Developing alternative strategies for managing seal-fisher interactions in the South Australian Lakes and Coorong Fishery

Jason Earl, Alice Mackay and Simon Goldsworthy

April 2021

FRDC Project No. 2016/001

ISBN: 978-1-876007-36-2

Developing alternative strategies for managing seal-fisher interactions in the South Australian Lakes and Coorong Fishery.

FRDC Project No. 2016/001

2021

The Fisheries Research and Development Corporation plans, invests in and manages fisheries research and development throughout Australia. It is a statutory authority within the portfolio of the federal Minister for Agriculture, Fisheries and Forestry, jointly funded by the Australian Government and the fishing industry.

Researcher Contact Details

Name: Dr Jason Earl
Address: SARDI, 2 Hamra Avenue
West Beach, South Australia, 5024
Phone: 08 8429 0904
Email: jason.earl@sa.gov.au

FRDC Contact Details

Address: 25 Geils Court
Deakin ACT 2600
Phone: 02 6285 0400
Email: frdc@frdc.com.au
Web: www.frdc.com.au

Contents

Figures

Tables

Acknowledgments

This project was supported by funding from the Fisheries Research and Development Corporation and PIRSA Fisheries and Aquaculture. We acknowledge the skill and professionalism of several licence holders of the Lakes and Coorong Fishery, particularly Garry Hera-Singh, Zane Skrypek and Roderick ‘Dingles’ Dennis during the fishing trials, as well as Neil MacDonald (Executive Officer, Southern Fishermen’s Association) for his support during the project. Thanks are extended to Mike Greig (Department for Environment and Water; DEW), and Mike Greenwood and Justin Febey (Department of Primary Industries, Water and Environment, Tasmania) for training fishers and project staff in the safe and ethical use of seal crackers; David Wilks (Marine Scalefish Fishery) for his contributions to the gear trials; Steve Kennelly (IC Independent Consulting) for providing technical advice that helped identify seal deterrents and alternative fishing methods for testing; Renate Velzeboer (DEW), Michael Drew and Matthew Heard (SARDI) for fieldwork support; and Jonathan Smart (SARDI) for his assistance with statistical procedures. We thank Michael Drew (SARDI), Roger Kirkwood (SARDI), Chris Izzo (FRDC), Karl Hillyard (DEW), Cristina Vicente (DEW) and Keith Rowling (PIRSA Fisheries and Aquaculture) for reviewing the draft report. The final report was approved for publication Dr Stephen Mayfield (Science Leader, Fisheries, SARDI Aquatic Sciences).

Abbreviations

ADD	Acoustic deterrent device
AHD	Acoustic harassment device
CPUE	Catch per unit effort
DEW	Department for Environment and Water
DPIPWE	Department of Primary Industries, Parks, Water and Environment, Tasmania
DPUE	Damage per unit effort
FRDC	Fisheries Research and Development Corporation
GLMM	Generalised linear mixed-effects model
IPUE	Interactions per unit effort
LCCC	Lakes and Coorong Consultative Committee
LCF	Lakes and Coorong Fishery
LDW	Large double-wing
LML	Legal minimum length
LNFSWG	Long-nosed Fur Seal Working Group
MSF	South Australia’s Marine Scalefish Fishery
PIRSA	South Australia’s Department of Primary Industries and Regions
SA	South Australia
SARDI	South Australian Research and Development Institute
SDW	Small double-wing
SFA	Southern Fishermen’s Association
SML	Saleable minimum length
SW	Single-wing
TL	Total length

Executive Summary

Overview

This report assesses the efficacy of alternative strategies for managing seal-fisher interactions in the gillnet sector of South Australia's Commercial Lakes and Coorong Fishery (LCF), including the use of deterrents and alternative fishing methods. It uses a range of information obtained through fishing trials undertaken by commercial fishers in areas of the LCF to assess: (1) the efficacy of seal crackers (a type of seal deterrent, also known as Seal Control Units) for reducing Long-nosed Fur Seal (*Arctocephalus forsteri*) impacts on LCF gillnet fishers; and (2) the operational effectiveness of three fyke nets and two hauling-net techniques as potential alternatives to existing gillnet practices. Findings have led to management outcomes for industry, including access to crackers as a tool for mitigating seal interactions; and provide a source of information for ongoing discussions about approaches for improving the economic viability of the fishery. This work represents a collaborative effort between the Southern Fishermen's Association (SFA), the South Australian Research and Development Institute (SARDI), South Australia's Department for Environment and Water (DEW), PIRSA Fisheries and Aquaculture and IC Independent Consulting.

Background

The LCF is a small-scale, multi-species, multi-method fishery that operates in Lakes Alexandrina and Albert (Lower Lakes), the Murray estuary and Coorong lagoons (Coorong Estuary), and the nearshore marine waters adjacent to the Murray Mouth. Currently, there are 36 LCF licence holders, most of whom use gillnets to harvest a variety of freshwater, estuarine and marine finfish species. The gillnet method is among the oldest used anywhere in the world and has changed little throughout the 160-year history of the fishery.

With the recent recovery of Long-nosed Fur Seal populations in South Australia, the number of interactions between Long-nosed Fur Seals and LCF fishers has increased and impacts to the fishery through depredation of fish caught in gillnets have been reported. The impacts occur as seals eat fish caught in gillnets, which can result in catch losses and gear damage. Many fishers estimate that a significant proportion of their catch is currently being lost to seals and are concerned that the fishery may soon not be viable if mitigation strategies are not developed. The South Australian Government has made it clear that management of this issue should focus on ways to keep seals away from catches, and developing alternative fishing methods based on best practice that are less vulnerable to seal depredation and may provide practical alternatives to current gillnet practices.

Objectives

1. Review global seal-fisher interactions, and mitigation and management options relevant to the LCF.
2. Assess operational changes to current practices, including the use of seal deterrent methods to reduce the rates of seal depredation on caught fish and damage to gear.

3. Develop and trial alternative fishing methods based on best practice that are less vulnerable to seal depredation of catches and gear damage, and may provide practicable alternatives to current gillnet practices.

Methodology

Literature review

A literature review provided a basis to better understand the nature of seal-fisher interactions globally and identify practical mitigation options relevant to the LCF for testing in this project. The review was limited to peer-reviewed literature and technical reports. On the basis of the review findings and consultation with industry, seal crackers were selected for field testing to assess their efficacy as a deterrent tool for mitigating seal impacts on LCF gillnet fishers. Two fishing gears were also chosen for pilot testing to provide preliminary information on their operational effectiveness as potential alternatives to gillnets in areas of the fishery. These were: (1) fyke nets; and (2) hauling-nets.

Seal deterrent trial

Seal deterrent trials were undertaken over nine nights during April–June 2016 in the Coorong Estuary to assess if they reduced seal depredation of gillnet catches. Each trial night involved two LCF fishers who used gillnets in a standardised way to target Mulloway (*Argyrosomus japonicus*). One fisher had access to crackers and the other did not - the control. Observers collected data relating to the nature and number of seal-fisher interactions; responses of seals to crackers; catches of Mulloway; and damage to gillnets.

Gear trials

Separate fishing trials were undertaken to provide preliminary information on the operational effectiveness of three fyke nets (a small double-wing fyke net, a large double-wing fyke net, and a single-wing fyke net), and two hauling-net techniques (mechanical and manual) in areas of the LCF. The nets were all tested in areas where, on the advice of the participating fishers, commercial species were likely to be encountered. The fyke net trials were undertaken by LCF fishers, with assistance from researchers, while the hauling-net trials were carried out by an experienced hauling-net fisher from South Australia's Marine Scalefish Fishery (MSF), with guidance from LCF fishers. The mechanical hauling-net trials involved a chartered MSF hauling-net vessel that was equipped with a hydraulic net-reel, while the manual hauling-net trials were undertaken using existing LCF vessels. Fyke net and hauling-net catch rates were compared to those of conventional gillnets in the trial areas.

