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Review of research and assessments on the efficacy of sea lion exclusion devices in reducing the incidental mortality of New Zealand sea lions *Phocarctos hookeri* in the Auckland Islands squid trawl fishery

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ABSTRACT

New Zealand sea lions are incidentally killed in the Auckland Islands squid trawl fishery. Sea lion exclusion devices (SLEDs) that allow animals to escape from the trawl net have received considerable development and assessment attention. Nonetheless, there are claims that some animals could suffer head trauma when colliding with the hard grid that forms part of the SLED and this may compromise post-escape survival. We reviewed published and unpublished research that assessed the effectiveness of SLEDs in reducing the incidental capture (i.e. bycatch) of sea lions, including assessments on the likelihood of post-SLED survival. The available evidence shows that SLEDs are effective in reducing sea lion bycatch in trawl nets and contribute to reduced rates of observed sea lion mortality in the Auckland Islands squid fishery. Efforts to test SLED efficacy have shown that most sea lions are likely to survive following their escape via a SLED, despite the shortage of verifying video evidence due to poor visibility at fishing depths. Laboratory necropsies of incidentally caught sea lions have been unable to reliably evaluate post-SLED survivability of sea lions due to the effects of on-board handling of carcasses, including the logistical necessity of freezing them. Some lesions initially considered to be evidence of trauma were subsequently deemed to be artefacts of freezing. Nonetheless, there was no clear difference in the trauma assessments between sea lions caught in nets with and without SLEDs. Biomechanical modelling suggested it was unlikely that impact with a SLED would cause fatal brain trauma and the probability of concussion that could result in post-SLED drowning was probably less than 10%. As fisheries bycatch has been reduced to levels that are unlikely to be driving continued decline of New Zealand sea lions at the Auckland Islands, future work may be better focussed on alternative research and management areas that may be more effective in addressing and reversing New Zealand sea lion population decline.

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1. Introduction

The endemic New Zealand sea lion (*Phocarctos hookeri*) (hereafter referred to as "sea lion") is listed as Vulnerable on the IUCN Red List (Gales, 2008) and Nationally Critical on the New Zealand Threat Classification system (Baker et al., 2010). Historically, subsistence hunting followed by commercial sealing greatly reduced both its population and breeding distribution (Childerhouse et al., 2010). Although formerly breeding throughout New Zealand, the species is now largely confined to the New Zealand sub Antarctic. Based on recent pup production estimates, 76% of all sea lion pups are born at the Auckland Islands, with most others born at Campbell Island (Maloney et al., 2009; Chilvers, 2012b; Ministry for Primary Industries (MPI), 2012; Fig. 1). Some breeding has also been recorded at the Snares Islands, Stewart Island and the Otago Peninsula (Chilvers et al., 2007).

Over the last twenty years, commercial trawl fisheries have been implicated in the observed decline of the sea lion population, due to the incidental mortality (hereafter referred to as "bycatch"[1]) of sea lions in trawl nets (Robertson and Chilvers, 2011). Annual estimates from all breeding locations in the Auckland Islands showed sea lion pup production which is the best index of relative overall population size for this species, decreased from a peak of 3021 pups in 1997/98 to a low of 1501 in 2008/09 (Chilvers et al., 2007; Robertson and Chilvers, 2011; Chilvers, 2012a; Childerhouse, 2014). Most sea lion bycatch has occurred in the Auckland Islands squid fishery, although bycatch has also been recorded in other trawl fisheries operating in the same region (Thompson et al., 2013). Sea lions may become caught when they opportunistically depredate from trawl nets, because the probability of fish being hauled nearer to the surface is high and because these events negate the need to undertake energetically expensive dives to search for prey (Hamer et al., 2013). They may choose to dive on a net when it is being set to depredate fish enmeshed from the previous fishing event (known as 'stickers'), or may use operational cues to dive on the net as it is being hauled to depredate freshly caught fish. Alternatively, sea lions may be caught when they are foraging naturally in the same areas and depths that trawl nets are operating.

