Assessment of cryptic seabird mortality due to trawl warps and longlines

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CONTENTS

EXECUTIVE SUMMARY

Understanding the nature and extent of interactions between commercial fisheries and marine protected species is one component of best practice fisheries management. These interactions can lead to mortalities of protected species, which may be detected (e.g., by fisheries observers on vessels), or not readily detectable, and undetected (also known as cryptic mortalities). For seabirds, cryptic mortalities may result, for example, when a bird carcass falls into the water after striking a trawl warp, or when a bird is landed alive on deck, removed from fishing gear and released, but later dies as a result of injuries sustained. The assessment of the risk that New Zealand commercial fisheries represent to seabird populations, conducted by Richard & Abraham (2013), considers cryptic mortality using a set of multipliers applied across the various fishing methods. These scalars are derived from sources including data collected in New Zealand and internationally.

Here, we draw on Richard & Abraham's (2013) approach, updated in 2014, to identify seabird species and fisheries for which cryptic mortality contributes particularly strongly to the overall assessed risk. We review assumptions and uncertainties inherent in Richard & Abraham's (2014) methods, as well as relevant new information which may contribute to the development of more robust cryptic mortality scalars applicable to New Zealand fisheries. Finally, we recommend options to improve the estimation of cryptic mortality for the seabird species groups and fisheries where this is particularly important.

From Richard & Abraham's (2014) assessment, cryptic mortality was especially influential in determining overall assessed risk for both albatross and petrel species, including black petrel (*Procellaria parkinsoni*) interacting with small-vessel surface and bottom longline fisheries, and Salvin's (*Thalassarche salvini*) and New Zealand white-capped (*T. cauta steadi*) albatross interacting with small inshore trawl vessels, and southern Buller's albatross (*T. bulleri bulleri*) interacting with large trawl vessels with meal plants. Key assumptions included that cryptic mortality scalars derived from fisheries outside New Zealand were appropriately applied to the New Zealand context despite differences in seabird assemblages, fishing operations and gear. Further, scalars applied to cryptic mortality of seabirds due to aerial warp strikes and interactions with trawl nets were entirely assumption-based.

Relevant new information that may contribute to refining scalars describing cryptic mortality includes work conducted on cryptic mortality associated with a Falkland Islands demersal trawl fishery, and two new studies reporting the outcomes of seabird strikes on trawl warps. Additional data sources that could prove valuable for the development of improved scalars include the database collected on seabird interactions with trawl fisheries in the Conservation of Antarctic Marine Living Resources Convention Area and from trawl fisheries off the Falkland Islands. Given the seabirds and fisheries for which cryptic mortality is a particularly important determinant of overall risk, and the additional information that may be available,

priority areas for improving estimates of cryptic mortalities in New Zealand fisheries include developing method-specific cryptic mortality scalars for bottom longline fisheries, exploring existing information to refine scalars applicable to inshore fisheries, and refining estimates of mortalities - both observed and cryptic - that result from aerial warp strikes. Applying scalars for broad groupings of large (i.e., predominantly albatrosses) and small seabirds appears appropriate given current information. The immediate amendment of data collection protocols used by New Zealand fisheries observers is recommended to document cryptic seabird mortalities. The implementation of new data collection protocols, potentially combined with experimental data collection, are also considered priorities in order to develop an understanding of cryptic mortality, especially in inshore fisheries.

1. INTRODUCTION

Understanding the nature and extent of interactions between commercial fisheries and marine protected species is one component of best practice fisheries management (FAO 1995, 2009). Interactions between protected species and fishing gear may be lethal or non-lethal. Mortalities due to injuries incurred during these interactions can result in the death of protected species at the time interactions occur, or sometime afterwards (Bull 2007, Braccini et al. 2012), and may result in population-level effects on seabirds (Croxall et al. 1990, Tuck et al. 2001, Lewison et al. 2004). Challenges with detecting mortalities when they occur (e.g., due to dead animals not being landed on the vessel deck) or when mortalities are delayed (e.g., due to injuries that eventually cause death) result in underestimates of the true extent of protected species bycatch. Mortalities occurring in such circumstances are termed unobserved or "cryptic".

In New Zealand, fisheries management frameworks that attempt to encompass cryptic mortalities include the National Plan of Action – Seabirds 2013 (Ministry for Primary Industries 2013a). Considering the assessed risks that fisheries bycatch represents to New Zealand seabirds at a population level was an integral component of this Plan. Recent risk assessments encompassing New Zealand seabirds and fisheries include Waugh et al. (2009) and Waugh et al. (2012). Ultimately, the development of the National Plan of Action – Seabirds 2013 (Ministry for Primary Industries 2013a) drew heavily on the level-2 risk assessment for seabird interactions with New Zealand commercial fisheries produced by Richard & Abraham (2013b). In estimating the risk that bycatch in New Zealand commercial fisheries presents to seabird populations, Richard & Abraham (2013b) used a multiplier approach to describe cryptic mortality. Scalars were developed for trawl and longline fisheries based on the available information. However, assumptions and uncertainties associated with these scalars limit the confidence with which they can be applied.

Developing a thorough understanding of the extent of seabird bycatch in trawl and longline fisheries, including cryptic mortality, is necessary in order to appropriately manage the environmental impacts of these fisheries. To facilitate the achievement of that understanding, the Overall Objective of this project is to estimate appropriate fishery- and species-group specific scalars to allow the robust quantification of total mortality from observed levels of seabird captures, in longline fisheries and on trawl warps (Conservation Services Programme 2013). The Specific Objectives are to:

- review available information from international literature and unpublished sources to characterise and inform estimation of cryptic mortality and live releases for at-risk seabirds in New Zealand trawl and longline fisheries
- identify those species and/or fishery groups for which current uncertainty regarding cryptic mortality contributes most strongly to high risk scores for at-risk seabird species, and,

- recommend options to improve estimation of cryptic mortality for those species/fishery group combinations.

Within trawl fisheries, the specified focus of the project was cryptic mortalities associated with trawl warps. However, mortalities associated with trawl nets are also considered here for completeness. Both net- and warp-related mortalities were considered by Richard & Abraham (2013b) and both are important and ongoing components of seabird bycatch associated with the trawl method (Abraham et al. 2013).

2. METHODS

To support the development of maximally robust fishery- and species-group specific scalars addressing cryptic mortality in trawl and longline fisheries, we considered past approaches and newly available information. First, we reviewed outputs from the level-2 risk assessment conducted by Richard & Abraham (2013b) and updated by Richard & Abraham (2014). We identified relatively higher-risk fisheries and species, for which cryptic mortality components contributed strongly to total estimated mortalities due to bycatch and therefore the estimated overall risk. We identified these groups by comparing the risk assessed using the Richard & Abraham (2013b) methodology, reported for seabird species in Richard & Abraham (2014). The definition of "risk" used in Richard and Abraham's (2013, 2014) work was the ratio of the estimated annual number of potential bycatch fatalities to the estimated number of seabirds that may be killed (taking the Potential Biological Removal approach) without reducing populations to below half of their carrying capacities. Here, we calculated the mean of the differences between risk ratios that incorporated and excluded cryptic mortality. Larger mean differences indicated greater importance of cryptic mortality in the estimation of risk. Fishery groupings (e.g., by target species and vessel size) are as in Richard & Abraham (2014) (Table 1). Having identified species and fishery groupings, we then ascertained the importance of uncertainties and assumptions within cryptic mortality components of risk scores.

To address the information gaps relating to cryptic mortality that were identified as important for higher risk fisheries and seabird species, and to potentially facilitate the development of cryptic mortality estimates less driven by assumptions, we reviewed newly available information relevant to cryptic mortality. This review encompassed published and grey literature. We also sought expert input, attempting to capture additional relevant information not available in the public domain. In addition, we report the existence of information that may be useful to inform cryptic mortality estimates, but that is not currently publically available in a usable form, e.g., data collected by international fisheries observer programmes.

Finally, having considered the existing and potentially available information, together with expert opinion, we identify fisheries and species groups for which estimates of cryptic mortality can pragmatically be improved.

Table 1: Fishery groupings used to define fishing effort by Richard & Abraham (2014) (SBW - southern blue whiting; SQU - squid; SCI - scampi; SNA - snapper). (For scientific names of commercial fish species, see Appendix 1).

Method	Fishery group	Description
Bottom longline (BLL)	Bluenose	Targeting bluenose, and vessel less than 34 m.
	SNA	Targeting snapper, and vessel less than 34 m.
	Ling	Targeting ling, and vessel less than 34 m.
	Small	Not targeting snapper, bluenose, or ling, and vessel less than 34 m.
	Large	Vessel 34 m or longer.
Surface longline (SLL)	Swordfish	Targeting swordfish, and vessel less than 45 m.
	Small	Not targeting swordfish, and vessel less than 45 m.
	Large	Vessel 45 m or longer.
Trawl	Small inshore	Targeting inshore species (other than flatfish), or targeting middle-depth species (principally hoki, hake, or ling) on vessels less than 28 m length.
	SBW	Targeting southern blue whiting.
	SCI	Targeting scampi.
	Mackerel	Targeting mackerel (primarily jack mackerel species).
	SQU	Targeting squid.
	Flatfish	Targeting flatfish species.
	Large trawler (no meal plant)	Targeting middle-depth species, vessel longer than 28 m, with freezer but without meal plant.
	Large trawler (with meal plant)	Targeting middle-depth species, vessel longer than 28 m, with freezer and meal plant.
	Large fresher	Targeting middle depth species, vessel longer than 28 m, with no processing on board, and so no freezer.
	Deepwater	Targeting deepwater species (principally orange roughy or oreos).

3. RESULTS

3.1 The Richard & Abraham risk assessment

Richard & Abraham (2013, 2014) assessed the risk that bycatch in New Zealand commercial fisheries presents to populations of 70 seabird species and sub-species. Seabirds identified as being at "very high risk" of population declines due to bycatch by Richard & Abraham (2014) were black petrel (*Procellaria parkinsoni*), Salvin's albatross (*Thalassarche salvini*), southern Buller's albatross (*Thalassarche bulleri bulleri*), Gibson's albatross (*Diomedea gibsoni*), flesh-footed shearwater (*Puffinus carneipes*), and New Zealand white-capped albatross (*T. cauta steadi*). Six additional species were considered to be at "high risk". These were Chatham Island albatross (*T. eremita*), Antipodean albatross (*D. antipodensis antipodensis*), Westland petrel (*Procellaria westlandica*), northern Buller's albatross (*T. b. platei*), Campbell black-browed albatross (*T. impavida*) and Stewart Island shag (*Leucocarbo chalconotus*). An additional 16 species were assessed as being at either "medium" or "low" risk. The other 45 species and sub-species assessed were considered unlikely to experience significant demographic impacts due to New Zealand commercial fisheries (Richard & Abraham 2014).

Sensitivity analyses conducted by Richard & Abraham (2013, 2014) showed that cryptic mortality scalars were never the greatest source of uncertainty contributing to the estimated risk of direct fishing impacts on seabird populations. However, the total extent of uncertainty was underestimated. This is because statistical uncertainty was explored but not "real world" uncertainty (e.g., due to differences in gear characteristics). Nonetheless, scalars increase the estimated number of total mortalities for some species (Richard & Abraham 2013, 2014). The mean of the differences between risk ratios that incorporated and excluded cryptic mortality ranged from 0 to 2.65. Seabird species and fisheries groupings for which cryptic mortality particularly influenced assessed risk were black petrel (bluenose *Hyperoglyphe antarctica*, snapper *Pagrus auratus* and other small-vessel bottom longline fisheries), and Salvin's albatross (inshore trawl fisheries). These groupings had mean differences between risk ratios of 1.77 to 2.65 (Table 2). Next, southern Buller's albatross and large meal trawl, New Zealand white-capped albatross and small inshore trawl, and black petrel and small tuna (*Thunnus* spp.) surface longline fisheries showed mean differences of 0.5 to 0.63. Mean differences between risk ratios with and without cryptic mortality of between 0.1 and 0.5 encompass additional surface and bottom longline fisheries and inshore and offshore trawl fisheries for seabird species classified as at very high to high risk (Table 2).