Results/key findings

Seal deterrent trial

Crackers produced a behavioural response in targeted Long-nosed Fur Seals approximately 85% of the time. They were most effective on seals that were approaching gillnets. In such situations, deployment of a cracker usually resulted in the seal immediately diving and re-surfacing >50 m away. In seals that were patrolling gillnets (presumably searching for caught fish), crackers elicited a similar avoidance response, although the seals moved away slightly less often. The crackers were relatively ineffective on seals that were feeding on fish caught in gillnets. Although crackers did not prevent depredation of catches, they did reduce damage to fishing gear. Gillnet damage rate was 55% lower for the vessel that used crackers than the control. There was limited evidence that crackers affected the behaviour of Mulloway around gillnets, although further research is required as underwater observations of fish not caught in the net were not possible. Seals are known to acclimate quickly to potential deterrents, so the responses of Long-nosed Fur Seals to crackers could be expected to reduce over time, especially if crackers are used repeatedly on the same animals. Our results suggest that if used judiciously, the crackers could be a useful mitigation tool for fishers who attend their gillnets.

<u>Gear trials</u>

The operational efficacy of the three fyke nets was investigated. Except for some minor technical issues, handling and deployment of each fyke net was straightforward. No negative interactions with Long-nosed Fur Seals were observed. Compared to gillnets, catches taken using each fyke net were negligible, with no legal-sized fish landed. Based on this result, the test fyke nets do not appear to provide a viable alternative to gillnets in the LCF. It is recognised, however, that further testing and adaptation of the fyke nets to local conditions (tides, fish behaviour etc.) may result in improved catches.

The operational efficacy of the mechanical and manual hauling-nets in the Lower Lakes and Coorong Estuary was explored. The turbid conditions (which are characteristic of these areas) limited the efficacy of both hauling-net methods. The main issue was that fishers were unable to identify areas suitable for hauling-nets to be used (i.e. areas clear of submerged snags); accordingly, around 70% and 20% of hauling-net shots attempted in the Coorong Estuary and Lower Lakes, respectively, were stalled due to the net snagging. The "snagged" shots were eventually completed after the net was lifted off the snags by the observer vessel. During conventional hauling operations, there generally is no second vessel, so snagging of the net would usually result in the shot being abandoned. The inability of fishers to avoid submerged snags and consistently execute this method casts considerable doubt over its viability for use in the LCF. Considerable modification to the standard technique would be required.

The turbid conditions also made it difficult for fishers to sight aggregations of target species prior to deploying the hauling-nets, and so each shot was undertaken over an area that was likely to contain fish rather than where fish were known to be. Consequently, both hauling-net methods produced substantially lower catches than conventional gillnets. Mechanical hauling occasionally produced moderate quantities of Bony Herring (*Nematalosa erebi*), Carp (*Cyprinus Carpio*) and Yelloweye Mullet (*Aldrichetta forsteri*), thereby demonstrating the capacity of the hauling method for catching LCF species. Nonetheless, catches were highly variable, with most manual and mechanical hauling shots yielding negligible catches.

Overall, results from the hauling-net trials suggest that they would be less economic than current gillnet techniques used in the LCF. If commercial quantities of target species could be located in suitable fishing areas (for example, if a sonar technique enabled location of target fish schools) and the problem of submerged snags could be resolved, manual hauling likely would be more viable than mechanical hauling because it could be undertaken from existing LCF vessels.

Implications for relevant stakeholders

Developments made during this project have already been adopted as part of the South Australian Government's integrated approach to managing the impacts of Long-nosed Fur Seals on LCF gillnet fishers. For example, fishers are now permitted to use crackers in any area of the fishery, subject to a range of permit conditions, training requirements and attainment of appropriate police clearances. Permit conditions require fishers to submit data returns to monitor usage and effectiveness of crackers, which will enable assessment of the short and long-term benefits of crackers to industry.

Successful methods for reducing seal-fisher interactions need to be cost effective, where the benefits from mitigation initiatives outweigh their costs. To properly assess the potential benefits of using seal crackers, alternate fishing gears and other mitigation options in reducing the impacts of seal depredation on the LCF, an objective assessment of the economic impacts that seal depredation is currently having on fishers is needed. This is the focus of a new FRDC-funded project (2018-036), currently underway. Key outputs of this new project will provide a basis to examine future options for mitigating seal impacts on LCF fishers in a cost-benefit framework.

Keywords

Seals, Long-nosed Fur Seals, seal interactions, depredation, seal impacts, gillnets, fyke nets, hauling-nets, seal deterrents, alternative fishing methods, deterrents, crackers.

1. General Introduction

1.1 Background

South Australia's Commercial Lakes and Coorong Fishery (LCF) is a small-scale, multi-species fishery that has operated in the lower Murray River region since at least 1846 (Olsen and Evans 1991). It has access to a diverse array of species in the freshwater Lakes Alexandrina and Albert (the Lower Lakes), the Murray River Estuary and Coorong lagoons (the Coorong Estuary), and the inshore marine waters adjacent to the Murray Mouth (Figure 1-1). With annual catches of approximately 1,760 t (5-year average), a Gross Value of Production of approximately $11.5M/year, and a fleet of up to 36 vessels directly employing an estimated 70 skippers and crew, the LCF is an important source of fresh fish, regional employment and income for South Australia (EconSearch 2019a).

Mesh gillnets are the primary fishing gear used in the LCF and have been in common use by commercial fishers in the region since the mid-1800s (Ferguson et al. 2013). In the Lower Lakes, large mesh gillnets (115–150 mm mesh) are used to target Golden Perch (*Macquaria ambigua ambigua*), Bony Herring (*Nematalosa erebi*), Carp (*Cyprinus Carpio*) and Redfin Perch (*Perca fluviatilus*) (Ferguson et al. 2018). In the Coorong Estuary, large mesh gillnets are used to target Mulloway (*Argyrosomus japonicus*), Greenback Flounder (*Rhombosolea tapirina*) and Black Bream (*Acanthopagrus butcheri*), and small mesh gillnets (50–64 mm mesh) are used to target Yelloweye Mullet (*Aldrichetta forsteri*). All gillnets are 50 m long and each licence holder has a daily entitlement of 25, 50, 75 or 100 gillnets. Gillnet soak times of up to 72 hours are permitted. Other fishing methods are used, although their collective contribution to total effort is negligible (Earl 2020).

Approximately 10 years ago (i.e. around 2009), significant numbers of Long-nosed Fur Seals (*Arctocephalus forsteri*) began interacting with gillnet fishers in both the Coorong Estuary and the Lower Lakes, i.e. in both salt and freshwater areas (Figure 1-1). Long-nosed Fur Seals are native to the coastal waters off southern Australia and New Zealand. During the early 1800s, Long-nosed Fur Seal numbers in South Australia were decimated by European sealers and remained critically low for the next 150 years or so (Kirkwood and Goldsworthy 2013). It was during this period of low seal abundance that the LCF was established. In the 1970s, Long-nosed Fur Seals were granted protection under State and Commonwealth legislation, and conservation efforts have contributed to a steady recovery of many populations, with presumed recolonisation of former sites (Shaughnessy et al. 2015). This has led to the recolonisation of Long-nosed Fur Seals into some areas that overlap with productive fishing areas, including the Lower Lakes and Coorong Estuary, and a consequent increase in seal-fisher interactions.

Reported interactions between Long-nosed Fur Seals and LCF fishers increased markedly after 2009 (Goldsworthy and Boyle 2019). The interactions have not involved the fishery impacting adversely on seals, but rather the seals affecting the harvest and operations of the fishery. This occurs as seals attempt to eat fish caught in gillnets, which can result in catch losses and damage to fishing gear (EconSearch 2019a). While there has been no attempt to quantify the economic losses attributable to seal depredation, fishers estimate that a significant and growing proportion of their total catch is currently being lost to Long-nosed Fur Seals, and that their expenses associated with repairing and replacing seal-damaged fishing gear are increasing. A social perception survey undertaken on LCF fishers identified that this sector is experiencing acute and immediate stress and economic impact, with some respondents reporting losses of up to 50% or more of their profit over the previous five years due to interactions with seals (Goldsworthy et al. 2019). This issue has intensified in recent years, with concerns from industry that the fishery may soon not be viable if strategies are not developed to reduce seal impacts.