The annual Auckland Islands squid fishery targeting *Nototodarus sloanii* is one of New Zealand's largest and more valuable fisheries, using a combination of bottom and mid-water trawls operating across the shelf at bottom depths of about 150–250 m (Ministry of Agriculture and Forestry, 2012). Peak activity in the fishery occurs between February and May (Ministry of Agriculture and Forestry, 2012), which coincides with part of the lactation period for breeding female sea lions when lactating mothers are regularly and frequently foraging at sea (Chilvers, 2008). Although the foraging areas and depths of sea lions are not completely understood, tracked sea lions have been shown to overlap, in part, with commercial trawl fishing activity in the Auckland Islands squid fishery (Chilvers, 2008, 2009).

The incidence of sea lion mortality in the Auckland Islands squid fishery has been monitored by government observers since 1988 (Wilkinson et al., 2003), although observer coverage has varied from less than 10% to 99% (Fig. 2). The mean estimated level of bycatch peaked in the mid to late 1990s (specifically at 131 in 1995/96 and at 142 in 1996/97; Thompson et al., 2013). As a result, sea lion conservation management has focused on this fishery, with a number of research projects commissioned to assess the impacts of sea lion bycatch and the development and assessment of new approaches to reduce those impacts. Management aimed at mitigating sea lion bycatch includes the establishment of a 12 nautical mile marine reserve around the Auckland Islands which excludes all fishing within that range, the imposition of mortality limits that can trigger spatio-temporal closures, and the development and implementation of a 'Sea Lion Excluder Device' or SLED (Fig. 3; Ministry of Agriculture and Forestry, 2012). The SLED comprises an additional section of netting inserted between the lengthener and codend of the trawl net with an angled two or three part metal grid that is designed to direct sea lions to an escape hole in the top of the net and exclude them from the trawl codend (Fig. 3; Wilkinson et al., 2003; Abraham, 2011; Middleton and Breen, 2011; Ministry of Agriculture and Forestry, 2012; Roe and Meynier, 2012). A standardised SLED design for the fishery has been widely adopted. This includes grid bar spacing of 23 cm to reduce the probability of smaller sea lions passing through the grid and becoming trapped in the codend, a hood and kite fitted to the top-mounted escape hole, and additional floats incorporated on the top of the hood to ensure the kite and hood operates properly in all conditions and the escape hole remains open during fishing (Ministry for Primary Industries (MPI), 2012). Similar exclusion devices have been developed in Australian fisheries to reduce the mortality of fur seals although exclusion devices can differ significantly between fisheries, particularly in terms of the location of the escape hole (Hamer and Goldsworthy, 2006; Tilzey et al., 2006; Lyle and Willcox, 2008) and the use of a kite and hood (Ministry for Primary Industries (MPI), 2012).

Any sea lion that is caught in a trawl net that does not have a SLED fitted will die whereas SLEDs provide an opportunity for sea lions to escape trawl nets. It is considered that SLEDs direct the majority of sea lions that enter trawl nets out of the net. However, a small number of sea lions are still incidentally caught, retained and hauled aboard by vessels fitted with SLEDs (Thompson et al., 2013). These animals die within the net by drowning or trauma (Roe and Meynier, 2012). Drowning may occur if the sea lion is unable to negotiate the SLED within its breath-holding ability or there is a failure with the SLED escape route such as when the hood collapses and subsequently closes the escape hole (Roe and Meynier, 2012). Issues with the hood potentially closing the escape hole have been largely addressed through use of a kite and floats and by regular audit and compliance checks of the fishing fleet (e.g. Clement and Associates Ltd, 2007). Trauma could occur either from impact with the SLED grid or some other part of the trawl net system (Roe and Meynier, 2012).

The implementation of the SLED as a mitigation measure has attracted controversy. Sea lion bycatch dropped substantially in the Auckland Islands squid fishery following the introduction of SLEDs which were in widespread use by 2004/05 (Fig. 2). However, the continued decline in the estimated sea lion population from 2004/05 to 2008/09 (when the lowest pup production was reported) led to concerns that fisheries-related mortality continued to be an issue for this species (Chilvers, 2012b; Robertson and Chilvers, 2011). This was based on claims that some animals entering a net may have suffered head trauma when they collided with the SLED's hard grid that caused either immediate or post-escape mortality (Robertson and Chilvers, 2011). Concerns were raised that some sea lions may die within the net and fall out of the escape hole during hauling (Roe, 2010; Roe and Meynier, 2012) or that some sea lions may die after escaping through a SLED (Robertson and Chilvers, 2011), both of which could lead to underestimates of bycatch.

