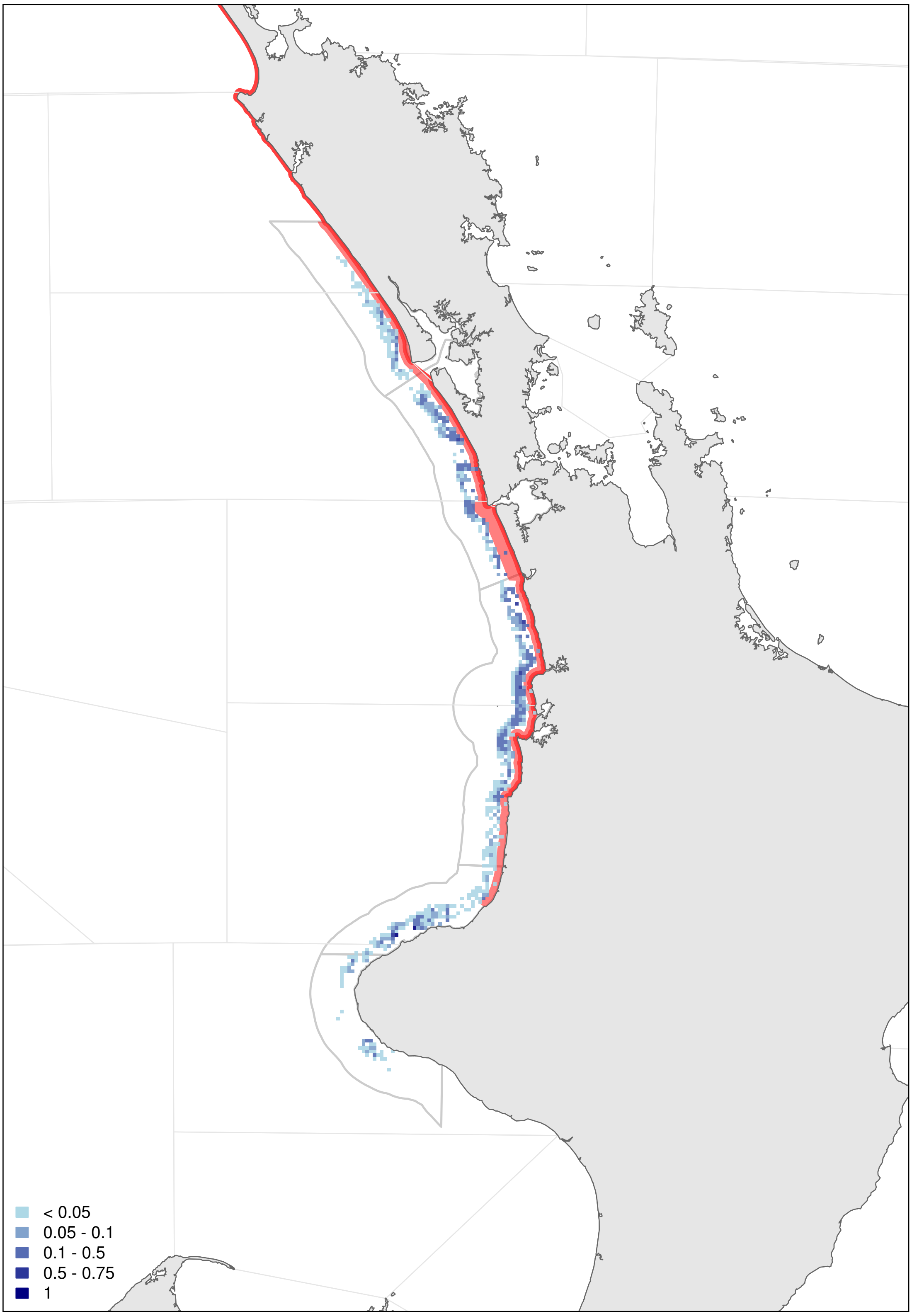

Figure A2.14. Intersection of Maui's dolphin distribution with all trawl effort between 2008 and 2011. The intersection (shown in blue) is calculated by multiplying the fishing effort with the dolphin distribution value in each cell. The values have been scaled so that the maximum value is 1. The various existing areas closed to trawl fishing are indicated in red. The grey outline marks the extent of the Marine Mammal Sanctuary, including the proposed southern extension.

Appendix 3

Maui's dolphin threat scoring

Table A3.1. Estimated number of Maui's dolphin mortalities per year, the risk ratio of mortalities to PBR and the likelihood of exceeding PBR for each threat, as scored by the panel. Individual threat scores were bootstrap resampled from distributions specified by the panel and aggregated to generate medians and 95% confidence intervals.