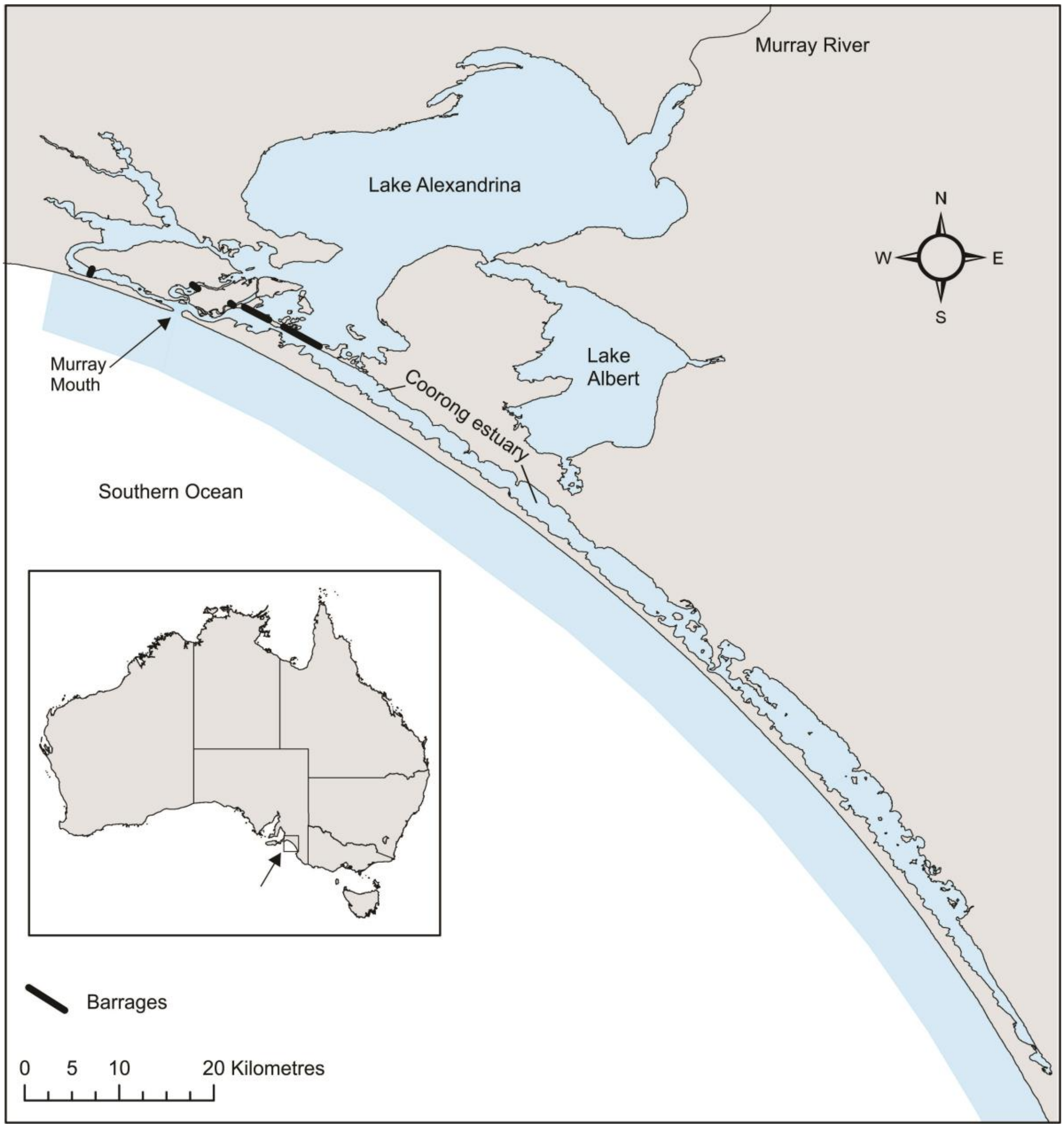


Figure 1-1. Map of the Lakes and Coorong region, South Australia. The Lakes and Coorong commercial fishing area is shaded in blue.

According to representatives from the Southern Fishermen's Association (SFA), most LCF fishers have modified their fishing practices to try and avoid interactions with Long-nosed Fur Seals. The operational changes include: reduced soak times of gear; attending nets more frequently; fishing at different times of the day to find when seals may be less active; shifting between fishing areas more frequently to try and be less predictable to the seals; allocating less time to target species for which effective targeting requires long gillnet soak times; fishing in sub-optimal areas; fishing longer hours each day; and deploying "sacrificial" nets on the fringe of preferred fishing areas to try and distract the seals from working nets (EconSearch 2019a). While these initiatives have proven effective in some situations, most fishers consider them to be not viable as long-term solutions to this issue. Furthermore, they do not prevent seal depredation and so a proportion of the catch is still being lost.

In recognition of the impact Long-nosed Fur Seals are having on the LCF, the South Australian Government (the Government) implemented temporary licence fee relief for fishers for the 2015/16, 2016/17, 2017/18 and 2018/19 fishing seasons. The fee relief was not provided in 2019/20. In response to requests from industry, temporary changes to management arrangements were also implemented during 2015/16–2018/19. These included: (1) an increase in the length of the hauling-net season in the upper Coorong Estuary by 105 days; (2) permitting all licence holders to use drum nets (a gear that was not endorsed on all licences); and (3) increasing the annual number of skipper relief days per licence holder from 28 to 90 days. While these temporary initiatives were welcomed by industry, there is a need for longer-term solutions to this issue.

1.2 Need

Numerous meetings between the Government and industry have been held to discuss potential solutions to the seal-fisher conflict in the LCF. The two parties have acknowledged that management strategies are urgently needed to reduce seal impacts on industry, given the increasing operational and social impacts to fishers, their families and the local communities that rely heavily on the industry. The Government has made it clear that it does not support the destruction of seals as a management option, and that management efforts need to focus on ways to keep seals away from the catch, potentially using deterrents, and/or through the use of alternative fishing methods that are less vulnerable to seal depredation and enable the fishery to catch sustainable and commercially viable quantities of fish.

As a first step, a stakeholder workshop was convened by PIRSA Fisheries and Aquaculture on 31 July 2015, to identify practicable seal deterrents and alternative fishing methods that could be tested to reduce seal depredation in the fishery (Kennelly 2015). Approximately 25 people attended the workshop, including LCF fishers, seal experts, representatives from South Australia's Department for Environment and Water (DEW), PIRSA Fisheries and Aquaculture, Conservation Council of SA, Fisheries Research and Development Corporation (FRDC), SARDI Aquatic Sciences and IC Independent Consulting. The primary output of the workshop was a commitment among fishery stakeholders to collaboratively investigate practicable mitigation options relevant to the LCF, including the use of deterrents and alternative fishing methods. A Long-nosed Fur Seal Working Group

(LNFSWG) was then established, comprising representatives from all fishery stakeholder groups. The LNFSWG became the main steering group for this project. The first task of the LNFSWG was to establish this project's objectives.

1.3 Objectives

The objectives of this project were to:

1. Review global seal-fisher interactions, and mitigation and management options relevant to the LCF (outcomes are summarised in Chapter 2).

2. Assess operational changes to current practices, including the use of seal deterrent methods to reduce the rates of seal depredation on caught fish and damage to gear (Chapter 3).

3. Develop and trial alternative fishing gear/methods based on best practice that are less vulnerable to seal depredation of catches and gear damage, and may provide practical alternatives to current gillnet practices (Chapter 4).

2. Review of global seal-fisher interactions and mitigation options relevant to the Lakes and Coorong Fishery

All fisheries contend with ecosystem interactions and changes over time that impact catch rates and force adaptations to practices (Carleton et al. 2013). Amongst the most obvious of these are those that involve large-bodied predators, such as sharks, cetaceans and seals. Not only are these animals large bodied, obvious and predators that are attracted to the resources that fisheries are trying to harvest, but they are often seen as charismatic and key species in ecosystems, and as such receive public sympathy and legislative protection (Kirkwood and Goldsworthy 2013).