In view of the uncertainty regarding the use of SLEDs in the Auckland Islands squid fishery, we undertook a review of the largely unpublished research and data assessments to evaluate the efficacy of SLEDs in reducing sea lion bycatch. There is benefit in ensuring

[1] For the purposes of this paper, the term "bycatch" is used, in general, to cover the accidental capture of sea lions in trawl nets. It is also assumed that captures are the equivalent to mortalities. Note that in New Zealand literature the term "bycatch" is used to describe non-target fish catch of commercial value and "incidental mortality" is used in relation to sea lions killed in fishing nets.

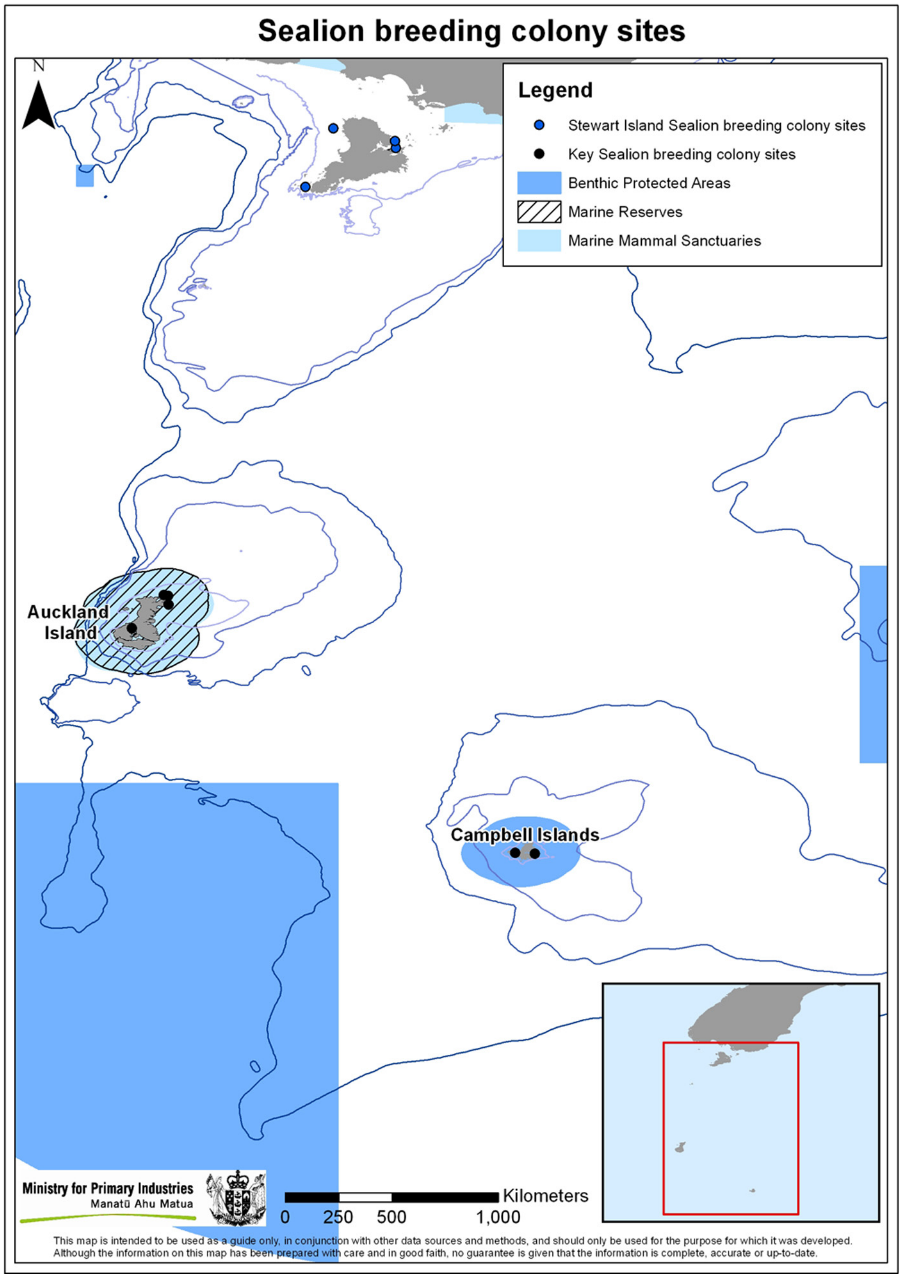

Fig. 1. Location of New Zealand sea lion breeding populations on New Zealand sub-Antarctic islands (figure provided by Ministry for Primary Industries, New Zealand).

that approaches developed to mitigate bycatch are effective and, if not, to move to adopt other measures to address a significant issue for sea lion conservation and for fishery management.