In summary, the contribution of cryptic mortality to assessed risk was especially important for both albatross and petrel species interacting with small-vessel bottom and surface longline fisheries, and southern Buller's albatross interacting with large trawl vessels with meal plants. Consequently, refining scalars applied to these fishery and vessel groups is expected to be particularly useful for improving the robustness of estimates of the overall risk that fisheries present to seabird populations.

3.1.1 Cryptic mortality scalars for longline fisheries

Across fisheries, levels of cryptic mortality will be influenced by all factors that affect seabird bycatch. However, the proportion of captures that is cryptic will be affected by a subset of these factors. In longline fisheries, the proportion of cryptic mortalities is expected to be influenced by operational and gear factors (Table 3), e.g., the duration of the soak and the type of hooks used may both affect the retention of seabird carcasses. More broadly, factors such as the nature of handling of captured birds (e.g., unhooking them) are expected to influence the extent of post-release mortalities. The factors affecting cryptic mortalities are common to both surface and bottom longline fisheries, but are expected to affect the extent of cryptic mortality differently. For example, snood length in surface longline fisheries would be longer than in bottom longline fisheries, although variation within each of these two broad method-based groupings is also expected.

For surface longline fisheries, cryptic mortality multipliers used by Richard & Abraham (2013, 2014) were based on the work of Brothers et al. (2010). Brothers et al. (2010) found that amongst 11 longliners working in four geographic regions over a 15-year period, 176 seabirds were observed caught on longline hooks during setting, and apparently unable to free

Table 2: Effect of cryptic mortality on the risk estimated in Richard & Abraham (2013b) by species and fishery. The median and 95% confidence intervals (c.i.) of the risk ratios with and without cryptic mortality for each combination of species and fishery are shown, as well as the mean and 95% c.i. of their difference. Only combinations with a mean difference in risk ratios greater than 0.1 are shown.

		Without cryptic mortality		With cryptic mortality		Difference	
Species	Fishery	Median	95% c.i.	Median	95% c.i.	Mean	95% c.i.
Black petrel	Bluenose BLL	2.37	1.31-4.03	4.95	2.67-8.40	2.65	1.26-4.64
Black petrel	Snapper BLL	2.10	1.21-3.58	4.38	2.51-7.44	2.35	1.18-4.14
Salvin's albatross	Small inshore trawl	0.26	0.14-0.46	2.11	0.98-4.15	1.97	0.83-3.74
Black petrel	Small BLL	1.56	0.81-2.83	3.24	1.68-5.88	1.76	0.79-3.25
Southern Buller's albatross	Large meal trawl	0.08	0.05-0.15	0.66	0.32-1.38	0.63	0.27-1.24
NZ white-capped albatross	Small inshore trawl	0.08	0.04-0.13	0.60	0.30-1.16	0.56	0.25-1.04
Black petrel	Small tuna SLL	0.43	0.19-0.85	0.92	0.40-1.80	0.50	0.17-1.01
Black petrel	Small inshore trawl	0.14	0.02-0.63	0.45	0.05-2.44	0.46	0.02-1.85
Flesh-footed shearwater	Snapper BLL	0.38	0.13-0.88	0.80	0.28-1.88	0.46	0.14-1.03
Southern Buller's albatross	Squid trawl	0.06	0.04-0.12	0.40	0.20-0.84	0.37	0.16-0.74
Southern Buller's albatross	Small tuna SLL	0.29	0.15-0.60	0.61	0.31-1.27	0.35	0.15-0.71
Gibson's albatross	Small tuna SLL	0.28	0.15-0.58	0.59	0.31-1.23	0.34	0.14-0.69
Chatham Island albatross	Small ling BLL	0.27	0.12-0.55	0.56	0.24-1.14	0.31	0.11-0.64
Salvin's albatross	Scampi trawl	0.04	0.02-0.07	0.31	0.15-0.64	0.29	0.12-0.58
Gibson's albatross	Small swordfish SLL	0.20	0.10-0.42	0.44	0.22-0.93	0.26	0.10-0.53
Antipodean albatross	Small tuna SLL	0.21	0.12-0.36	0.44	0.26-0.76	0.24	0.10-0.44
Salvin's albatross	Large processor trawl	0.03	0.02-0.05	0.26	0.13-0.47	0.23	0.11-0.42
Southern Buller's albatross	Large processor trawl	0.03	0.02-0.06	0.23	0.10-0.51	0.21	0.09-0.46
Salvin's albatross	Large meal trawl	0.03	0.02-0.05	0.22	0.11-0.42	0.20	0.09-0.38
Salvin's albatross	Small ling BLL	0.18	0.09-0.33	0.37	0.19-0.70	0.20	0.09-0.38
NZ white-capped albatross	Squid trawl	0.02	0.01-0.04	0.20	0.11-0.36	0.18	0.09-0.33
Flesh-footed shearwater	Scampi trawl	0.07	0.03-0.15	0.21	0.07-0.62	0.17	0.04-0.50
Southern Buller's albatross	Small inshore trawl	0.02	0.00-0.08	0.14	0.02-0.64	0.17	0.01-0.57
Northern Buller's albatross	Small tuna SLL	0.13	0.06-0.26	0.27	0.13-0.56	0.15	0.06-0.31
Southern Buller's albatross	Scampi trawl	0.02	0.01-0.05	0.14	0.04-0.41	0.14	0.03-0.37
Antipodean albatross	Small swordfish SLL	0.11	0.06-0.19	0.23	0.13-0.40	0.13	0.05-0.24
Flesh-footed shearwater	Small BLL	0.09	0.02-0.28	0.18	0.04-0.60	0.11	0.02-0.32
Flesh-footed shearwater	Small inshore trawl	0.03	0.00-0.15	0.10	0.01-0.53	0.11	0.01-0.41
Southern Buller's albatross	Flatfish trawl	0.01	0.00-0.06	0.07	0.00-0.51	0.10	0.00-0.46

themselves. Of these birds, only 85 carcasses were retrieved on hauling. Richard & Abraham (2013b) used these results to derive a probability distributon for cryptic mortalities, based on the binomial distribution and incorporating statistical uncertainty. A multiplier of mean 2.08 (95% confidence interval: 1.79–2.44) was applied across all surface longline fisheries and all seabird species groups. Therefore, the total annual potential fatalities calculated by Richard & Abraham (2013, 2014) comprised the estimated observable captures multiplied by a sample from the cryptic mortality probability distribution. For bottom longline fisheries, the same multiplier was used given the lack of information on cryptic mortalities associated specifically with this fishing method.

3.1.2 Cryptic mortality scalars for trawl fisheries

In trawl fisheries, factors influencing the proportion of mortalities that is cryptic are expected to include operational and gear factors including the exposed length of trawl warps, and where trawls occur in the water column (i.e., pelagic, mid-water or demersal) (Table 3). As for longline fisheries, factors operating across all fisheries apply, such as the effects of handling bycaught birds on post-release mortality. Factors affecting cryptic mortalities are common across trawl fisheries, but are expected to affect the extent of cryptic mortality differently amongst fisheries. For example,

Table 3: Factors considered likely to affect the proportion of seabird mortalities that is cryptic in longline and trawl fisheries.

Fishing method	Factor	Rationale
Longline	Timing of line setting	Affects suite of scavengers available to access carcasses (e.g., for scavengers undertaking diel vertical migrations)
	Gear configuration (e.g., floats, weights)	Affects soak depth (see next)
	Line soak depth	Affects suite of scavengers accessing carcasses and nature of physical disturbance of line (e.g., moving around on the sea floor)
	Line soak time	Affects carcass exposure to scavengers and potential for physical disturbance of line
	Hook type (e.g., "J" or circle hook)	Affects likelihood of capture and carcass retention
	Where on the body captured birds are hooked	Affects likelihood of escape and survival
	Gear sink rate	Affects time for escape as gear sinks underwater
	Snood length	Affects time for escape as gear sinks underwater
	Loss of baited snoods during setting	Affects extent of undetected hooking
	Fish waste discharge with embedded hooks	Affects extent of undetected hooking
	Gear remaining on and/or inside birds released alive	May affect movement, foraging ability, and survival (e.g., by causing injury and infection)
	Ocean currents	May affect likelihood of carcass retention during the soak
Trawl	Tow depth	Affects exposure of carcasses to scavengers, and gear and operational factors (e.g., length of exposed warp)
	Tow duration	Affects exposure of carcasses to scavengers and likelihood of carcass dropping out of trawl net
		Affects likelihood carcass is dislodged from sweeps, bridles, doors
	Tow speed	May affect likelihood of carcass retention in net
	Turns conducted during tows	May dislodge carcasses ensnared on sweeps, bridles, doors, and sprags
	Occurrence of net-raising during tows	May dislodge carcasses ensnared on sweeps, bridles, doors, and sprags
	Length of exposed warps	May affect extent of warp strikes
	Length of warp above and below surface	May affect carcass capture and retention
	Presence of warp sprags or splices	May affect retention of birds striking trawl warps
	Location of warp sprags above or below surface	May affect retention of carcasses
	Greasiness of trawl warps	Affects retention of birds striking trawl warps
	Location of warp interaction (air, water)	May affect likelihood of injury, and carcass retention
	Gear components unable to retain additional carcasses	Limits number of mortalities detected as additional carcasses drop off (e.g., if one bird is impaled by a sprag and therefore additional birds cannot be)
	Net remaining on bird released alive	May affect movement, foraging ability, and survival
	Net mesh size	May affect retention of carcasses
All methods	Composition and abundance of local predator and scavenger assemblages	
	Handling of captured birds	May affect likelihood of post-release survival
	Observer duties	Affects likelihood that captures are detected

all trawl warps create a risk of cryptic mortality due to warp interactions. Factors such as the availability of offal and discards for seabirds to forage on exacerbates this risk (Pierre et al. 2012). However, pelagic trawlers tow with more exposed warp than deepwater trawlers, thereby creating a potentially greater risk of cryptic mortalities if seabirds are present around the warps and effective warp strike mitigation is not in place.

The approach used by Richard & Abraham (2013b) to explore cryptic mortality in trawl fisheries considered three causes of mortality: net entanglement, surface warp strike, and aerial warp strike. The multipliers developed were applied identically across all trawl fisheries.

Cryptic mortalities resulting from seabird interactions with trawl nets were considered by Richard & Abraham (2013b) to comprise birds that were entangled in meshes but that subsequently became separated from trawl nets (e.g., carcasses falling off gear into the water before being detected). As quantitative data describing the relationship between observed and cryptic net mortalities was unavailable, Richard & Abraham (2013b) implemented an approach following Richard et al. (2011). The ratio between cryptic and observable mortalities was given an assumed value (0.3) and distribution (log-normal with an associated 95% confidence interval of 0.1 to 0.7) (Richard & Abraham 2013b).