In this review of global seal-fisher interactions and associated mitigation options, the focus is seal impacts on small-scale fisheries. The literature search was conducted using a number of online search engines that included Web of Knowledge, ScienceDirect, Web of Science, Scopus and Fisheries Abstracts. To ensure a high level of quality and independence in the source information, peer-reviewed literature and scientific reports were used as much as possible. Where necessary, review documents and web-based information was also sourced.

2.1 Interactions between fisheries and seals

Many seal populations around the world are recovering from industrial sealing that occurred during the eighteenth and nineteenth centuries (Riedman 1990). This has led to the recolonisation of seals into some areas that overlap with productive fishing grounds, and an increase in operational interactions between seals and fisheries (Kirkwood et al. 2010). Such interactions can result from seals either not detecting fishing gear, or learning that fishing gear can be productive foraging sites (Shaughnessy et al. 2003). They can involve seals getting entangled in equipment; stealing baits; feeding on caught fish; and deterring target species (Kirkwood and Goldsworthy 2013), all of which can cause significant harm to seals and financial losses to fishers.

Operational interactions most obviously damaging to the profitability of fisheries involve seals depredating fish caught in fishing gear, which can result in catch losses and gear damage (Cosgrove et al. 2015). Such impacts are globally widespread and commonly perceived to be increasing, especially where seal populations are recovering. Studies on seal depredation of fishery catches have been undertaken in many countries across the world including South Africa (Wickens 1996), Chile (Sepúlveda et al. 2007), Ireland (Cronin et al. 2016), Greece (Ríos et al. 2017), United States and Canada (Rafferty et al. 2012), France (Vincent et al. 2016), Uruguay (De Maria et al. 2014) and Australia (Hamer and Goldsworthy 2006), and have been particularly prevalent in the Baltic Sea (Fjälling 2005; Kauppinen et al. 2005; Sara et al. 2006; Westerberg et al. 2008; Konigson et al. 2009; Lundstrom et al. 2010).

Small-scale coastal fisheries are among those impacted most by seal depredation (Königson 2011). Such fisheries usually involve fishers working alone, using minimal capital, low-level technologies and small vessels making short trips to nearshore areas. These fishers generally use fixed gear (e.g. gillnets, traps), which are low-cost and easy to handle (Cosgrove et al. 2015; Natale et al. 2015). Unlike active gear which are moved in order to catch fish, fixed gear is deployed and left to soak (usually unattended by fishers) for long periods. As such, seals have plenty of time to encounter nets and remove caught fish. This reduces the number of fish landed, and often leaves behind damaged fish and damaged equipment. These impacts can create great frustration to fishers and cause significant loss of income.

2.2 Managing seal-fisher interactions in small-scale fisheries

Considerable research has been directed toward developing strategies to reduce seal impacts on small-scale fisheries. Potential solutions fall into two categories: (1) the removal of seals from the fishing area; and (2) technical approaches that involve modifying existing fishing practices to prevent seals accessing the catch, including the use of deterrents; or transitioning to alternative fishing methods that are less vulnerable to seal depredation and maintain catches of target species.

Various methods have been trialled to remove problem seals from fishing areas. Trapping and relocation of seals has been trialled in several countries (Brown et al. 2011), including Australia (Robinson et al. 2008). Trapping is usually conducted near prominent haul-out sites, from which the seals are transported several hundreds of kilometres away and released. While this method has provided short-term relief, it has generally failed to reduce interactions over the long-term because the translocated seals often returned, with some recaptured repeatedly in the same place (Robinson et al. 2008). One proposed approach to removing problem seals among commercial fishers is selective culling (Goldsworthy et al. 2019), yet there is uncertainty about the effectiveness of culls as a management tool (Pemberton and Shaughnessy 1993; Quick et al. 2004; Varjopuro and Salmi 2006). Furthermore, culling is controversial in many cultures and considered unacceptable by many members of the general public.

In theory, seal-fisher conflict can be managed using technical approaches that prevent seals accessing fish caught in fishing gear (Varjopuro and Salmi 2006). Many potential technical solutions have been trialled with varying success. These include: (1) modifications to existing fishing practices (e.g. reducing soak times of gear; and fishing at times when seals are less abundant), including the use of deterrents to scare seals away from fishing gear; and (2) transitioning to alternative fishing methods that are less vulnerable to seal depredation and maintain catches of target species.

2.2.1 Modifications to existing fishing practices

Usually, the first option trialled by fishers to reduce seal impacts is to modify aspects of their existing fishing practices, such as, the time of day that gear is deployed, soak time duration, the fishing season (if the presence of seals is seasonal), and/or the location of the fishing activity (Königson 2011). While such solutions may not incur significant financial costs, they are usually difficult to implement in a fishery that has evolved its practices over a long period.

A second approach often trialled by fishers is to scare seals away from fishing gear using deterrents. Such methods work by exposing problem seals to acute visual, olfactory, electric or acoustic stimuli which they find uncomfortable and try to avoid. Many kinds of deterrents, the most common being acoustic deterrents, have been trialled on seals with varying success (Pemberton and Shaughnessy 1993; Reeves et al. 1996). An effective acoustic deterrent produces sound that exceeds the comfort threshold of seals and discourages them from entering or staying within a particular area. It creates enough risk to the seal, whether real or perceived, such that the costs of interacting with the fishing gear are greater than the potential benefits of depredating the catch (Schakner and Blumstein 2013). For small-scale fisheries being impacted by seals, a practicable acoustic deterrent must be low-cost, quick and easy to deploy from small vessels, and effectively scare seals without causing them harm.

Many different types of acoustic deterrents are available to fishers. Among these are acoustic harassment devices (AHD) and acoustic deterrent devices (ADDs). AHDs and ADDs are basically different names for the same thing, although the term AHD generally is given to larger and more powerful devices. Large AHDs have mostly been used in aquaculture industries and can produce a range of sounds of differing strengths, frequencies and intervals, including sounds of potential predators like killer whales (Jefferson and Curry 1996; Deecke et al. 2002).

An example of an ADD is an acoustic pinger which can be attached to fishing gear and allows marine mammals to detect the presence of gear and so to not approach or entangled in it. Such devices have been used in gillnet fisheries to reduce interactions with small cetaceans (e.g. Trippel et al. 1999; Culik et al. 2001; Barlow and Cameron 2003; Dawson et al. 2013; Götz and Janik 2013). Pingers can be passive and reflect echolocation from species such as dolphins that use echolocation to scan their environment, or active and produce an ongoing audible sound.

While AHDs and ADDs have effectively deterred seals in some situations, such as from aggregations of migrating fish in rivers (Yurk and Trites 2000), in most situations seals have acclimated to the noises and not been deterred by them in the longer-term (Jefferson and Curry 1996; Fjälling et al. 2006). In fact, after prolonged exposure to an ongoing acoustic deterrent, some seals learn to associate them with a foraging opportunity (i.e the "dinner bell effect"; Jefferson and Curry 1996).

The problem with many deterrents is that seals are highly motivated to approach known feeding opportunities and can tolerate considerable discomfort to reach them. They are also highly inquisitive: a fur seal has been known to put its head into a harassment device set so loud that it could have caused the seal auditory damage (Pemberton 1989). To be effective, the deterrent has to startle the seal and preferably be encountered before the seal has established an association between the fishing operation and it being a feeding opportunity.

Seal crackers, also known as Seal Control Units, are another type of acoustic deterrent that is used extensively by fishing industries globally to discourage seals. They are designed to explode underwater and produce aversive sound waves that scare seals without causing injury (Mate and Harvey 1987; Jefferson and Curry 1996). Crackers are often the first deterrent option trialled by fishers because they are small, light-weight, easy to use, relatively inexpensive, and their use on pinnipeds is expected to be highly effective, because pinnipeds are particularly sensitive to high-intensity underwater sound (Wartzok and Ketten 1999). Crackers have been used for decades by commercial fishers in Tasmania to prevent seals from interacting with gillnets (Pemberton and Shaughnessy 1993, M. Greenwood, personal communication). Reports of their efficacy have been mixed. Most users report that crackers provide short-term relief, with their effectiveness diminished once individual seals realise they will not be hurt by them and are motivated toward a known feeding opportunity (Shaughnessy et al. 1981; Mate and Miller 1983; Fraker 1994; Kemper et al. 2003).