2. Methods

We reviewed all available published and unpublished literature on research that aimed to assess the efficacy of SLEDs in reducing sea lion bycatch. Two areas of research were identified that, in general, addressed the following questions:

(i) Do SLEDs allow sea lions to escape from trawl nets and do these animals survive?
(ii) Is head trauma likely when a sea lion comes into contact with a stainless steel SLED grid?

The bodies of work that were reviewed included:

- an experimental approach where sea lions were deliberately trapped after passing through a SLED;
- assessments of the survivability of sea lions passing through a SLED based on reported reviews of necropsy results and video monitoring;
- attempts to obtain additional video footage of SLEDs during fishing operations;
- re-analysis of video footage from an Australian study of fur seals passing through a Seal Exclusion Device (SED) to obtain comparative data on the nature of collisions;
- a biomechanical study that simulated the impact of sea lions hitting the metal grid of a SLED; and,
- modelling of the risk of sea lions suffering mild traumatic brain injury (concussion) after striking a SLED grid.

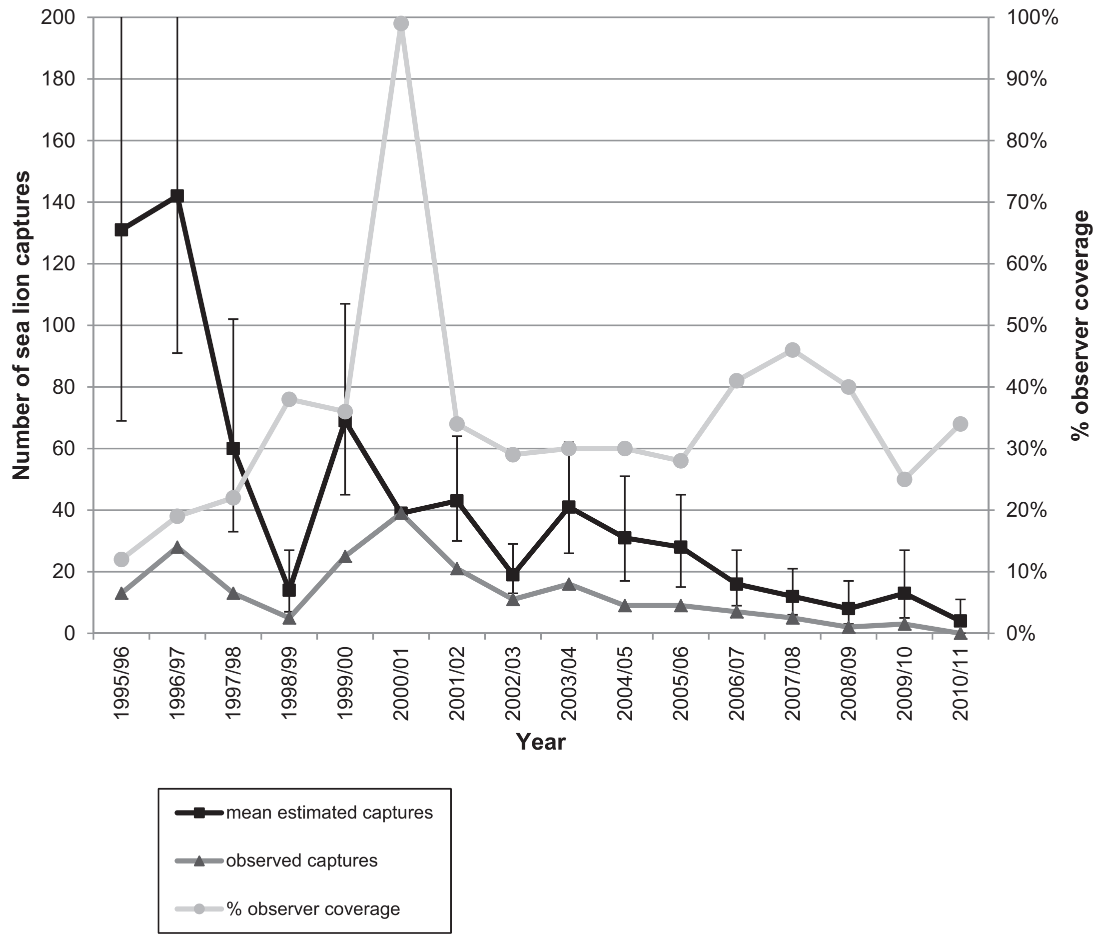

Fig. 2. The observed number of captures (dark grey triangles) and mean estimated captures (black squares; error bars = 95% confidence interval) per year of New Zealand sea lions in the Auckland Islands squid fishery from 1995/96 to 2010/11. The % observer coverage (light grey circles) is also shown. Data taken from Thompson et al. (2013).

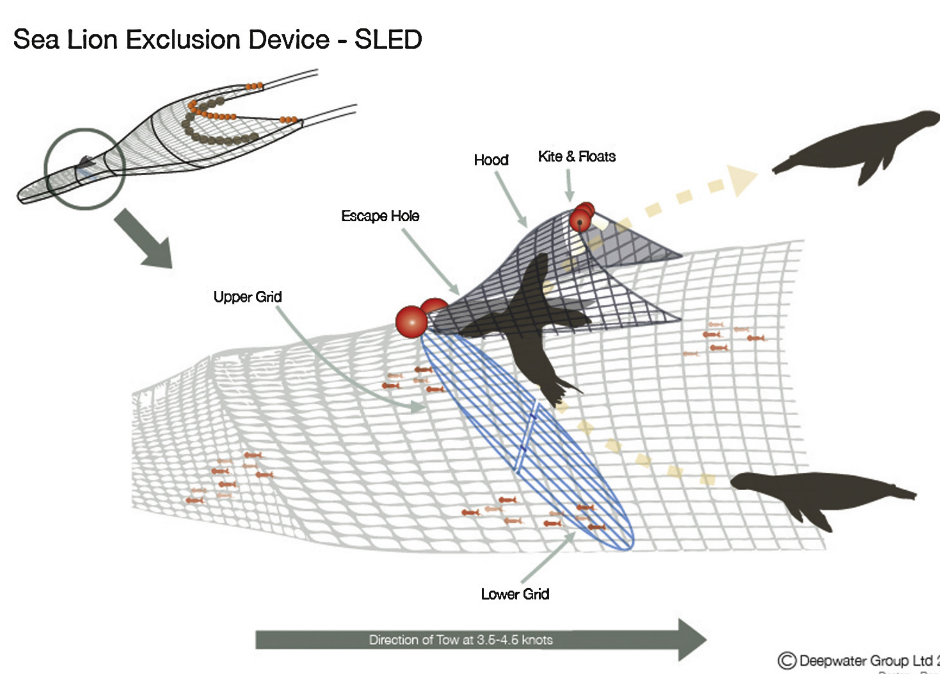

Fig. 3. Standard New Zealand Sea Lion Excluder Device used within the Auckland Islands squid trawl fishery (figure provided by Deepwater Group Ltd., New Zealand).

3. Results and discussion

3.1. Evidence that SLEDs allow sea lions to escape from trawl nets and that they survive