In contrast to the absence of information relating to observed and cryptic fatalities due to trawl nets, a limited amount of information was available to Richard & Abraham (2013b) to inform a quantitative consideration of the extent of cryptic mortalities due to trawl warp strikes. Two studies were considered. These were conducted in South Africa (Watkins et al. 2008) and New Zealand (Abraham 2010). The information contained in these sources was applied to develop (either log-normal or beta) probability distributions from which the relationship of fatalities and captures was characterised. Thus, the number of large-bird fatalities per observed surface warp capture was estimated at 18.54 (95% confidence interval 10.88–28.8). Large birds were all albatross species, giant petrel *Macronectes* spp., and Subantartic skua *Catharacta antarctica*). For small birds, this value was 111.35 (95% confidence interval 26.95–295.44) (Richard & Abraham 2013b). The small birds grouping encompassed all other seabirds.

Aerial warp strikes were assumed to not result in warp captures (Richard & Abraham 2013b). Therefore, fatalities resulting from aerial strikes were considered to be entirely cryptic. Richard & Abraham (2013b) speculated that fatality rates for aerial warp strikes would be low overall (e.g., 0 to 5%), whilst being highest for large birds, moderate for small fast-flying birds (e.g., white-chinned petrel *Procellaria aequinoctialis*), low for small slow-flying birds (e.g., broad-billed prion *Pachyptila vittata*). For small slow-flying birds, warp strikes were considered to mostly arise from the lateral movement of the trawl warp. For diving birds (e.g., penguins and shags), aerial warp strikes were considered non-existent. Fatality rates due to aerial warp strikes were described using a beta distribution. The number of fatalities due to aerial warp strikes per observed seabird capture was 3.2 (95% confidence interval 1.86–5.05) for large birds, 72.79 (95% confidence interval 24.1–175.27) for small fast-flying birds and 36.5 (95% confidence interval 11.93–81.95) for slow-flying birds (Richard & Abraham 2013b).

Overall, for each large bird capture observed in trawl fisheries, a multiplier of 8.23 (95% confidence interval: 5.44–12.04) was applied to incorporate cryptic mortalities and estimate overall potential mortalities. For small fast-flying birds, the multiplier was 3.38 (95% confidence interval: 1.82–12.04). For small slow-flying birds and small diving birds, these values were 2.95 (95% confidence interval: 1.70–5.70) and 1.30 (95% confidence interval: 1.10–1.69) respectively (Richard & Abraham 2014).

3.2 Assumptions influencing Richard & Abraham's estimates of cryptic mortality

While representing the best available information on cryptic mortality in surface longline fisheries, the appropriateness of applying the findings of the Brothers et al. (2010) study to New Zealand surface and bottom longline fisheries is unknown. Two key considerations affecting this extrapolation are the extent of commonalities in the seabird assemblage found in New Zealand and the characteristics of fishing operations, including gear.

Brothers et al. (2010) utilised data collected from four geographic regions where different seabird assemblages occurred. Across all areas except one (the central Pacific), assemblages included albatrosses, petrels, shearwaters and the southern skua. However, the species composition within these assemblages varied. For example, the Indian and Southern Ocean assemblages were most similar to each other. Further, these two regions and the Coral Sea were more similar to species assemblages occurring in New Zealand waters than the assemblage observed in the central Pacific was (Brothers et al. 2010). Most birds observed by Brothers et al. (2010) that were caught on hooks and unable to free themselves comprised three species: Laysan albatross (*Phoebastria immutabilis*), black-footed albatross (*Phoebastria nigripes*), and black-browed albatross (*Thalassarche melanophris*). Laysan and black-footed albatross do not occur in New Zealand waters. In the absence of these species, others may attack baits, possibly at similar rates and with similar propensities to being hooked. However, this is unknown and creates uncertainty in the application of the cryptic mortality multiplier derived from the Brothers et al. (2010) work to New Zealand contexts.

Given that different seabird species are known to have different propensities to attacking, being caught, and being caught and retained on longline hooks, one option for exploring the appropriateness of including data from non-New Zealand species in the derivation of the cryptic mortality multiplier is to reanalyse the dataset collected by Brothers et al. (2010) having eliminated species that do not occur in New Zealand waters. This approach would still only partially address uncertainties however. Remaining areas of uncertainty include the potential effects of interspecific interactions amongst seabird species on captures and the effects of differences amongst longline gear types used in the fishery areas. Also, the size of the dataset without non-New Zealand species would be substantially smaller, which is expected to significantly constrain analyses. An alternative approach is to explore the Brothers et al. (2010) dataset to develop a multiplier based on categories of birds such as large (e.g., albatross and giant petrel) and small (all other seabirds).

Finally, the observations conducted by Brothers et al. (2010) only detected the captures of seabirds on hooks at or above the sea surface. Diving species (e.g., white-chinned *Procellaria aequinoctialis* and grey petrel *Procellaria cinerea*) were observed by Brothers et al. (2010) attacking baits. Additional attacks and captures probably occurred underwater during the 15 years of the study, but remained unobserved. This situation would apply also to the New Zealand context.

The second key assumption relevant to applying the findings of Brothers et al. (2010) to New Zealand fisheries relates to fishing operations and gear. Across the four geographic regions two main types of fishing vessels were observed by Brothers et al. (2010): Japanese industrial longliners and vessels working in the Hawaiian pelagic longline fishery. The effects of different operational patterns and gear characteristics amongst the vessels monitored in the 15-year period of this study on cryptic mortality rates have not been explored. However, it is reasonable to expect that gear types and characteristics of fishing operations could affect cryptic mortality rates. Operationally, large Japanese pelagic longline vessels on which Brothers et al. (2010) collected data could be expected to be broadly similar to charter vessels operating in New Zealand waters. The smaller vessels operating in the Hawaiian pelagic longline fishery may have some operational similarities to inshore New Zealand vessels.

Characteristics of gear deployed such as hook type and hook size are likely to affect the retention of captured seabirds on hooks (Table 3). For example, circle hooks may be less likely to catch birds (Li et al. 2012) but also likely to retain captured birds more effectively than "J" hooks, increasing detection of seabird captures on the haul. In New Zealand longline fisheries, a diversity of hook types is used (including circle and J hooks), in accordance with skipper preference, target species, and whether vessels are operating manual or autoline systems (Brouwer & Griggs 2009, Goad 2011, Pierre et al. 2014b).

While not assessed by Brothers et al. (2010), weighting configurations used in longline fisheries may affect gear sink rates (Table 3). Birds caught on slower-sinking gear may have more time to escape prior to being pulled underwater by the sinking longline. A number of factors such as the use of line-weights, floats and gear setting speeds affect gear sink rate (Goad et al. 2010, Goad 2011, Pierre et al. 2013). Similarly, where snoods are longer, seabirds may have more time to escape hooks or entanglement as gear is pulled underwater.

The extent of exposure that scavengers such as sea lice and sharks have to seabird carcasses will affect the likelihood that carcasses remain in whole, or in part, for detection at the haul. Brothers et al. (2010) reported that 4% of seabird carcasses showed bite marks, suggestive of shark attack.

However, they considered it more likely that sharks removed carcasses in their entirety. Gear and operational factors affecting the extent of exposure to scavengers include soak time (i.e., the period of time that the gear is in the water), the extent of drift (i.e., the horizontal distance the gear travels during the soak), fishing depth (i.e., the location of the gear in the water column), gear position in relation to hydrographic or bottom characteristics that may contribute to the formation of scavenger aggregations, and the timing of the set (influencing the potential overlap with cycles of scavenger activity).

Cryptic mortalities due to trawl warp strikes were explored using the Abraham (2010) and Watkins et al. (2008) findings. In doing so, two assumptions are applied, similar to those applied to longline fisheries. These relate to the characteristics of the seabird assemblages found in New Zealand and South Africa, and the characteristics of fishing operations (Table 3).

The seabird assemblage encountered by Watkins et al. (2008) included some species occuring in New Zealand waters (e.g., black-browed albatross, white-chinned petrel), and others that are not found here (e.g., Cape gannets *Morus capensis*, great shearwater *Puffinus gravis*). The influences of assemblage composition and interspecific interactions on warp strike and cryptic mortality rates are unknown.

Similar to longline fisheries, there are differences in the characteristics of gear and operations used amongst trawl fisheries targeting different commercial species. Watkins et al. (2008) reported warp strikes from a demersal deepwater trawl fishery. Abraham (2010) analysed data collected across a broader range of fisheries including pelagic, mid-water and inshore trawls, but most data was collected from demersal trawl fisheries. Key differences amongst these fisheries include trawl depth, net dimensions (e.g., mesh size and net size), and the length of the exposed warps astern. Overall, the effects of trawl gear characteristics and operational procedures on cryptic mortalities have not been investigated. However, differences are reasonable to expect. For example, trawl depth may affect carcass retention. Carcasses may be more likely to fall out of nets during pelagic trawling, whereas at the sea floor, carcasses may be more likely to be attacked by sea lice. Further, during mid-tow turns where the net is raised, any carcasses snagged on the sweeps or bridles may be dislodged (Table 3).

Richard & Abraham (2013b) were unable to consider cryptic mortalities resulting from seabird captures in trawl nets due to an absence of information. Therefore, their estimation of cryptic mortalities resulting from trawl net captures is entirely assumption-based.

For warp captures, a key assumption made by Richard & Abraham (2013b) is that aerial warp strikes are entirely cryptic. This is unlikely to be the case, given seabirds in the air that strike trawl warps may be stuck on sprags or greasy warps. Further, seabirds striking trawl warps in the air may slide down trawl warps and be ensnared on sweep wires, bridles, or the trawl doors (R. Guild, pers. comm., Department of Conservation and Ministry for Primary Industries unpublished data). Therefore, some aerial warp strikes are expected to result in observed fatalities. Further, Richard & Abraham (2013b) assume that overall, fatality rates for aerial warp strikes are low. This is unknown.

Richard & Abraham (2013b) considered that size and flight characteristics of seabirds affect the risk of warp strikes, both in the air and on the sea surface, and calibrate their description of cryptic mortality accordingly. Within the small bird grouping, the effect of flight speed on warp strikes and captures is unknown and is assumed.

3.3 Additional information

Since the risk assessment work of Richard & Abraham (2013b) was published, a small amount of new literature relevant to cryptic mortality has become available. This includes a broader definition of cryptic mortality, one study exploring cryptic mortality of seabirds interacting with a trawl fishery, and two studies from which information on the potential outcomes of trawl warp strikes is available.

Richard & Abraham (2013b) considered seabirds hooked on longlines and not landed dead, and a proportion of seabird interactions with trawl warps and nets, to result in cryptic mortalities. However, Gilman et al. (2013) defined cryptic fishing mortality more broadly, identifying some components of unobservable mortality also reflected by Warden & Murray (2011). Gilman et al. (2013) considered cryptic mortality to include:

- pre-catch losses, when a mortality occurs due to the fishing operation but the carcass is not landed,
- ghost-fishing by lost or abandoned gear,
- "collateral mortalities",
- post-release mortality when animals are released alive, and,
- mortality resulting from the cumulative effects of stress and injury resulting from fishing operations.

Pre-catch losses would include the deliberate discarding of carcasses or injured birds before observers are aware of captures (Department of Conservation and Ministry for Primary Industries, unpubl.). Ghost-fishing could include when snoods with bait attached are accidentally lost overboard on setting or hauling (D. Goad, pers. comm.), and hooks are discarded in fish cut off snoods on the haul or remaining in offal after processing (Gilman et al. 2005, Otley et al. 2007, Phillips et al. 2010). Collateral mortalities result from exclusion from habitat by fisheries and predation of animals released alive following capture and also include the death of young onshore when the single parent remaining alive cannot successfully raise its offspring (Gilman et al. 2013).