Other deterrent techniques trialled by fishers include the use of predator sounds (Jefferson and Curry 1996; Deecke et al. 2002), tactile deterrents (e.g. rubber bullets, bear-scare darts, blunt-tipped arrows), vessel harassment (Gearin et al. 1988), taste aversion (Pemberton 1989), scent deterrents and gunshots (Pemberton and Shaughnessy 1993).

2.2.2 Use of modified or alternative fishing gear

Another potential technical solution to the problem of seal depredation of fishery catches involves modifying existing fishing equipment to prevent seals accessing caught fish or using alternative fishing methods that are less vulnerable to seals and maintain catches. The latter of these approaches is often the last to be trialled by fishers because their existing fishing techniques have usually evolved over a long period, are known and trusted by them, and often are “tailor-made” to catch commercial quantities of their target species in the most economically efficient manner (Suuronen et al. 2012). Also, where fishing practices are engrained in tradition there is often a perception that practical alternative gear are not available, resulting in fishers being unwilling to invest the time and money to explore alternate options.

For some fisheries, seal impact mitigation can be achieved by modifying existing fishing gear to create a physical barrier between seals and caught fish (Lunneryd et al. 2003; Oksanen et al. 2015). For example, the Swedish trap-net fishery has “seal-proofed” their traditional fish trap method, making a “pontoon net”, which has reduced catch losses to seals by 80% (Hemmingsson et al. 2008). The pontoon net is constructed from Dyneema® netting, which is four times stronger than the nylon used to construct the traditional traps, and includes both exclusion grids and a protective “seal-sock” that creates a seal-proof barrier around the fish aggregating chamber (Hemmingsson et al. 2008). Pontoon nets are now used by 86% of Swedish Salmon-trap fishermen (Hemmingsson and Lunneryd 2007).

For gillnet fisheries, no effective gillnet modifications have been developed that prevent seals from accessing fish caught in the gear, and so mitigation has generally focussed on trying to deter and avoid seals, or transitioning to alternative fishing methods (Königson 2011). A number of studies have demonstrated the potential for fish traps as alternatives to gillnets (e.g. Königson and Lunneryd 2013), with several types of “seal-proofed” traps now used by what were exclusively gillnet fisheries (Suuronen et al. 2006; Varjopuro and Salmi 2006; Hemmingsson et al. 2008; Königson et al. 2015). However, not all fish species are susceptible to capture using traps and, for those that are, such methods are likely to have already been tried by fishers because traps have relatively low operating costs compared to most other fishing gear.

Traps and gillnets are both passive fishing methods, meaning they are set and left in place and fish swim into them. Another potential solution for passive fisheries being impacted by seal depredation is to transition to an active fishing method. Key advantages of active methods over gillnetting, when it comes to mitigating seal impacts, are that the fishing gear is continuously moved in order to catch fish (i.e. not soaked), so seals have less time to access caught fish. Furthermore, as fishers are generally present during the entire operation, deterrents can be used at different stages to ward off problem seals. Unfortunately, most active methods (e.g. bottom and midwater trawling, and purse seining) require large, high-powered vessels to tow and retrieve the equipment, which can make them cost-prohibitive for small-scale fisheries (Eyo and Akpati 1995). An exception is hauling-netting – an active method that is used in small-scale fisheries globally, including South Australia’s Marine Scalefish Fishery (MSF) (Steer et al. 2020). Unlike most active methods, haul-netting can be conducted from small vessels, with the net retrieved manually (i.e. by hand) or using a mechanical net reel. A hauling-net is generally deployed in a large circle around an area likely to contain fish, and then hauled back onto the boat, so fish are caught by encirclement. Hauling-nets vary in size depending on the size and hauling capability of the vessel; target species; topography of the fishing area; and local conditions (e.g. water depth). Not all fishing areas are suitable for hauling though, and not all target species are susceptible to capture using hauling-nets.

Any change to fishing operations in an area requires considerable trial and adaptation of alternative gear. Prior to this project, a number of seal deterrents and alternative fishing methods that could be tested to reduce seal depredation in the LCF were short-listed at a fishery stakeholder workshop on 31 July 2015. To help select the final methods from this short-list, key findings of the above literature review were presented to the LNFSWG. After further consultation with industry representatives, seal crackers were chosen as the deterrent to be trialled in this project, and two fishing gear/methods were chosen for field testing: (1) fyke nets (a small double-wing fyke net; a large double-wing fyke net; a single-wing fyke net); and (2) hauling-nets (mechanical and manual). To this end, Chapters 3 and 4 of this report presents the results of field trials.

3. Assessing the effectiveness of seal crackers for reducing seal impacts in the Lakes and Coorong Fishery

3.1 Introduction

Seal crackers are small explosive devices that are designed to be thrown into the water, where they explode beneath the surface (Figure 3-1; Jefferson and Curry 1996). They are weighted so that they sink and have a fuse that burns underwater. The sound of the cracker exploding, along with the flash of light produced and associated pressure waves, is designed to startle targeted seals, make them fear injury, and so flee the immediate area. Provided the crackers do not explode within a few metres of the seal, they are unlikely to cause auditory or other physical damage to them, however, there is always this risk. Crackers have been used extensively in many fisheries around the world, including in Tasmania where fishers reported that when used sparingly, they effectively deterred Australian Fur Seals (*Arctocephalus pusillus doriferus*) from interacting with gillnets (Kemper et al. 2003). Information on the efficacy of crackers for deterring seals from fishing gear, though, is largely based on anecdotal reports from fishers and a limited number of field trials (e.g. Shaughnessy et al. 2003).

The aim of this study was to undertake field trials to obtain quantitative information on the usefulness of seal crackers for mitigating the impacts of Long-nosed Fur Seals on commercial gillnet fishers in the Coorong Estuary. Such information will provide an empirical basis from which to consider whether the use of crackers should form part of the management strategy to mitigate seal impacts in the LCF. The specific objectives addressed were to: (1) better understand the nature of the seal-fisher interactions currently impacting the LCF; (2) assess the behavioural responses of Long-nosed Fur Seals to crackers; and (3) assess whether the use of crackers can effectively reduce impacts of Long-nosed Fur Seals on the fishery.

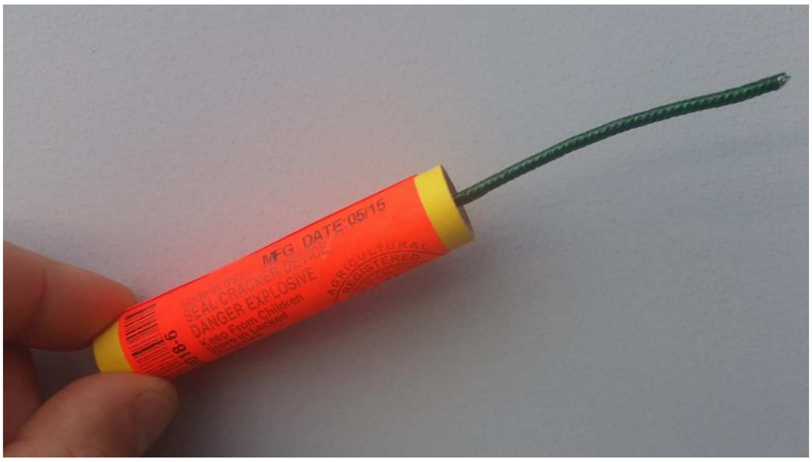


Figure 3-1. Seal cracker – a small water-proof deterrent device that is designed to scare seals.