An experiment was carried out where sea lions that successfully exited the SLED were retained within an external cover net (with a small number documented on video) and later necropsied to assess whether SLEDs enabled the escape of sea lions from trawl nets and whether they survived the process, (Wilkinson et al., 2003). Due to the extended periods (i.e. up to several weeks) that trawlers spend at sea each trip, it has been necessary to freeze the carcasses of caught sea lions for any later research examinations (Roe and Meynier, 2012). During 1999 and 2000, six sea lions were incidentally caught in nets fitted with SLEDs and, of these, five were directed out of the SLED and retained in the cover net (Wilkinson et al., 2003). In 2001, 33 sea lions were caught in trawl nets with cover nets and, of these, 30 (i.e. 91%) passed through the SLED and were retained in the cover net, although video footage was obtained for only three animals. Although the sample size was very small, the footage indicated the three animals were likely to have survived if the cover net had not been present (Wilkinson et al., 2003). However, a veterinary pathologist who examined the retained and frozen carcasses concluded that at least one and possibly two of these animals exhibited severe internal trauma which was considered, at the time of the assessment, would have led to their subsequent death (Gibbs et al., 2001 cited in Wilkinson et al., 2003). Necropsy assessments of all 30 animals retained and frozen in 2001 concluded that at least 55% of them had suffered trauma that would have compromised their post-exit survival (Gibbs et al., 2001 cited in Wilkinson et al., 2003). However, Gibbs et al. (2003) acknowledged that freezing the carcasses may have induced changes that could be confused with true lesions. In 2008 and 2009, an experiment using five chilled and five frozen New Zealand fur seals (*Arctocephalus forsteri*) recovered from trawl nets (without SLEDs) in the Cook Strait hoki (*Metanephrops challenger*) fishery (Roe and Meynier, 2012) reported that, although based on a small sample size, some lesions originally interpreted and reported to be due to trauma were indeed artefacts of freezing (Roe and Meynier, 2012).