For seabird species captured in New Zealand fisheries, some information is available to support exploration of the broader definition of cryptic mortality presented by Gilman et al. (2013). Records of discarded gear made by observers may support an exploration of ghost fishing risks. Collateral mortalities due to the death of breeding birds with eggs or chicks onshore could be explored using information derived from seabird carcasses retained by government fisheries observers. Observers return the carcasses of seabirds landed dead to onshore experts who make an assessment of breeding status (Bell 2012). An extremely inclusive approach could also explore potential impacts on population trajectories when widowed animals are effectively removed temporarily from the active breeding population due to the time taken to form a new pair bond. Banding records are also expected to include some information on mortalities not detected elsewhere (e.g., the record of a black petrel found dead snagged in a tree by a longline snood (E. Bell, pers. comm.)). Researchers and other visitors to seabird breeding colonies may also record information relating to collateral mortalities (e.g., birds seen carrying hooks or trailing fishing gear (Phillips et al. 2010)).

In relation to post-release mortality, fisheries observers in New Zealand and internationally record information about the state of seabirds released alive (Pierre et al. 2014c). New Zealand fisheries observers record the status of seabirds caught in terms of 21 different injuries or states (e.g., broken beak, body in rigour) and the outcome of the capture (i.e., whether the bird is released alive or is dead). Classifying all captured birds as fatalities represents a precautionary approach, which is supported by the New Zealand management context. However, information on the injuries of captured birds could be used to inform a consideration of the extent of lethal seabird injuries caused by interactions with fishing gear. While the survival prognoses of seabirds released alive are unknown, the lethality of some injuries is certain. Further, while deck strikes are excluded from current estimations of fishing mortalities, seabirds may incur potentially lethal injuries when returned to the sea from vessel decks.

The single new field-based study emerging since the publication of Richard & Abraham (2013b) that specifically explored cryptic mortality was conducted off the Falkland Islands. In Falkland Island trawl fisheries, fisheries observers monitor seabird captures and strikes on trawl warps. Seabirds observed to have died or been seriously injured are included in recent bycatch estimates, including when their carcasses are not recovered. However, to investigate the extent of seabird mortalities for which death occurred at the time of the interaction with fishing gear, but resultant carcasses were not hauled aboard, researchers in a patrol vessel followed a demersal trawler and also experimented with a device designed to retain carcasses of birds killed (Parker et al. 2013). Overall, the vessel-based observer recorded more interactions between seabirds and the fishing gear that resulted in death (ten compared to two interactions with fatal outcomes, plus 19 interactions of unknown outcome). However, from the patrol vessel, four additional mortalities or probable mortalities were detected. Overall, interactions with an ultimately fatal outcome that were undetected by the vessel-based observer comprised 38% of total mortalities. Therefore, for every bird considered killed by an on-deck observer, actual levels of incidental mortality may have been almost double, although the authors note the preliminary results their work represents and that additional research is necessary (Parker et al. 2013). In addition, the work was conducted in favourable weather conditions, which may result in an underestimate of mortalities occuring when more inclement weather results in more warp movement (Parker et al. 2013).

Since the publication of Richard & Abraham (2013b), new information on observer-assessed outcomes of seabird interactions with trawl warp cables has been promulgated for two fisheries. While not assessing cryptic mortality specifically, preliminary observations from the Uruguayan demersal trawl fishery targeting Argentine hake (*Merluccius hubssi*) document the number of seabirds, by species, potentially killed compared to landed dead on deck as a result of cable strikes (Domingo et al. 2014). For example, amongst 96 instances when black-browed albatross contacts with trawl warps were defined as "heavy", six birds were confirmed dead and 19 birds were considered "potentially dead". Further, for a total of 14 recorded heavy contacts of white-chinned petrel with trawl warps, three birds were considered potentially dead. (Heavy contacts in this study involved any of the following: a bird sustaining an injury, a bird on the water being completely submerged, the cable strike causing a bird in flight to deviate from its course and fall into the water, and/or the strike occurring at high speed). Similarly, in the demersal Australian Southern and Eastern Scalefish and Shark Fishery, observations by government observers provide for the estimation of the extent to which interactions with trawl warps result in birds on the water being pushed under the surface (Pierre et al. 2014a). This may result in observed (i.e., if carcasses are landed on deck at the haul) or cryptic mortality.

The new information presented in these three studies on the consequences of warp strikes in three demersal trawl fisheries could be explored to refine estimates of cryptic mortality applied to New Zealand demersal trawl fisheries. For example, the Australian work may be especially relevant to New Zealand inshore trawl fisheries given the smaller sizes of the vessels involved (Pierre et al. 2014a).

In addition to published information that has become available since the work of Richard & Abraham (2013b) was completed, there are existing datasets which could contain information relevant to refining cryptic mortality estimates. Data collected by observers deployed in fisheries managed by the Commission on the Conservation of Antarctic Marine Living Resources (CCAMLR) includes information on seabird strikes on trawl warps in pelagic and demersal fisheries. Heavy contacts are recorded when birds are in the air (i.e., birds hit the warp and subsequently hit the water with little or no control of their flight) or on the water (i.e., contact with the trawl warp forces part of the bird underwater). Observers also record when birds strike trawl warps and as a result, are completely submerged (CCAMLR 2013). Records of birds hitting the water or being completely submerged as a result of striking trawl warps could be evaluated alongside numbers of seabirds landed on deck to explore cryptic mortality in these fisheries. Exploring warp strike information collected from CCAMLR's pelagic trawl fisheries could be especially informative, given most information available on warp strikes has arisen from demersal trawl fisheries.

Similarly, in Falkland Island finfish trawl fisheries, observers collect warp strike information that includes the assessed outcome of warp strikes. Observers also record when birds are retrieved from warp sprags (Falkland Islands Fisheries Department 2011).

In New Zealand fisheries, a substantial volume of information is collected at sea by fisheries observers that would support explorations of the effects of different fishing gear and operations on cryptic mortality. For example, the Trawl Catch Effort Logbook records detailed gear characteristics, and new forms are being developed for the collection of information describing longline gear (Sanders & Fisher 2010, Pierre et al. 2014c). Currently however, observer data collection specifically excludes the collection of data on potential cryptic mortalities. Observers are tasked with recording seabird captures defined as when the bird "has become fixed, entangled or trapped, so that it is prevented from moving freely or freeing itself" (Ministry for Primary Industries 2013b). Observers do *not* record seabirds as captured when birds:

- strike a warp but are not actually caught on the warp,
- hit or land on the vessel, unless they fall to the deck injured, or cannot move freely under their own power, or the bird is dead,
- are snagged temporarily and free themselves,
- are only evidenced by traces of interactions, such as feathers caught in a warp splice, and,
- do not come aboard the vessel unless they were definitely caught and cannot be recovered safely.

Over time, as well as in combination with other data collected (e.g., numbers of hooks observed in longline fisheries), these records would contribute to a better understanding of cryptic mortalities. For information collected by observers to date, comment fields may include references to cryptic mortalities including in the above cases, although these comments would not represent the full extent of cryptic mortalities.

4. DISCUSSION

4.1 Priority species / fishery groupings

Richard & Abraham (2013, 2014) described the risk that bycatch in New Zealand commercial fisheries represents to seabird species as the ratio of the estimated annual number of bycatch fatalities to the number of seabirds that may be killed without reducing populations to below half of their carrying capacities. While they note that the methdology used for their assessment is not yet mature, the work provides a platform for exploring priorities for future work. We used Richard & Abraham's (2013, 2014) approach to identify seven groupings of seabird species and fisheries, for which cryptic mortality scalars were a relatively important component of the overall assessed risk. These were black petrel and small vessels undertaking bottom longline fishing and surface lining for tuna, Salvin's and white-capped albatross and small inshore trawl vessels, and southern Buller's albatross and large trawlers with meal plants. The approach taken to identifying combinations of seabird species and fishery groupings for which cryptic mortality is especially important can readily be repeated in future as the Richard & Abraham (2014) risk assessment is updated with new data. This provides for an ongoing assessment of the relative importance of cryptic mortality estimates in overall assessments of risk. Both albatross and petrel species and a diversity of fishing vessels and methods are represented in these groupings. Therefore, improving the quality of scalars for these groupings would most likely result in more robust scalars for others as well.

Data describing cryptic mortalities are inherently difficult to collect. Given the diversity amongst fisheries, fishing vessels and fishing operations, cryptic mortality can reasonably be expected to vary considerably at a variety of scales. Seasonal and annual effects are also reasonable to expect. However, to pragmatically progress the refinement of scalars when the information base is limited and data collection is extremely challenging, we propose groupings of vessels that are broader than utilised in Richard & Abraham (2014), and that are characterised by the scale of the operation and gear type. We propose that longline vessels are separated by method and by size (surface longline vessels being divided into large or small categories at 45 m in overall length, and bottom longline vessels at 34 m) (Table 4). For trawl fisheries, we take a similar approach, and recommend two groups of vessels: those smaller and those larger than 28 m in overall length (Table 5). For vessels greater than 28 m in overall length that fish using the trawl method, we recognise that dividing vessels conducting pelagic, mid-water and bottom trawl fishing is desirable. However, we recommend that these categories are refined as the volume of data available describing cryptic mortality increases. In the first instance, we consider it more important to identify what are expected to be more significant differences between cryptic mortalities occurring in association with smaller trawl vessels (that tend to operate in inshore fisheries), and the larger vessels (operating offshore).

We also consider it appropriate due to the current state of knowledge, to consider scalars for groups of large (all albatross species, giant petrel) and small (all other) seabirds, given the broad differences in morphology and behaviour exhibited by these species groups. Subdividing small seabirds into additional categories based on flight speed and effects this is speculated to have on warp interactions is not recommended, as such subdivisions are currently entirely assumption-based. (However, removing flightless birds such as penguins from considerations of aerial warp strikes, for example, is obviously appropriate and should be continued).

Table 4: Longline fishery and vessel groupings considered practicable for the development of cryptic mortality (CM) scalars, compared to those used by Richard & Abraham (2014)

Fishing method and vessel groups for practicable development of CM scalars	Richard & Abraham (2014) fishery group
Bottom longline: vessels less than 34 m in overall length	Bluenose bottom longline Snapper bottom longline Ling bottom longline Small bottom longline
Bottom longline: vessels more than 34 m in overall length	Large bottom longline
Surface longline: vessels less than 45 m in overall length	Small surface longline
Surface longline: vessels more than 45 m in overall length	Large surface longline

Table 5: Trawl fishery and vessel groupings considered practicable for the development of cryptic mortality (CM) scalars, compared to those used by Richard & Abraham (2014)

Fishing method and vessel groups for practicable development of CM scalars	Richard & Abraham (2014) fishery group
Trawl: vessels less than 28 m in overall length	Small inshore trawl Flatfish trawl
Trawl: vessels more than 28 m in overall length	Mackerel trawl Southern blue whiting trawl Scampi trawl Squid trawl Large trawler (no meal plant) Large trawler (with meal plant) Large fresher trawl Deepwater trawl

4.2 Uncertainty associated with cryptic mortality estimates

Due to the limited amount of data available, significant uncertainties remain in cryptic mortality estimates. In turn, this limits the robustness of scalars developed to estimate total mortalities. For example, for longline fisheries, Brothers et al. (2010) reflects the best available information. The relevance of the study to New Zealand is affected by the seabird assemblages present and differences in gear and fishing operations. Applying one multiplier to both small vessel and large vessel operations is likely inappropriate. In addition, Brothers et al. (2010) were not able to assess subsurface interactions. Applying the findings of Brothers et al. (2010) to bottom longline fisheries is most likely inappropriate, but was done due to the absence of other information (Richard & Abraham 2013b). Differences between surface and bottom longline fisheries that may affect cryptic mortality rates are extensive. Consequently, amongst fisheries using the longline method, uncertainties are currently greatest in cryptic mortality scalars applied to bottom longline fisheries.