3.2 Methods

3.2.1 Experimental protocol

A field experiment was undertaken over nine nights (April–June 2016) in traditional gillnetting grounds for Mulloway in the Coorong Estuary, specifically in areas where regular interactions between fishers and Long-nosed Fur Seals were known to occur (Figure 3-2). Each night of the experiment involved the same two LCF fishers and their vessels. One fisher was equipped with crackers that could be used to deter seals from gillnets (treatment boat), while the other fisher did not have access to crackers (control boat). Access to crackers was alternated between fishers each night (i.e. *Fisher A* had crackers on nights 1, 3, 5, 7 and 9; *Fisher B* had crackers on nights 2, 4, 6 and 8). During each trial night (1700–0000 hours), the fishers operated in the same general area (approximately 3 km from each other), and each used three fixed large mesh gillnets, each with a length of 100 m and mesh size of 114 mm, to target Mulloway. The gillnets of each fisher were positioned within a 1 km diameter and inspected at approximately 45-min intervals.

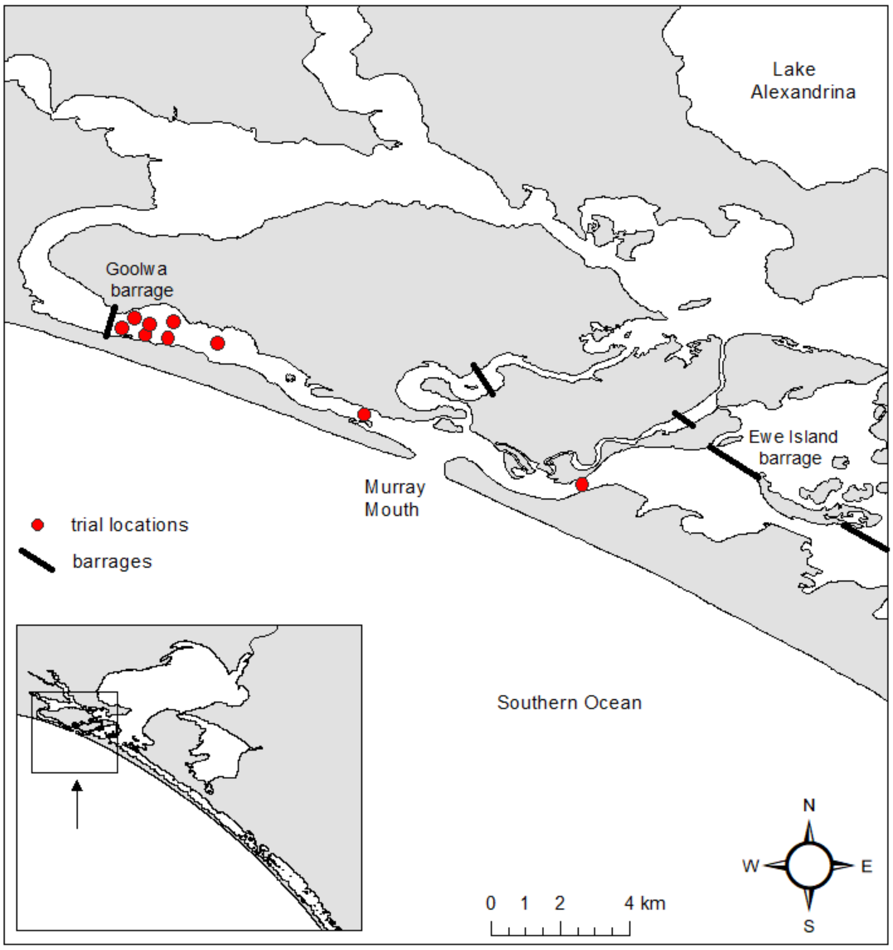


Figure 3-2. Map of the upper Coorong Estuary showing the locations (red dots) of the gillnetting activities undertaken during the field experiment to assess the usefulness of crackers for deterring Long-nosed Fur Seals.

3.2.2 Safe and ethical use of seal crackers

Prior to the experiment, a set of guidelines for the safe and ethical use of seal crackers was developed. Guidelines were based on protocols developed by the Tasmanian Department of Primary Industries, Parks, Water and Environment (DPIPWE) for the use of crackers in Tasmania (DPIPWE 2012). Under the guidelines, there was no limit on the number of crackers that could be thrown at individual Long-nosed Fur Seals. However, fishers could only use crackers to harass seals that were positioned <20 m from a gillnet and exhibited intent to interact with the net. To prevent harm to seals, fishers were not allowed to throw a cracker toward the head of a seal, or to within 2 m of its last known position. The fishers and project staff involved with this study completed training on the use of seal crackers prior to the experiment. Training included demonstrations from seal deterrent experts from the DPIPWE, and representatives from DEW and SafeWork SA. The project was approved by the PIRSA Animal Ethics Committee (08/16) and carried out under PIRSA Exemption 9902785 and DEW Permit E26519-1.

3.2.3 Data collection

An observer was on-board each of the two vessels at all times during the experiment. The observers recorded a range of information relating to the fishing activities that were being undertaken. This included basic metadata for each net set (e.g. time and location of deployment, time of retrieval, weather conditions), as well as information on any seal interactions that occurred.

For the purposes of this study, an interaction was defined as a directed swim by a seal toward a gillnet which resulted in it being <50 m from the net. Because the experiments were undertaken at night, it was difficult to determine if individual seals were involved in more than one interaction per night. As such, an interaction was presumed to have ended once the seal had moved >50 m from a gillnet. If more than one seal was observed interacting with a net at any time, separate interactions were recorded for each seal. Each interaction was classified into one of four classes depending on the position of the seal relative to the gillnet (Table 3-1).

Observers also collected data on the responses of individual Long-nosed Fur Seals to the deployment crackers. Seals could respond to crackers in a range of different ways: observers only assessed the distance of movement in relation to the net. The immediate response of the targeted seals was classified into one of five behavioural categories (Table 3-2), each of which were based on the distance moved by the seal immediately after the cracker detonated. Where interactions involved more than one cracker, observers recorded separate responses for each cracker that was thrown. In the event of an unsuccessful cracker deployment, the likely technical reason was noted, and the deployment was repeated if required. Observers also noted the presence of other animals (e.g. birds) in the area when crackers were used. No impacts to other wildlife were observed.

At the end of each net set, observers collected the following data to quantify levels of gillnet damage and catch: (i) the number of new holes in the net caused by seals (each new hole was marked using coloured twine to preclude double counting); (ii) the total number of legal-sized (>460 mm total length) Mulloway caught; and (iii) the total number of seal-damaged Mulloway that were discarded due to being unsaleable. Any remains of fish that had been partially eaten by seals and were floating near the net were also noted.

Table 3-1. Types of interactions (1–4) between individual Long-nosed Fur Seals and gillnets, indicating when fishers were permitted to use crackers.

Interaction type	Position and behaviour of seal relative to gillnet	Seal crackers allowed to be used?
1	20–50 m from net; no intent to interact (passing by)	No
2	10–20 m from net; intent to interact (approaching the net)	Yes
3	0–10 m from net; repeatedly swimming along net (patrolling the net)	Yes
4	Eating fish caught in net (depredating)	Yes

Table 3-2. Types of behavioural responses (1–5) exhibited by Long-nosed Fur Seals to crackers.

Response type	Observed response	Interpretation
1	No response observed; behaviour did not change	Seal not startled
2	Dived (submerged) and resurfaced 0–10 m away	Minor startle
3	Dived and resurfaced 10–20 m away	Moderate startle
4	Dived and resurfaced 20–50 m away	Major startle
5	Dived and resurfaced >50 m away	Extreme startle

3.2.4 Data analyses

Generalised linear mixed effects models (GLMM) were used to determine the relationship between gillnet damage per unit effort (DPUE, new holes.net.hr^{-1}) and treatments (treatment vs control) using the package "glmmTMB" in the R statistical environment (Brooks et al. 2017; R Core Team 2017). Prior to analysis, all net-damage and catch data were standardised to account for differences in soak times among net sets. A negative binomial error structure was used to account for over-dispersion with 'treatment' as a fixed effect and 'fishing night' as a random effect. The best GLMM model was determined as part of a stepwise approach that examined different combinations of random effects; it had the lowest Akaike Information Criterion value (Equation 1, Table A1). P-values were obtained by likelihood ratio tests of the model of best-fit against a null model with the fixed effect removed. The same approach was used to compare the effect of treatment on the catch per unit effort (CPUE, fish.net.hr^{-1}) for legal-sized Mulloway. In this analysis, however, the stepwise approach determined that the best GLMM model included 'treatment' as a fixed effect and 'fisher' nested within 'fishing night' as a random effect (Equation 2, Table A2).