A re-evaluation of the 2000/01 trial when sea lions were retained in a cover net after successfully exiting a SLED (Wilkinson et al., 2003), concluded that assessing the likelihood of longer term post-SLED survival was difficult (Roe and Meynier, 2012). This was due to the inconsistencies between observations of the three video-taped sea lions, the small sample size, the uncertainties with necropsy findings as well as the inability to measure longer term survival of these animals (Roe and Meynier, 2012). Middleton and Breen (2011) supported the original conclusion by Wilkinson et al. (2003) that the three videoed animals who escaped via a SLED (and retained in a cover net) were likely to have survived their interaction with the SLED as their post-SLED survival was questioned solely on the basis of necropsy results that were subsequently deemed inconclusive.

Although it would be desirable to obtain more visual evidence of sea lions passing through SLEDs, there is an absence of useful video footage of SLED interactions for this fishery due to poor visibility at fishing depths. We reviewed a sample of video footage (of approximately 600 h recorded) which has primarily been collected to assess SLED deployment and engineering characteristics (R. Wells, personal communication). We found it was impossible to observe SLED efficacy at fishing depths as visibility was very poor due to lighting limitations, water depth, fine debris and squid ink suspended in the water column.

Necropsy data have been collected from sea lions incidentally caught in trawl fisheries since 1996/97. A review of necropsy data was carried out for sea lions recovered from nets with ($n = 98$) and without ($n = 50$) SLEDs as well as a further 15 carcasses that had no information on whether a SLED was used or not (Roe and Meynier, 2012). Although the aim of necropsies undertaken from 1996/97 to 1999/2000 was to obtain morphometric information and not to assess the types or severity of injuries (Roe, 2010), a consistent method of trauma classification criteria was applied to all past data (Roe and Meynier, 2012). It was acknowledged that any assessment of long-term necropsy data was compromised by the understanding that some lesions originally thought to be due to trauma were artefacts of freezing (Roe and Meynier, 2012). However, necropsy assessments for all 163 animals concluded that all had died as a result of drowning (Roe, 2009; Roe and Meynier, 2012). Furthermore, the data indicated that the overall reported trauma severity, the prevalence of apparent head bruising and/or patterns of bruising involving the sternum, shoulders and axillae appeared to be unrelated to whether or not a SLED was fitted to the trawl net (Roe and Meynier, 2012). In addition, many injuries that were observed on carcasses were thought to have occurred well before death (Gibbs et al., 2003; Roe and Meynier, 2012). It is known that, prior to freezing, dead animals have been handled poorly on board vessels with reports that carcasses were often moved considerable distances through the vessel and, by necessity, dropped up to 8 m into vessel holds as they could not pass through product handling systems due to their size (R. Wells, personal communication).

Middleton and Breen (2011) undertook a review of veterinarian evaluations of necropsy assessments from incidentally caught sea lions and reiterated that Roe (2010) and Roe and Meynier (2012) established that a number of lesions previously classified as 'acute blunt trauma' were most likely artefacts from freezing the carcasses. Supported by reviews of original necropsy data by Roe and Meynier (2012), the cause of death for all necropsied sea lions remained as drowning and not the direct effects of trauma injuries. However, Middleton and Breen (2011) identified that there was an increasing focus on the possibility of head trauma during several veterinary assessments that aimed to inform the likelihood of sea lions surviving overall trauma if the animal had not drowned in the net (e.g. Roe, 2010; Roe and Meynier, 2012). Despite indications that head lesions could equally also be artefacts of carcass freezing, necropsy assessments scored such lesions conservatively and considered that any indication of head injury had the potential to reduce survival through reduced consciousness (Middleton and Breen, 2011).