THREAT	ESTIMATED MORTALITIES			RISK RATIO			LIKELIHOOD OF EXCEEDING PBR
	MEDIAN	95% CI LOWER	95% CI UPPER	MEDIAN	95% CI LOWER	95% CI UPPER	MEDIAN PERCENTAGE
Fishing	4.97	0.28	8.04	71.5	3.7	143.6	100.0
Commercial setnet bycatch	2.33	0.02	4.26	33.8	0.3	74.3	88.9
Recreational/customary setnet bycatch	0.88	0.02	3.14	12.8	0.3	50.9	88.7
Commercial trawl bycatch	1.13	0.01	2.87	16.7	0.1	48.5	88.9
Recreational driftnet bycatch	0.05	0.01	0.71	0.7	0.1	10.9	41.3
Trophic effects of fishing	0.01	<0.01	0.08	0.1	<0.1	1.2	4.7
Vessel noise/disturbance from fishing	<0.01	<0.01	0.10	<0.1	<0.1	1.6	9.0
Mining and oil activities	0.10	0.01	0.46	1.5	0.1	7.4	61.3
Habitat degradation from mining & oil activities	0.03	<0.01	0.17	0.4	<0.1	2.7	26.4
Noise (non-trauma) from mining & oil activities	0.03	<0.01	0.23	0.5	<0.1	3.6	28.6
Noise (trauma) from mining & oil activities	0.01	<0.01	0.13	0.2	<0.1	2.0	8.8
Pollution (discharge) from mining & oil activities	<0.01	<0.01	0.13	0.1	<0.1	2.2	13.4
Vessel traffic	0.07	<0.01	0.19	1.0	0.1	3.1	47.8
Boat strike from all vessels	0.03	<0.01	0.10	0.5	<0.1	1.6	17.9
Vessel noise/disturbance from other vessels	0.02	<0.01	0.12	0.3	<0.1	1.9	14.4
Pollution	0.05	<0.01	0.36	0.8	<0.1	5.9	40.2
Oil spills	0.02	<0.01	0.15	0.4	<0.1	2.4	20.4
Agricultural run-off	<0.01	<0.01	0.12	<0.1	<0.1	1.9	9.6
Industrial run-off	<0.01	<0.01	0.11	<0.1	<0.1	1.7	7.6
Sewage and stormwater	<0.01	<0.01	0.11	<0.1	<0.1	1.6	7.3
Trophic effects of pollution	<0.01	<0.01	0.06	<0.1	<0.1	0.9	2.1
Plastics	<0.01	<0.01	0.01	<0.1	<0.1	0.1	<0.1
Disease	<0.01	<0.01	0.36	<0.1	<0.1	5.5	29.5
Stress-induced diseases	<0.01	<0.01	0.35	<0.1	<0.1	5.2	20.7
Domestic animal diseases	<0.01	<0.01	0.07	<0.1	<0.1	1.1	3.9
Total	**5.27**	**0.97**	**8.39**	**75.5**	**12.4**	**150.7**	**100.0**

Table A3.2. Estimated number of Maui's dolphin mortalities per year, the risk ratio of mortalities to PBR and the likelihood of exceeding PBR for each threat, as scored by 8 of 9 members of the panel (excluding the outlying panellist). Individual threat scores were bootstrap resampled from distributions specified by the panel and aggregated to generate medians and 95% confidence intervals.

THREAT	ESTIMATED MORTALITIES			RISK RATIO			LIKELIHOOD OF EXCEEDING PBR
	MEDIAN	95% CI LOWER	95% CI UPPER	MEDIAN	95% CI LOWER	95% CI UPPER	MEDIAN PERCENTAGE
Fishing	5.16	3.02	8.13	75.1	39.1	143.9	100.0
Commercial setnet bycatch	2.48	1.18	4.3	36.2	15.5	76.1	100.0
Recreational/customary setnet bycatch	0.97	0.20	3.17	14.4	2.8	52.7	99.7
Commercial trawl bycatch	1.21	0.44	2.91	18.3	6.1	49.7	100.0
Recreational driftnet bycatch	0.04	0.01	0.73	0.6	0.1	11.3	34.9
Trophic effects of fishing	0.01	<0.01	0.07	0.1	<0.1	1.0	3.0
Vessel noise/disturbance from fishing	<0.01	<0.01	0.01	<0.1	<0.1	0.1	<0.1
Mining and oil activities	0.08	0.01	0.47	1.2	0.1	7.6	57.0
Habitat degradation from mining & oil activities	0.02	<0.01	0.18	0.3	<0.1	2.8	21.1
Noise (non-trauma) from mining & oil activities	0.03	<0.01	0.24	0.4	<0.1	3.7	23.7
Noise (trauma) from mining & oil activities	0.02	<0.01	0.14	0.2	<0.1	2.1	10.0
Pollution (discharge) from mining & oil activities	<0.01	<0.01	0.14	0.1	<0.1	2.1	6.7
Vessel traffic	0.07	<0.01	0.19	1.0	0.1	3.1	48.9
Boat strike from all vessels	0.03	<0.01	0.14	0.5	<0.1	2.1	19.9
Vessel noise/disturbance from other vessels	0.02	<0.01	0.12	0.3	<0.1	1.9	13.7
Pollution	0.04	<0.01	0.19	0.6	<0.1	3.1	34.0
Oil spills	0.03	<0.01	0.16	0.4	<0.1	2.5	23.1
Agricultural run-off	<0.01	<0.01	0.06	<0.1	<0.1	0.8	1.5
Industrial run-off	<0.01	<0.01	0.03	<0.1	<0.1	0.5	<0.1
Sewage and stormwater	<0.01	<0.01	0.01	<0.1	<0.1	0.1	<0.1
Trophic effects of pollution	<0.01	<0.01	0.01	<0.1	<0.1	0.1	<0.1
Plastics	<0.01	<0.01	0.01	<0.1	<0.1	0.1	<0.1
Disease	<0.01	<0.01	0.37	<0.1	<0.1	5.7	22.0
Stress-induced diseases	<0.01	<0.01	0.35	<0.1	<0.1	5.4	20.6
Domestic animal diseases	<0.01	<0.01	0.06	<0.1	<0.1	0.8	1.5
Total	**5.47**	**3.31**	**8.47**	**80.2**	**42.3**	**153.7**	**100.0**