Equation 1: Damage ~ Trial + offset(log(Soak_time)) + (1 | Night_ID)

Equation 2: N_Mulloway ~ Trial + offset(log(Soak_time)) + (1 | Night_ID/Fisher_ID)

3.3 Results

3.3.1 Interaction rates

Across the nine nights, a total of 312 net sets were completed (158 by a treatment boat; 154 by a control boat; Table 3-3), with an average soak time of 46 min per net set (standard deviation ± 21 min). A total of 170 interactions between Long-nosed Fur Seals and gillnets was observed, of which 72 involved a boat with crackers, and 98 involved a control boat (Table 3-3). Interaction rates varied among trial nights and ranged from 0.11–2.67 interactions.net.hour^{-1} (mean: 0.88, standard error: ± 0.29) and 0.17–1.54 interactions.net.hour^{-1} (0.8 ± 0.18) for the treatment and control boats, respectively. Weather conditions during the experiment (5–15 km.h^{-1} winds) were typical of those experienced during conventional gillnet fishing undertaken in the LCF.

Table 3-3. Summary of the numbers of gillnets deployed (net sets), numbers of net sets with seal interactions, and numbers seal interactions for the 'control' and 'treatment' boats for each night (n=9) of the experiment. The number of interactions per unit effort (IPUE, interactions.net.hr^{-1}) is also shown. For the treatment boat, the number of interactions involving the use of crackers is shown in brackets.

		Control boat				Treatment boat			
Trial night	Date	No. net sets	No. net sets with interactions	No. Interactions	IPUE	No. net sets	No. net sets with interactions	No. Interactions	IPUE
1	18/4/16	12	4	5	0.45	24	2	2 (2)	0.29
2	19/4/16	17	2	2	0.18	14	6	12 (8)	1.78
3	20/4/16	18	6	8	0.44	18	8	19 (16)	2.67
4	26/4/16	22	6	15	0.88	15	5	12 (8)	1.28
5	28/4/16	15	7	11	0.73	29	5	8 (7)	0.91
6	29/4/16	12	3	3	0.17	9	1	1 (1)	0.11
7	13/5/16	22	15	19	1.45	14	5	5 (5)	0.15
8	15/5/16	15	3	14	1.36	23	4	5 (5)	0.44
9	1/6/16	21	9	21	1.54	12	5	8 (8)	0.28
		154	57	98	0.80	158	41	72 (60)	0.88

3.3.2 Seal behaviour prior to using crackers

Of the 98 interactions involving the control boat, most were Type 3 (seals patrolling the net, 48%) or Type 4 (seals eating fish, 34%) interactions, while Type 1 (seals passing by, 9%) or Type 2 (seals approaching the net, 9%) interactions occurred less often (Table 3-1, Figure 3-3).

Eighty-eight per cent of all interactions with the treatment boat qualified for the use of crackers (i.e. seals approaching (35%), patrolling (32%) or eating fish at (21%) the net; Figure 3-3). Other interactions (12%) involved seals passing by the fishing area and exhibiting no intent to interact with gillnets.

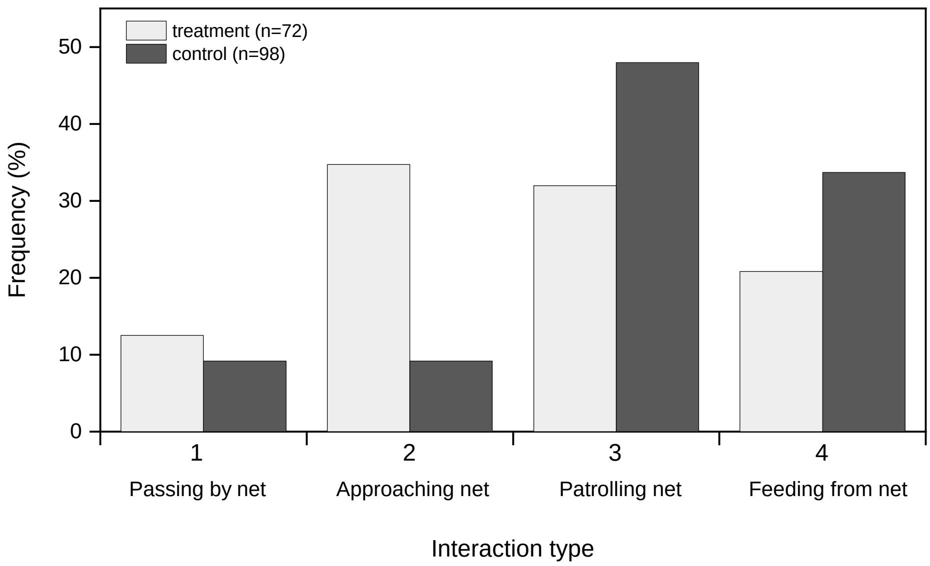


Figure 3-3. Frequency (%) of occurrence of the four interaction types for the treatment and control boats. Type 1 = seal passing by the net, Type 2 = seal approaching from net (10-20 m away), Type 3 = seal patrolling the net, Type 4 = seal eating caught fish (Table 3-2).

3.3.3 Numbers of crackers deployed per interaction

For the treatment boat, a total of 94 crackers were deployed across 63 interactions. The number of crackers deployed per interaction ranged from 1–5 (1.57 ± 0.13) (Figure 3-4). Sixty-eight per cent of the interactions involved the use of a single cracker, 17% involved the use of two crackers, and 15% involved the use of three of more crackers.

The mean number of crackers deployed per interaction varied among the three interaction types that qualified for their use. On average, around twice as many crackers (2.64 ± 0.25 crackers) were used in attempts to deter seals that were feeding from the net (Type 4 interactions), compared to seals approaching the net (Type 2, 1.23 ± 0.15) or patrolling the net (Type 3, 1.24 ± 0.09) (Figure 3-5).

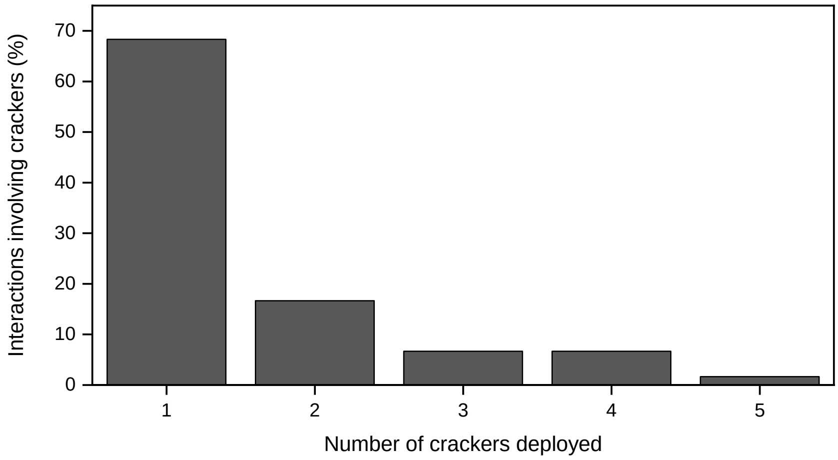


Figure 3-4. Frequency histogram showing the proportion of interactions (n=63) that involved the use of 1–5 crackers.