Richard & Abraham (2013b) used information from one South African and one New Zealand study (Watkins et al. 2008, Abraham 2010) to develop their estimates of cryptic mortality in trawl fisheries. Existing information quantifying the cryptic mortality of seabirds in trawl fisheries is limited to warp interactions, with data collected largely from demersal fisheries. Estimates of cryptic mortalities resulting from aerial warp strikes and net interactions are entirely assumption-based. Amongst small seabirds, species were grouped according to flight characteristics. The appropriateness of these groupings has not been explored quantitatively, and therefore is assumption-based and a source of uncertainty. Finally, differences between cryptic mortalities amongst smaller- and large-vessel trawl fisheries and fishing in the pelagic, mid-water, or demersal zones, are unknown but reasonable to expect.

4.3 Additional information

The small amount of relevant information available constrains the precision of cryptic mortality estimates. However, since the work of Richard & Abraham (2013b) was completed, some progress has been made in relation to the conceptualisation and documentation of cryptic mortality. This includes a broader definition of cryptic mortality, for example, including when the deaths of breeding seabirds result in the mortality of dependent offspring onshore (Gilman et al. 2013). Information is available from New Zealand fisheries which could be used to explore this broader interpretation of cryptic mortality (Bell 2012). A small amount of new information is also available from three demersal trawl fisheries in Australia, Uruguay, and the Falkland Islands, that relates to cryptic mortality associated with interactions between seabirds and trawl warps (Parker et al. 2013, Domingo et al. 2014, Pierre et al. 2014a). This could be explored in the context of current scalars applied to trawl fisheries, particularly in the case of demersal trawling.

In addition to information already in the public domain, datasets were identified which may be profitable to explore further. In particular, fisheries observers deployed in CCAMLR fisheries make warp strike observations on pelagic and demersal trawl vessels (CCAMLR 2011). Information on seabird strikes on trawl warps is also collected by fisheries observers in the Falkland Islands (Falkland Islands Fisheries Department 2011). These datasets are subject to assumptions relating to the commonality of species composition of seabird assemblages, fishing operations and gear types, between CCAMLR and New Zealand fisheries. Differences will occur. However, new data sources relevant to developing cryptic mortality scalars are valuable to explore especially where information is sparse or lacking.

Beyond existing information, new data collection by fisheries observers and experimental work could provide important insights into cryptic mortality. For example, it is recommended that how New Zealand observers record seabird interactions with fishing gear is amended to include potential cases of cryptic mortalities. Conducting dedicated observations is also desirable, and is discussed in detail in Appendix 3. In a more experimental context, repeating and expanding the preliminary work of Parker et al. (2013) would be valuable. Observers in New Zealand trawl fisheries could deploy a Parker et al. (2013) "corpse catcher" on vessels in an exploratory context or as part of a structured experiment designed across vessels, target species, or gear types. In longline fisheries, additional information about the retention of hooked seabird carcasses could be collected using already dead birds manually attached to gear at the set, soaked for a period typical of the fishery of interest, and then hauled (again, using normal methods for the fishery under examination). In trawl fisheries, already dead seabirds could be introduced to trawl nets at the shoot to explore carcass retention and detection at the haul. For seabirds landed alive, implementing research approaches that provided for an assessment of survival over time (e.g., remote tracking of birds released alive, or monitoring of banded birds at known breeding sites) would shed light on post-release mortalities. Based on current estimates (Appendix 2), experimental approaches to cryptic mortality are likely to be more powerful, effective, and produce higher quality data in the short-term, given the high number of fishing events that must be observed to improve the confidence associated with cryptic mortality multipliers.

4.4 Recommendations

In summary, the following points are considered most important to address, in order to improve cryptic mortality estimates applied to New Zealand fisheries:

- confirm the definition of cryptic mortality to be applied to New Zealand fisheries

- amend data collection protocols used by New Zealand fisheries observers such that potential cryptic mortalities will be documented routinely

- develop method-specific scalars for bottom longline fisheries, especially vessels less than 34 m in overall length
- refine estimates of mortalities, both observed and cryptic, resulting from aerial warp strikes astern trawl vessels
- explore the development of scalars applicable to cryptic mortalities associated with trawl vessels less than 28 m in overall length
- refine cryptic mortality scalars applied to smaller-vessel surface longline fisheries, and,
- consider the role of experimental approaches to refining cryptic mortality estimates.

More challenging methodologically, but still valuable to progress in the long-term are an understanding of cryptic mortality resulting from seabird interactions with trawl nets, and mortality on longlines due to diving birds attacking longline baits underwater.

Information describing cryptic mortality, and quantifying this source of mortality, is by definition difficult to collect. For example, the observations documented by Brothers et al. (2010) took place over 2,000 hours and 15 years across 11 surface longline vessels. Dedicated experimental work can provide some insights in shorter timeframes. However, developing a better overall understanding of cryptic mortality requires a long-term approach to undertaking data collection together with ongoing analysis as new information becomes available. To progress this in New Zealand fisheries, we discuss the amount of observation effort to improve the confidence in cryptic mortality scalars in Appendix 2 of this report. We also provide candidate protocols for data collection by government fisheries observers (Appendix 3).

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7. APPENDIX 1: COMMERCIAL FISH SPECIES

Richard & Abraham (2014) grouping	Scientific name
Bluenose	*Hyperoglyphe antarctica*
Flatfish	*Arnoglossus scapha, Colistium nudipinnis, C. guntheri, Peltorhamphus novaezeelandiae, Pelotretis flavilatus, Rhombosolea leporina, R. plebeia, R. retiaria, R. tapirina*
Ling	*Genypterus blacodes*
Mackerels	*Scomber australasicus, Trachurus declivis, T. novaezelandiae, T. murphyi*
Orange roughy	*Hoplostethus atlanticus*
Oreos	*Pseudocyttus maculates, Allocyttus niger, A. verrucosus, Neocyttus rhomboidalis*
Scampi	*Metanephrops challengeri*
Snapper	*Pagrus auratus*
Southern blue whiting	*Micromesistius australis*
Squid	*Nototodarus gouldi, N. sloanii*
Swordfish	*Xiphias gladius*

8. APPENDIX 2: POWER ANALYSIS

Detecting cryptic mortality is inherently challenging. Work attempting to document cryptic mortalities of seabirds resulting from interactions with commercial fishing gear has involved many hours of observation and novel methodological approaches (Brothers et al. 2010, Parker et al. 2013). To explore the effort required to better estimate cryptic mortality (CM), we used the CM multipliers currently implemented by Richard & Abraham (2014) and considered the number of fishing events that would need to be observed to produce multipliers with certain amounts of confidence, represented by coefficients of variation (CVs).

8.1 Methods

A power analysis was conducted in order to assess the relationship between the number of fishing events observed and the uncertainty in the estimated CM multiplier, defined as the number of fatalities by observed capture.

Richard & Abraham (2013a) estimated the number of observable seabird captures in commercial trawl and longline fisheries in New Zealand, representing the number of captures that would be recovered on-board fishing vessels and recorded by observers if every vessel carried observers. Estimates of observable captures were provided using modelling of observed captures and fishing effort for New Zealand white-capped albatross, Salvin's albatross, southern Buller's albatross, other albatrosses, sooty shearwater (*Puffinus griseus*), white-chinned petrel, and other birds, and predictions of 4 000 samples of the number of observable captures for each fishing event and species were made from the models. A mean capture rate, defined as the mean number of observable captures by unit of fishing effort (number of tows for trawl, or sets for longline fisheries), was then calculated for each combination of seabird type (albatross or other), fishery (defined by the method and target species), fishing year, month, and statistical area, in order to take into account the variability among fisheries, areas, and seasons. Only the fishing effort between the fishing years 2010–11 and 2012–13 was considered, in order to represent recent fishing practices, distribution, and effort.

For each fishing trip, the number of cryptic fatalities was simulated by drawing a sample of 4 000 values from a Poisson distribution, with a mean equal to the product of the capture rate previously calculated of the corresponding stratum, the fishing effort of that trip, and the cryptic-mortality (CM) multiplier for the species type and fishing method minus 1 (in order to keep only the cryptic fatalities). For the CM multiplier, we used fixed typical values based on the CM multipliers estimated in Richard & Abraham (2014): 8 for large seabirds (albatrosses) in trawl fisheries, 2.5 for small seabirds in trawl fisheries, and 2 for all seabirds in longline fisheries. The cryptic fatalities were then aggregated by fishing trip, because observers are typically assigned to whole fishing trips instead of individual fishing events.

In order to assess the relation between the number of events observed and the uncertainty in the calculated CM multiplier, the number of trips observed was drawn randomly 3 000 times so that the number of fishing events observed varied between 0.1% of the total fishing events and a maximum of 5 000 observed events for trawl and bottom-longline fisheries, or a maximum of 1 000 observed events for surface-longline fisheries. These ranges were chosen after preliminary analyses indicated that the uncertainty stabilises at the upper limits of the number of observed fishing events.

At each iteration, the CM multiplier was calculated by dividing the total number of captures (cryptic or recovered on board) by the number of recovered captures, across all the observed fishing trips, and the coefficient of variation (the ratio of the standard deviation to the mean) of the CM multiplier was calculated from the 4 000 samples.

The CM multiplier is not defined when no captures are recovered on board, which may happen when the number of observed fishing events or the capture rate is low. The iterations for which the CM multiplier was not defined were removed, and only the iterations with a sufficient number of observed fishing events were kept, in order to not reduce artificially the uncertainty around the CM multiplier due to the selection of specific trips with high capture rates. The minimum number of observed fishing events required was chosen so that the CM multiplier was defined in at least 95% of the samples on average.

Several assumptions were made during this analysis:

- The capture rate does not vary within each combination of seabird type (albatross or other), fishery (method and target species), fishing year, month, and statistical area.
- The CM multiplier does not vary among fisheries for a given seabird type (albatross or other), fishing method (trawl, bottom longline, or surface longline), and vessels class (large or small).
- The observer observes all the fishing events of a given fishing trip.
- Every cryptic capture (i.e., capture not recovered on board the vessel) is detected by the observer.

8.2 Results

The relation between the number of observed fishing events and the uncertainty (coefficient of variation) in the calculated CM multiplier is shown in Figure 1 for each combination of species type (albatrosses or other seabirds), fishing method, and vessel class. As expected, the coefficient of variation of the calculated CM multiplier decreased rapidly as the number of observed fishing events increased, and stabilised at high numbers of observed fishing events. The stabilisation occurred at different levels depending on the species type, fishing method, and vessel class. The number of observed fishing events required to achieve a coefficient of variation of 0.2 was estimated to be between 3 and 4 times that of the number of fishing events for a CV of 0.4 (Table 6). In trawl fisheries, the number of observed fishing events required to achieve a given CV was larger for the small vessel fleet (length less than 28 m) than for the large vessel fleet. For example, for albatross species, approximately 1 250 observed fishing events were found to be required to get a CV of 0.4 in the large vessel fleet, but 2 000 observed fishing events were necessary in the small-vessel fleet. For other seabird species in trawl fisheries, the number of observed fishing events necessary to achieve the same precision in the CM multiplier was approximately 1 000 for the large-vessel fleet, but 3 000 in the small-vessel fleet. In bottom-longline fisheries, only 400 observed fishing events were necessary to achieve a CV of 0.4 in the small-vessel (< 34 m) fleet, but 600 in the large-vessel fleet for seabirds other than albatross.