3.2. Evidence of a low risk of significant head trauma when sea lions come into contact with stainless steel SLED grids

In the absence of substantial video footage of New Zealand sea lions interacting with SLEDs, the New Zealand government and other squid fishery stakeholders considered that the behaviour and responses of fur seals to SED interactions may provide information to help assess the possible nature of sea lion and SLED interactions and, in particular, the potential of head trauma injuries that may result from head-first collisions with a metal grid (Ministry for Primary Industries (MPI), 2012). Therefore, a review was undertaken (Lyle, 2011) of video footage from a 2006/07 study of fur seals interacting with SEDs deployed in the Australian Small Pelagic Fishery (Lyle and Willcox, 2008). The nature (i.e. whether seals struck the grid, the speed at which they struck and where on the grid the impact occurred) and potential consequences of collisions with a rigid steel grid were reviewed (Lyle, 2011). Interactions with the SED were described for 132 seals, although the clarity and quality of the video footage influenced how much information could be obtained for each interaction (Lyle, 2011). About one third of the seals that entered via the mouth of the trawl approached the SED head-first and most of them experienced a head-first collision with the grid (usually the upper half of the SED grid) with the angle of the head usually more or less perpendicular to the grid (Lyle, 2011). Impact speeds were estimated with head-first impacts from the first interaction a seal had with the SED occurring at a slightly faster speed (average 3.5 m s^{-1}, range 2.9–6.1 m s^{-1}) than subsequent head-first collisions (Lyle, 2011). Impact speeds were a function of trawl speed and seal swimming speed, with trawl speeds ranging 1.5–2.6 m s^{-1} (3–5 knots), suggesting that some seals were gliding rather than actively swimming within the net (Lyle, 2011). There was no significant difference in the mortality rates between seals that had at least one head-first collision with the SED grid and those that did not contact the SED head-first (Lyle, 2011). It was considered that the likely speed and location of collisions that were inferred and the estimated collision speeds were consistent with the observed swimming speeds for New Zealand sea lions (Ministry for Primary Industries (MPI), 2012). Lyle (2011) did not discuss the implications of the video footage assessment on the extent and nature of impact injuries or the subsequent survival of fur seals as there had been no post-interaction or post-mortem examination of the seals during the original 2006/07 study.

Biomechanical modelling to estimate the impact of head-first collisions between sea lions and SLED grids (Ponte et al., 2010; Ministry for Primary Industries (MPI), 2012) indicated that it was extremely unlikely that an impact with a SLED would cause brain trauma at a level to cause death (Abraham, 2011). To assess the likelihood of a sea lion acquiring a life-threatening brain injury or mild traumatic brain injury (i.e. concussion) as a result of a head impact with a SLED stainless steel grid, Ponte et al. (2010) used a validated method for measuring head impact injury in human pedestrians (‘crash tests’) with scaling and extrapolating to account for the relative head and brain mass of a sea lion. For particular impact locations on the grid, the likelihood of a life-threatening brain injury, based on swim and collision speed and effective sea lion head mass, was determined using the ‘crash test’ results (Ponte et al., 2010). These results indicated that a sea lion impacting with the grid may incur some sort of brain injury. Ponte et al. (2010) summarised a scenario where a female sea lion had a 10 m s^{-1} collision with the SLED grid at the stiffest location which indicated the likelihood of a life-threatening brain injury may be higher than 85%. However, this impact speed is likely to represent the worst case scenario, especially if Lyle’s (2011) fur seal interaction speeds (average 3.5 m s^{-1}, range 2.9–6.1 m s^{-1}) are considered indicative of New Zealand sea lion interactions, and may be more dependent on individual sea lion behaviour than the grid design (Industrial Research Ltd., 2011). It was considered that a more realistic scenario would be to estimate the probability of a fatal impact and then design the SLED accordingly (Industrial Research Ltd., 2011). Using modelling simulations, Abraham (2011) estimated the probability that a sea lion interacting with a SLED suffers concussion using results from the ‘crash-test’ methodology (Ponte et al., 2010) and re-analysis of video footage of fur seals interacting with SEDs (Lyle, 2011). This study sought to test the likelihood of the conditions (speed, orientation, number of impacts, area of the grid) needed to induce concussion. The simulation included parameters such as the location that animals collide with the SLED grid and the speed of impact, as well as data on the typical number of head collisions between fur seals and the grid (Abraham, 2011). The probability of a concussion that could result in the animal drowning after exiting the SLED was very unlikely to exceed 10% (Abraham, 2011). There are a number of limitations in this modelling work when considering sea lion interactions with the Auckland Islands squid fishery. These include the unknown level of scaling of the simulated risk of brain injury predictors to actual values experienced by sea lions, the use of data derived from humans to calculate concussion probability, and the use of data from fur seals in an Australian fishery to obtain grid collision information (Abraham, 2011).