In our simulations, with a CM multiplier of 8 (the value we used for albatross in trawl fisheries), a CV of 0.2 corresponds approximately to a 95% confidence interval (c.i.) of 5.8–12.2, and a CV of 0.4 to a 95% c.i. of 4.7–18.0. With a CM multiplier of 2 (the value we used for any seabirds in longline fisheries), a CV of 0.2 corresponds to a 95% c.i. of approximately 1.5–3.1, and a CV of 0.4 to 1.3–5.0.

There were only four fishing trips every year in the large-vessel surface-longline fisheries during the three fishing years between 2010–11 and 2012–13, and the capture rate of seabirds other than albatrosses was very low in this fishery group. This led the CM multiplier to not be defined in all iterations for over 5% of the samples, hence preventing a reliable assessment of its CV in this case. Similarly the CV could not be reliably estimated when the number of observed fishing events was low, preventing the estimation of the required number of observed fishing events to achieve a CV of 0.4 for albatrosses in the large-vessel bottom-longline fishery group and in all surface-longline fisheries.

8.3 Conclusions

The inherent challenges of detecting cryptic mortality events are underscored by the results of this analysis. To improve the confidence in current cryptic mortality multipliers, a significant amount of observation effort is required over time. Further, these results were obtained in the context of assumptions that represent best-case scenarios, for example, that all fishing events are observed and every cryptic capture is detected. In New Zealand commercial fisheries, observers generally do not observe every fishing event during a trip. This is because when a single observer is deployed on a vessel, they are required to spread their attention across a diversity of duties. Further, fishing events often occur at night, at least in part, when it is dark and therefore observations are challenging to conduct. Also, the observer must sleep and will therefore miss fishing events occurring at that time.

While the assumptions are significant, the main conclusion of the analysis stands. That is, that a *lot* of observational effort is required to improve our understanding of the nature and extent of cryptic mortality. Refining the

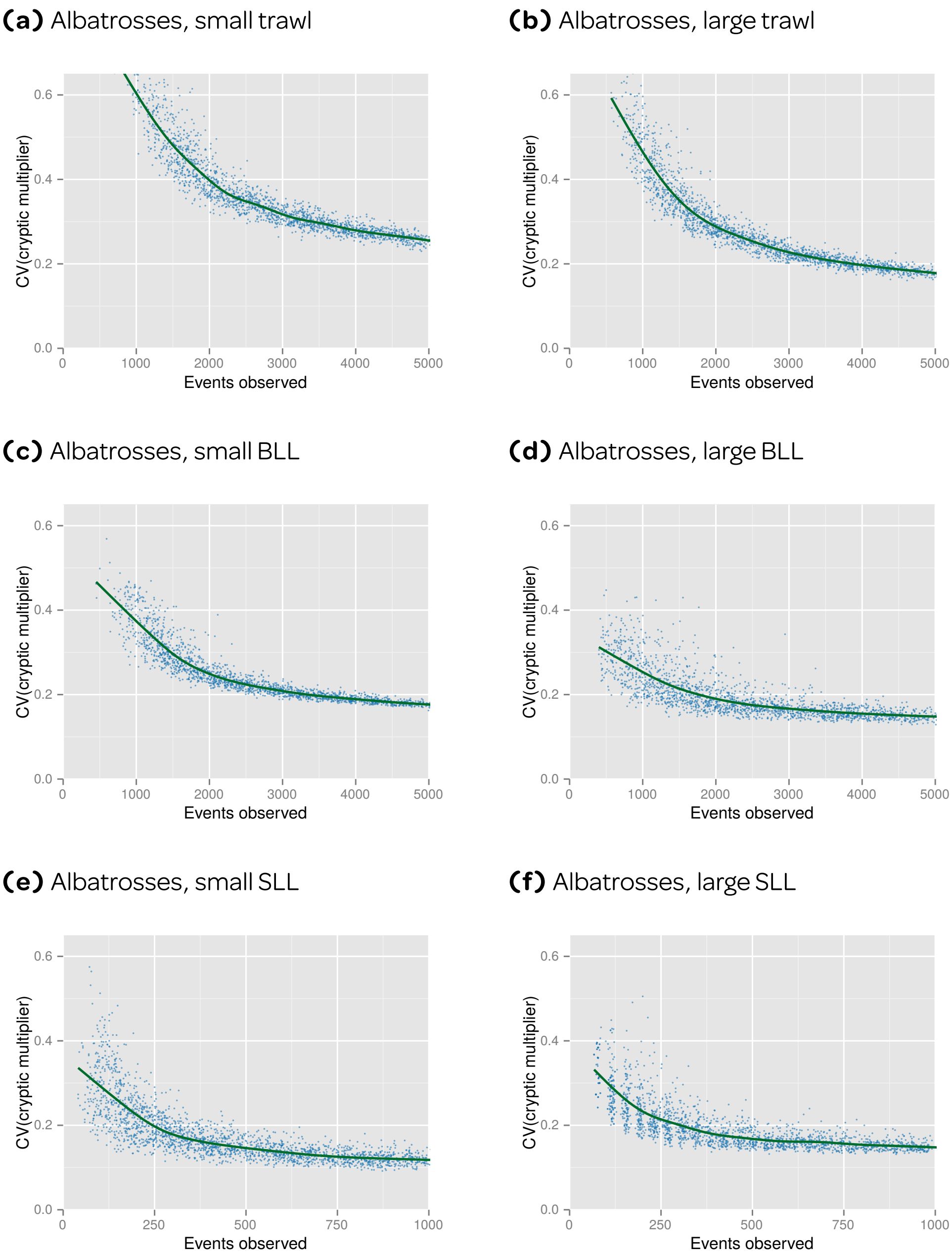
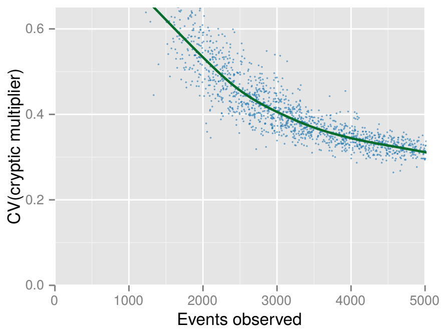
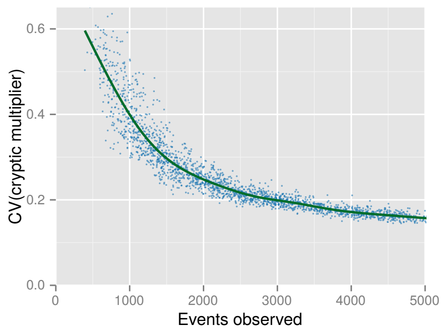


Figure 1: Relation between the coefficient of variation in the estimated cryptic mortality (CM) multiplier and the number of fishing events observed, for each combination of seabird type (albatross or other), fishing method (trawl, bottom longline, and surface longline), and vessel size (large and small, the the cut-off being an overall vessel length of 28 m for trawl, 34 m for bottom longline, and 45 m for surface longline). Each point represents the CM multiplier that was calculated from the observed captures after randomly drawing a number of observed fishing trips. The green line shows the smoothing function obtained by fitting a generalised additive model (GAM) on the points.

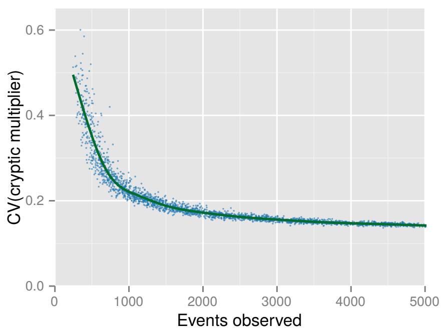
(g) Other seabirds, small trawl



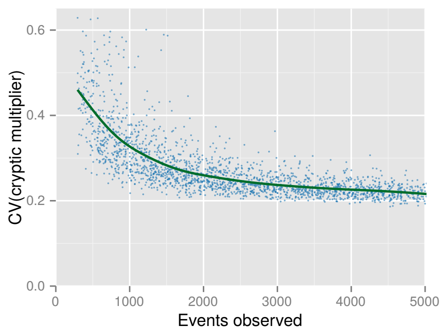
(h) Other seabirds, large trawl



(i) Other seabirds, small BLL



(j) Other seabirds, large BLL



(k) Other seabirds, small SLL

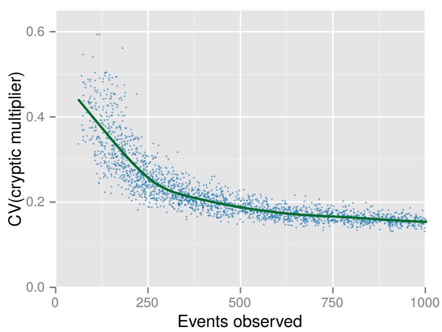


Figure 1: (cont.) Relation between the coefficient of variation in the estimated cryptic mortality (CM) multiplier and the number of fishing events observed, for each combination of seabird type (albatross or other), fishing method (trawl, bottom longline, and surface longline), and vessel size (large and small, the cut-off being an overall vessel length of 28 m for trawl, 34 m for bottom longline, and 45 m for surface longline). Each point represents the CM multiplier that was calculated from the observed captures after randomly drawing a number of observed fishing trips. The green line shows the smoothing function obtained by fitting a generalised additive model (GAM) on the points.

Table 6: Approximate number of observed fishing events required to estimate the cryptic mortality (CM) multiplier (ratio of all fatalities to the number of captures recovered on board) with a coefficient of variation of 0.2 and 0.4, for each seabird type (albatrosses or other seabirds), fishing method (trawl, bottom-longline (BLL), or surface-longline (SLL)), and vessel size (large and small, the cut-off being an overall vessel length of 28 m for trawl, 34 m for bottom longline, and 45 m for surface longline)

Species type	Fishing method	Vessel size	Observed fishing events	
			CV = 0.2	CV = 0.4
Albatrosses	Trawl	Small	>5 000	2 000
		Large	4 000	1 250
	BLL	Small	3 500	800
		Large	1 750	-
	SLL	Small	250	-
		Large	300	-
Other seabirds	Trawl	Small	>5 000	3 000
		Large	3 000	1 000
	BLL	Small	1 250	400
		Large	>5 000	600
	SLL	Small	430	90
		Large	-	-

assumptions of this analysis to create a more realistic scenario (e.g., if 50% of cryptic mortalities are assumed to be detected) would lead to the conclusion that an even larger number of fishing events would have to be observed to achieve a specified level of confidence. Therefore, in the context of the limited information currently available on cryptic mortality, the results presented here provide guidance on a minimum effort requirement. This emphasises the need for a long-term commitment to the collection of cryptic mortality data by fisheries observers.

As an alternative, or ideally, a complementary approach to data collection by fisheries observers, experimental approaches are valuable. These may be methodologically difficult and expensive in the short-term. However, if designed and executed well, experiments should provide high quality data much more rapidly than is possible using normal observer deployments.

9. APPENDIX 3: PROTOCOLS FOR OBSERVER DATA COLLECTION TO IMPROVE ESTIMATION OF CRYPTIC MORTALITY

One objective of this project was to recommend options to improve estimation of cryptic mortality (CM). These options include exploring existing datasets in more detail (described in the main text) and the collection of new data at-sea. In this appendix, we describe approaches to at-sea data collection by government fisheries observers that are simple and practical to implement, and will contribute to improved estimation of CM over time. Methods are discussed for trawl and longline fisheries, and apply across vessel sizes and target species.