4. Summary and future directions

Since the implementation of mitigation techniques, including the widespread deployment of SLEDs, there has been an encouraging reduction in the sea lion bycatch reported for the Auckland Islands squid fishery (Fig. 2; Thompson et al., 2013). It is considered that the risk of sea lions dying in the net and falling out of the escape hole and, therefore, not being included in reported fisheries-related bycatch observations is unlikely (although there has been no specific work to address this) due to the SLED configuration, primarily the fitting of a hood on a top-mounted escape hole (Ministry for Primary Industries (MPI), 2012). With continued commitment to mitigation, and maintaining adequate observer coverage, further reductions in estimated bycatch levels should be achievable.

While there is evidence to suggest SLEDs reduce the numbers of animals trapped by increasing the number that can escape, there have been suggestions that SLEDs may be ineffective in reducing sea lion mortality because some animals may die later from injuries, particularly head trauma. However, the extensive efforts to test the efficacy of SLEDs have shown that most sea lions are likely to survive following their escape from a trawl net via a SLED. Future research to address any remaining uncertainty regarding the post-SLED survival of sea lions could focus on the use of technology to remotely record animals that pass through a SLED, followed up with assessments of the survival of these animals. Technological options could include the use of acoustic tags fitted to sea lions and receivers installed on the escape holes of SLEDs as suggested by Bradshaw et al. (2013). However, such work would require the handling of large numbers of animals, substantial financial investment and, depending on the technology used, may require assessments on the impact of this research on target species catch rates

It is likely that there are other factors that are primarily responsible for the continued reported decline of the New Zealand sea lion population at the Auckland Islands. Disease events have been reported at sea lion breeding colonies over the last 20 years that have affected adult females and their pups. Epizootic events affecting pup production were reported for the 1997/98, 2001/02 and 2002/03 seasons, with adult female mortality also occurring during the 1997/98 event (Wilkinson et al., 2003; Castinel et al., 2007; Chilvers, 2008; Department of Conservation, 2009). Population modelling, taking into account infrequent epizootic events (once every 15 years) and current levels of fisheries bycatch, indicated that, even under these pressures, there would be slow population growth of the sea lion population at the Auckland Islands (Hamilton and Baker, unpublished). However, there are recent indications that both the frequency and magnitude of epizootic events may have been underestimated due to researchers leaving the Auckland Islands before pups go to sea (S. Childerhouse, personal communication). Recent modelling has indicated that the continued New Zealand sea lion population decline at the Auckland Islands is unlikely to be related to direct fisheries impacts (with reported bycatch of adult animals), but more likely linked to decreased breeding productivity and mortality in the first year or two of life (Hamilton and Baker, unpublished; Roberts and Doonan, 2014).

The research and assessments reviewed here indicate that SLEDs have contributed to the reduction in New Zealand sea lion bycatch in the Auckland Islands squid fishery and that most sea lions are likely to survive subsequent to their escape from a trawl net via a SLED. Furthermore, recent modelling has concluded that fisheries-related mortality is unlikely to be the main driver of the continued decline in the sea lion population at the Auckland Islands (Hamilton and Baker, unpublished; Roberts and Doonan, 2014). Therefore, future work may be better directed towards alternative research and management areas that may be more effective in addressing issues to reverse New Zealand sea lion population decline. This may include research into the frequency, magnitude and mitigation of epizootic events, the scale and importance of changes in food availability, and management actions that increase pup survival on the colony and in the first couple of years at sea.

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