9.1 Longline fisheries

Government fisheries observers working in longline fisheries are already tasked with making some observations during the set and haul stages of the fishing operation. As part of the optimisation of observer protocols (Pierre et al. 2014c), revised set and haul logs have been produced to document events of interest during these processes. Cryptic mortality observations can be readily and efficiently recorded on these forms. These observations can then be related to other elements of data collected by the new forms developed by Pierre et al. (2014c) to characterise cryptic mortality risks, e.g., rate of hook setting or hauling and gear characteristics. In New Zealand longline fisheries, much setting activity occurs during the night (Pierre et al. 2013, 2014b), restricting the opportunity for cryptic mortality observations. Consequently, capturing potential cryptic mortalities on the haul assumes particular importance.

Codes used on the Setting Event Log and Hauling Event Log to describe interactions that may result in cryptic mortality, based on Brothers et al. (2010) are:
1: Bird takes bait and is not hooked or entangled
2: Bird attempts to take bait but fails, and is not hooked or entangled
3: Bird is observed hooked but escapes
4: Bird is observed entangled but escapes
5: Bird is observed hooked and appears unable to escape
6: Bird may be hooked and unable to escape, but this is uncertain
7: Bird is entangled and appears unable to escape
8: Bird may be entangled and unable to escape, but this is uncertain
9: Other (to be described in Comments field)

Space for observers to enter a species (or species group) code for each interaction observed is also provided on the revised data collection forms (Figure 2, Figure 3).

Adding a new code to the Non-fish Bycatch Form is also recommended to provide for the documentation of carcasses retrieved on the haul from sections of the line that were observed during the set. This code would best be added to the codes available to complete the Capture method field.

Note that here we propose to restrict observations to a distance of 100 m astern the vessel. This is purely based on the practicality of conducting observations, rather than because hooks become unavailable at that distance. For example, work conducted in New Zealand bottom longline fisheries has shown that hooks are located at depths accessible to some seabirds well beyond 100 m astern (Pierre et al. 2013).

9.1.1 Instructions to observers making cryptic mortality observations in longline fisheries

You are tasked with making observations on longline sets and hauls that will allow researchers to investigate the extent of seabird interactions, captures and mortalities that are not readily detectable. These are termed "cryptic mortalities". Current estimates from surface longine fisheries overseas suggest that for every seabird mortality that is recorded by observers monitoring the haul, on average, approximately one additional mortality occurs that is not documented. An example of one type of cryptic mortality is when a seabird hooked on the set is killed, but its carcass is dislodged from the line during subsequent stages of the set, or during the soak or haul. Therefore, the capture remains detected. There is no information available currently on cryptic mortalities in bottom longline fisheries, or in any New Zealand longline fishery. Improving the NZ-specific understanding of cryptic mortalities is the purpose of these observations.

Incidents of cryptic mortality are relatively rare. Therefore, the longer you are able to observe the set for, the better. However, these observations must obviously be reconciled with your other observing duties. Aim to complete at least 15 minutes of observations at a time. If possible, aim to observe an hour per set (i.e., four 15 minute periods). Taking a break to rest your eyes every 15 minutes is recommended.

- Observations at setting

Record your observations on the Setting Event Log (Figure 2) as follows:
1. Start a Setting Event Log if you haven't already, for the set you are to observe. Record the Trip Number and Set Number. If you have started a log already, continue recording your observations on the same log.

2. Record the start time of your cryptic mortality observation period.

3. Monitor seabird interactions with the hooks and line as it is set, to 100 m astern. You can estimate 100 m using the length of the tori line, the length of a basket (and buoy locations) or any other method you devise that is practical and reasonably accurate.

4. Complete a line on the form for each incidence of a seabird interaction that matches the cryptic mortality codes listed on the back of the form.

Include the appropriate species code for each observation. If the type of interaction you observe is not effectively described by an existing code, but could lead to a mortality, use the "Other" code.

5. Be sure to complete any other fields of the Setting Event Log that you observe at the same time as the interaction, e.g., the Interruption Code or Offal Dumping may be especially important.

6. Use the "Comments" line to document any other factors of interest that may relate to the interaction you observe.

7. Record the end time of your observation period.

8. If no cases of potential cryptic mortalities were observed during your observation period, write NONE in the cryptic mortality column.

9. If possible, make a note that will allow you to identify the line observed on the set at the haul. If, on the haul, seabird carcasses are retrieved from the observed length of line, document this with records for those captures on the Non-fish Bycatch Form. (A new code has been added to the Non-fish Bycatch Form for this).

10. If you are able to conduct cryptic mortality observations on the same length of line on the haul as you observed at the set, please do so.

Note: These observations are given additional meaning when used in combination with the Surface or Bottom Longline Gear Form and the Surface or Bottom Longline Setting Log. Therefore, it is important that you complete those forms as well.

- Observations at hauling

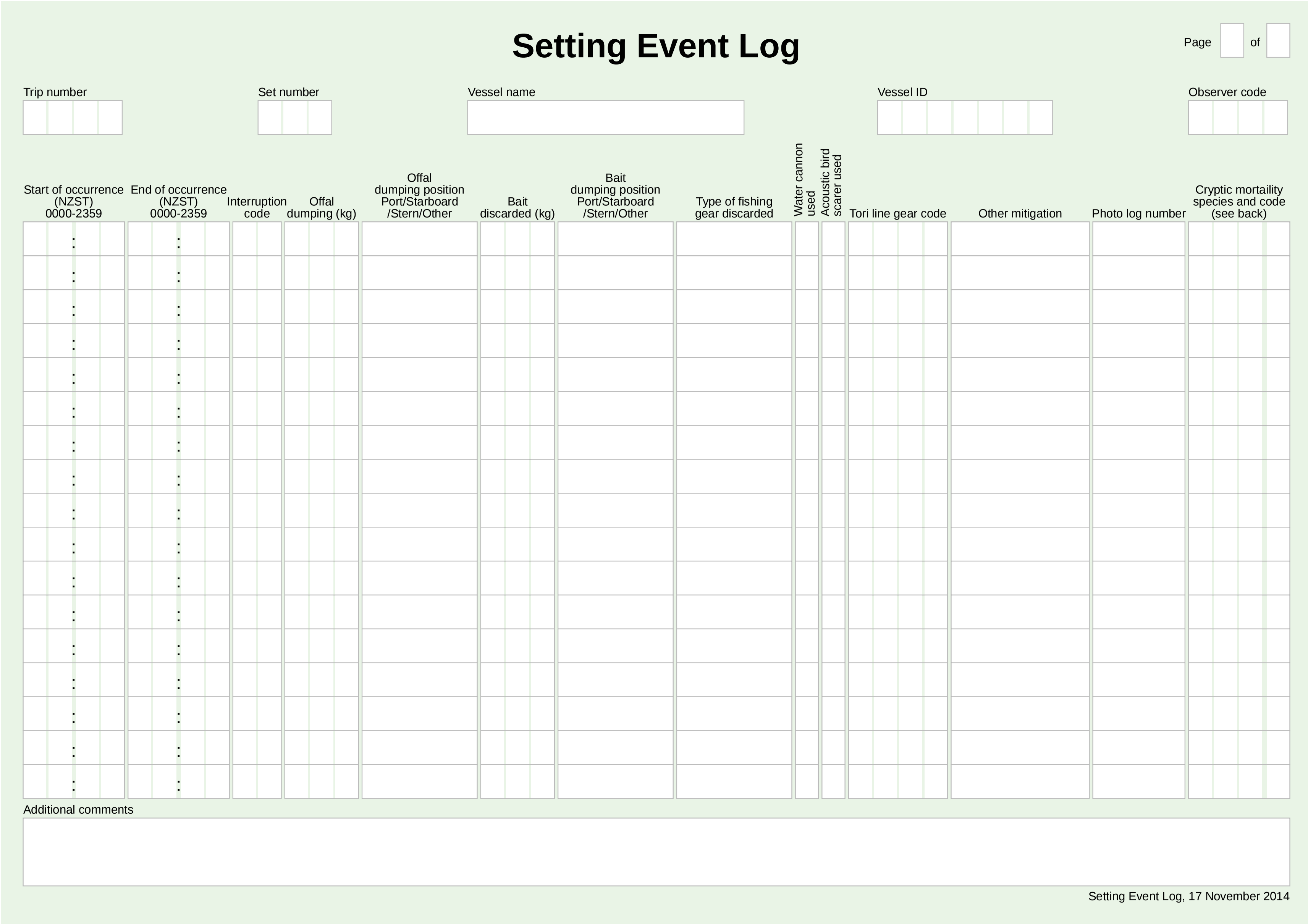
Record your observations on the Hauling Event Log (Figure 3) as follows:

1. Start a Hauling Event Log if you haven't already, for the haul you are to observe. Record the Trip Number and Set Number. If you have started a log already, continue recording your observations on the same log.

2. Record the start time of your cryptic mortality observation period.

3. If you are observing the same portion of line as you observed during cryptic mortality observations made at the set, please note this in the "Comments" field of the form.

4. Monitor seabird interactions with the hooks and line as it is hauled, to 100 m astern if the line is visible at that distance. You can estimate 100 m using the length of a basket (distances between buoys), letting out a rope of known length, or any other method you devise that is practical and reasonably accurate.



Setting Event Log

Page ___ of ___

Trip number | Set number | Vessel name | Vessel ID | Observer code

Start of occurrence (NZST) 0000-2359	End of occurrence (NZST) 0000-2359	Interruption code	Offal dumping (kg)	Offal dumping position Port/Starboard /Stern/Other	Bait discarded (kg)	Bait dumping position Port/Starboard /Stern/Other	Type of fishing gear discarded	Water cannon used	Acoustic bird scarer used	Tori line gear code	Other mitigation	Photo log number	Cryptic mortality species and code (see back)
:	:												
:	:												
:	:												
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Additional comments

Setting Event Log, 17 November 2014

Figure 2: The proposed Setting Event Log for longline fisheries (Pierre et al. 2014c).

Hauling Event Log

Page ___ of ___

Trip number	Set number	Vessel name	Vessel ID	Observer code	Entire haul observed (✓)	Number of hooks observed*

Start of occurrence (NZST) 0000-2359	End of occurrence (NZST) 0000-2359	Interruption code	Offal dumping (kg)	Offal dumping position Port/Starboard /Stern/Other	Bait discarded (kg)	Bait dumping position Port/Starboard /Stern/Other	Type of fishing gear discarded	Water cannon used	Acoustic bird scarer used	Brickle curtain gear code*	Other mitigation	Photo log number	Cryptic mortality species and code (see back)
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:	:												
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*Bottom longline only

Additional comments

Hauling Event Log, 17 November 2014

Figure 3: The proposed Hauling Event Log for longline fisheries (Pierre et al. 2014c).

5. Complete a line on the form for each incidence of a seabird interaction that matches the cryptic mortality codes listed on the back of the form. Include the appropriate species code for each observation. If the type of interaction you observe is not effectively described by an existing code, but could lead to a mortality, use the "Other" code.

6. Be sure to complete any other fields of the Hauling Event Log that you observe at the same time as the interaction, e.g., the Interruption Code or Offal Dumping may be especially important.

7. Use the "Comments" line to document any other factors of interest that may relate to the interaction you observe.

8. Record the end time of your observation period.

9. If no cases of potential cryptic mortalities were observed during your observation period, write NONE in the cryptic mortality column.

10. If, on the haul, a seabird carcass is retrieved from a part of the line you are confident you observed when making cryptic mortality observations on the set, document this with records for the capture on the Non-fish Bycatch Form. (A new code has been added to the Non-fish Bycatch Form for this situation).

Note: These observations are given additional meaning when used in combination with the Surface or Bottom Longline Gear Form and the Surface or Bottom Longline Setting Log. Therefore, it is important that you complete those forms as well.

9.2 Trawl fisheries

In the past, government fisheries observers working on trawl vessels have made observations of seabird strikes on trawl warps (Abraham 2010). Recommencing warp strike observations is recommended as these will provide information that can be used to improve cryptic mortality scalars. The warp strike protocols used on previous occasions in offshore fisheries are appropriate in this regard (Sanders & Fisher 2010), with one alteration. That is, an indication of the outcome of the warp strike should be included. To that end, it is recommended that observers record whether seabirds dropped into the water after sustaining an aerial warp strike, or were submerged by a surface warp strike. These observations could be readily documented by adding another row below the "No. heavy contacts" row on the current "Seabird Warp-strike Observations (Trawl)" form (Sanders & Fisher 2010) (Figure 4). Observer instructions for completing the current warp strike form would be altered to reflect the addition of this new field.

Note that the "Mitigation Assessment Warp-strike Form" (Figure 5) and

"Mitigation Assessment Worksheet" (Figure 6) developed for deployment in inshore fisheries already include assessments of the outcomes of warp strikes. Deploying these forms in offshore trawl fisheries is an alternative to amending the Seabird Warp-strike Observations (Trawl) form.

SEABIRD WARP-STRIKE OBSERVATIONS (TRAWL)

1. Fishing event descriptors

Observer trip number: wa.trip_number
Observer tow no.: wa.station_number
TCEPR form number: wa.tcepr_number
wa.tcepr_tow
Page ____ of ____ for this tow

Date tow ended: wa.tow_date
Tow start time: wa.tow_start_time
Tow start time code: wa.time_code
Observer initials: ss.obs_initials
Side observed: P / S ss.side_observed

2. Fifteen-minute warp/mitigation device strike observations and bird abundance

	Sampling period 1		*Sampling period 2*		*Sampling period 3*		*Sampling period 4*	
Observed	ss.sample_number Warp / Mitigation device: ss.warp_or_decive_observation		Warp / Mitigation device:		Warp / Mitigation device:		Warp / Mitigation device:	
15-Minute Observation	*Time Start* ss.time_start	*Time End* ss.time_end	*Time Start*	*Time End*	*Time Start*	*Time End*	*Time Start*	*Time End*
	Large birds	*Small birds*	*Large birds*	*Small birds*	*Large birds*	*Small birds*	*Large birds*	*Small birds*
Bird abundance	ss.large_birds	ss.small_birds						
No. heavy contacts	ss.contacts_large	ss.contacts_small						

3. Mitigation devices and environmental factors

Mitigation equipment codes	wd.device_type			
Mitigation event codes	me.event_code			
Swell height (m)	ss.swell_ht			
Swell direction (1-12 h)	ss.swell_dir			
Wind speed (Beaufort)	ss.wind_speed			
Wind direction (1-12 h)	ss.wind_dir			
Discharge side	P / S / B / N ss.discharge_side	P / S / B / N	P / S / B / N	P / S / B / N
Discharge rate	0 / 1 / 2 / 3 ss.discharge_rate	0 / 1 / 2 / 3	0 / 1 / 2 / 3	0 / 1 / 2 / 3
Discharge type *	S / M / C / O / D ss.discharge_type	S / M / C / O / D	S / M / C / O / D	S / M / C / O / D

*several types permissible

Codes for use in completing this form

Discharge rate:
Record one only
- **0** = none
- **1** = negligible
- **2** = intermittent
- **3** = continuous

Discharge type:
Record one or more
- **S** = sump water
- **M** = minced
- **C** = cutter pump
- **O** = offal, i.e. heads and guts
- **D** = discards of whole fish.

Elsewhere:
- **P** = Port
- **S** = Starboard
- **B** = Both

- **N** = Neither / None / No
- **Y** = Yes
- **U** = Unknown

Form version: 24/08/2007

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Figure 4: Form used by government fisheries observers to collect warp strike observations from offshore trawl vessels (front side).

4. Comments : Record anything that may result in a sample being removed from the analysis, e.g. gear failure or the environmental or fishing factors changed, or the vessel does a turn meaning that the conditions, such as wind direction changes during the sampling period

Sample 1	ss.comments
Sample 2	
Sample 3	
Sample 4	

Beaufort Scale of Wind Force

Beaufort Number	Descriptive term	Mean wind speed (knots)	Probable wave height * (m)
0	Calm	<1	
1	Light air	1 - 3	0.1 (0.1)
2	Light breeze	4 - 6	0.2 (0.3)
3	Gentle breeze	7 - 10	0.6 (1.0)
4	Moderate breeze	11 - 16	1.0 (1.5)
5	Fresh breeze	17 - 21	2.0 (2.5)
6	Strong breeze	22 - 27	3.0 (4.0)
7	Near gale	28 - 33	4.0 (5.5)
8	Gale	34 - 40	5.5 (7.5)
9	Strong gale	41 - 47	7.0 (10.5)
10	Storm	48 - 55	9.0 (12.5)
11	Violent storm	56 - 63	11.5 (16.0)
12	Hurricane	64 and over	14 (-)

* This table is intended as a rough guide for the open sea. Figures in brackets indicate the probable maximum wave heights. In coastal areas greater heights will be experienced.

Mitigation Event codes

Enter up to six codes indicating mitigation related events that you observed during the observation period:

A = Tori line observed to be continuously slack (i.e. not taut) for some of the time that it was deployed
B = Aerial extent of Tori line observed to extend less than about 10m beyond the warp for some of the time
C = Tori line observed to have tangled streamers for some of the time that it was deployed
D = Tori line main-line observed to be entangled with a warp, or another Tori line, for some of the time
E = Streamers of Tori line observed not to reach to waterline, allowing for wind and swell
F = A delay between when the brakes went on and when the Tori line was deployed (specify in Comments)
G = A delay between when the Tori line was removed and when hauling began (specify in Comments)
H = Warp scarer main-line top connector observed to be set more than 4 metres from the stern
J = Warp scarer main-line observed to be entangled with the warp, for some of the time that it was deployed
K = Warp scarer streamers (if present) observed not to reach the waterline.
L = Warp scarer observed to have tangled streamers (if present) for some of the time that it was deployed
M = Warp scarer observed to snag when warp length is adjusted
N = A delay between when the brakes went on and when the Warp scarer was deployed (specify in Comments)
O = A delay between when the Warp Scarer was removed and when hauling began (specify in Comments)
P= The bottom connector on the Warp scarer is between 2 and 5 metres (measured along the warp) of the point where the warp enters the water (allowing for wind and swell)
Q = The bottom connector on the Warp scarer is further than 5 metres (measured along the warp) away from the point at which the warp enters the water
R = Bird baffler dropper lines observed to be tangled for some of the time that was deployed
S = Strong winds are having a negative impact on the effectiveness of the mitigation equipment
T = Part of a mitigation device was observed to be damaged or lost. Make a comment to explain what happened
U = A whole mitigation device was lost part-way through, or malfunctioned during, the fishing event. If it is replaced you should complete a new mitigation details form. Make a comment to explain what happened
Y = More than six mitigation events, or mitigation events not covered by existing codes –document in comments section

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Figure 4: (cont.) Form used by government fisheries observers to collect warp strike observations from offshore trawl vessels (back side).

Mitigation Assessment Warp-Strike Form

1. Fishing event descriptors

Observer trip #		Observer tow #		TCEPR #		# of vessels in vicinity		Page __ of __ for this tow	
Date		Tow start time		Observer initials		Side observed	P / S	Treatment	1 / 2 / 3/ 4

2. Fifteen-minute warp/mitigation device strike observations and bird abundance

	Sampling period 1					*Sampling period 2*					*Sampling period 3*					*Sampling period 4*				
15-Minute Observation	*Time Start*		*Time End*			*Time Start*		*Time End*			*Time Start*		*Time End*			*Time Start*		*Time End*		
	L Alb	*S Alb*	*P*	*CP*	*S*	*L Alb*	*S Alb*	*P*	*CP*	*S*	*L Alb*	*S Alb*	*P*	*CP*	*S*	*L Alb*	*S Alb*	*P*	*CP*	*S*
Bird abundance																				
No. light contacts																				
No. heavy contacts																				
Air																				
Water																				
Warp – Deflected																				
Warp – Dragged under																				
Mitigation – Deflected																				
Mitigation – Dragged under																				

3. Mitigation devices and environmental factors

Swell height (m)				
Swell direction (1-12 h)				
Wind speed (Beaufort)				
Wind direction (1-12 h)				
Discharge side	P / S / R / N	P / S / R / N	P / S / R / N	P / S / R / N
Discharge rate	0 / 1 / 2 / 3	0 / 1 / 2/ 3	0 / 1 / 2 / 3	0 / 1 / 2/ 3
Discharge type *	S / O / D	S / O / D	S / O / D	S / O / D

Figure 5: Form used by government fisheries observers to collect warp strike observations from inshore trawl vessels (front side)..

4. Haul Observation

	Time net at surface				Time net on deck			
Haul time								

	L Alb	*S Alb*	*P*	*CP*	*S*
Bird abundance					
No. landing on codend					
No. swimming around codend					
No. actively feeding on codend					
No. diving on codend					

5. Comments : Record anything that may result in a sample being removed from the analysis, e.g. gear failure or the environmental or fishing factors changed, or the vessel does a turn meaning that the conditions, such as wind direction changes during the sampling period

Sample 1	
Sample 2	
Sample 3	
Sample 4	

Beaufort Scale of Wind Force

Beaufort Number	Descriptive term	Mean wind speed (knots)	Probable wave height * (m)
0	Calm	<1	
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10	Storm	48 - 55	9.0 (12.5)
11	Violent storm	56 - 63	11.5 (16.0)
12	Hurricane	64 and over	14 (-)

* This table is intended as a rough guide for the open sea. Figures in brackets indicate the probable maximum wave heights. In coastal areas greater heights will be experienced.

Codes

Discharge rate:
Record one only
0 = none
1 = negligible
2 = intermittent
3 = continuous

Discharge type:
Record one or more
S = sump water (deck wash)
O = offal, i.e. heads and guts
D = discards of whole fish.

Elsewhere:
P = Port
S = Starboard
B = Both
R = Stern
N = Neither / None / No
Y = Yes

Figure 5: (cont.) Form used by government fisheries observers to collect warp strike observations from inshore trawl vessels (back side).

Mitigation Assessment Worksheet

Observer trip #	Observer tow #	Sampling period #

Date	Sampling period start time	Observer initials	Side observed	Treatment
			P / S	1 / 2 / 3

Species group	Light contact	Heavy contact: No consequence; deflected/ continues flying	Heavy contact: Lands on water, apparently unharmed	Heavy contact: Lands on water, visibly damaged	Heavy contact: Unknown	Surface contact: No consequence	Surface contact: Apparent damage	Surface contact: Dragged underwater, re-emerges	Surface contact: Dragged underwater, doesn't re-emerge	Surface contact: Unknown
LA						WARP	WARP	WARP	WARP	WARP
						MITIGATION	MITIGATION	MITIGATION	MITIGATION	MITIGATION
SA						WARP	WARP	WARP	WARP	WARP
						MITIGATION	MITIGATION	MITIGATION	MITIGATION	MITIGATION
P						WARP	WARP	WARP	WARP	WARP
						MITIGATION	MITIGATION	MITIGATION	MITIGATION	MITIGATION
CP						WARP	WARP	WARP	WARP	WARP
						MITIGATION	MITIGATION	MITIGATION	MITIGATION	MITIGATION
S						WARP	WARP	WARP	WARP	WARP
						MITIGATION	MITIGATION	MITIGATION	MITIGATION	MITIGATION

Figure 6: Form used by government fisheries observers to collect observations on the outcome of trawl warp strikes astern inshore trawl vessels.