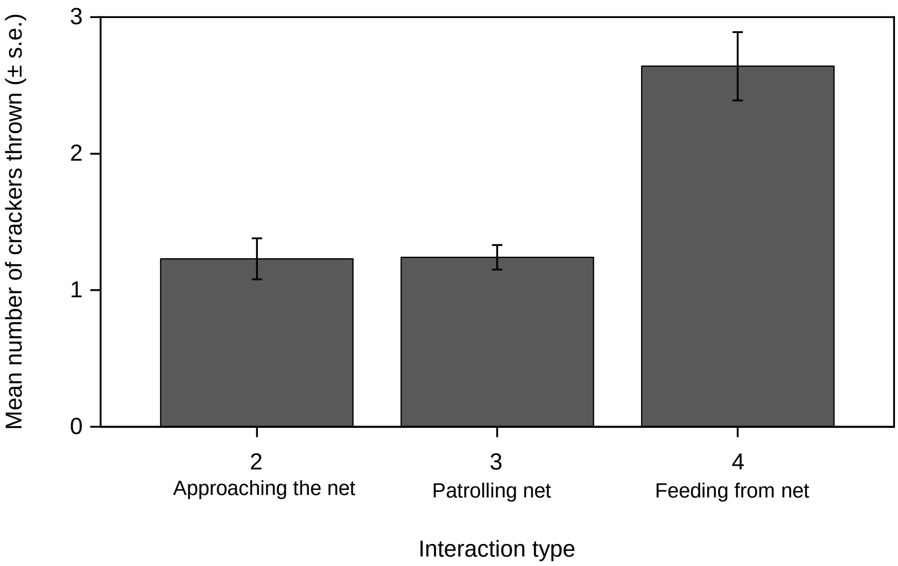


Figure 3-5. Mean (± standard error) number of crackers deployed for each interaction type (crackers were not used to deter Long-nosed Fur Seals involved in Type 1 interactions, i.e. when seals were <20 m from net). Type 2 = 10-20 m from net, Type 3 = patrolling the net, Type 4 = eating caught fish (Table 3-2).

3.3.4 Response of Long-nosed Fur Seals to crackers

Distances seals moved away

Eighty-five per cent of crackers deployed elicited an instant change in seal behaviour that saw the targeted seal immediately dive and re-surface some distance away from its original position (Figure 3-6). Approximately 40% of crackers deployed were highly effective and resulted in the targeted seal fleeing and re-surfacing >50 m away (Response Type 5), 29% caused seals to move and re-surface 10–50 m away (Response Types 3-4), 16% resulted in the seals moving <10 m away, and 15% failed to change the behaviour of the targeted seal.

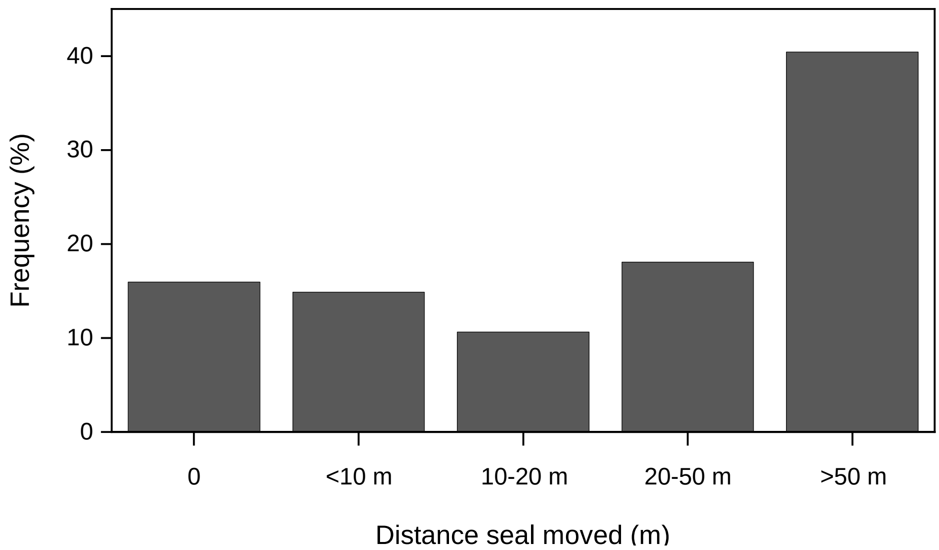


Figure 3-6. Distanced moved by Long-nosed Fur Seals in response to crackers (n=96).

Response relative to seals prior behaviour

Crackers were most effective when used on Long-nosed Fur Seals that were approaching a gillnet (Type 2 interactions). In such situations, 65% of the time the targeted seal immediately dived and resurfaced >50 m away from its original position, 27% per cent of the crackers deployed resulted in the seal fleeing to re-surface 10–50 m away, while less than 3% failed to change the behaviour of the seal.

Crackers were also highly effective when seals were patrolling the net, presumably in search of caught fish (Type 3 interactions). In such situations, around 40% of seals immediately dived and resurfaced >50 m away, 35% fled to 10–50 m away; and 20% (n=2) did not move away.

By comparison, crackers were generally ineffective when used on seals that were actively feeding on fish caught in gillnets (Type 4 interaction). Sixty per cent of the crackers deployed at such seals did not change their behaviour (i.e. they remained in their original position and continued to feed). Most of the remaining crackers deployed toward feeding seals resulted in them moving <20 m away.

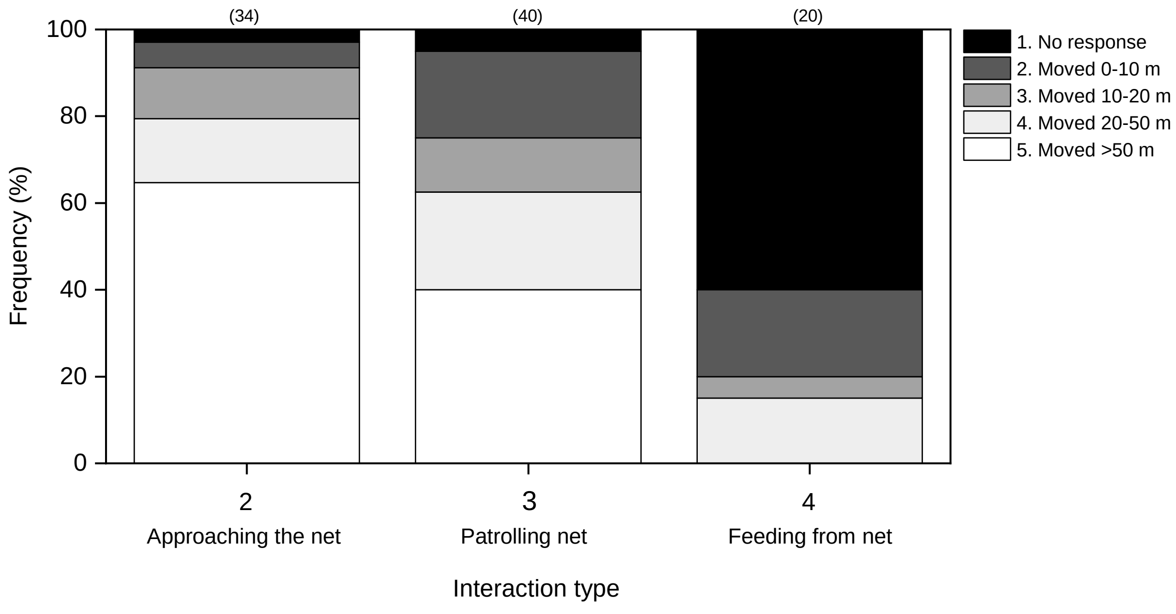


Figure 3-7. Comparisons of the responses of Long-nosed Fur Seals to crackers, for the three types of interactions that qualified for the use of crackers. A description of each Interaction type is provided in Table 3-2. The number of interactions for each interaction type is shown in brackets above the coloured bars.

Feeding interactions involving multiple crackers

Of the 60 interactions involving the use of crackers, 30% involved the use of more than one cracker (Figure 3-5). Examples of these are Interactions recorded as 10 and 23, which involved five and four crackers, respectively (Figure 3-8). For Interaction 10, deployment of the first two crackers failed to induce a response in the seal that was actively feeding on fish caught in the net (Type 4 interaction). A third cracker was subsequently deployed, to which the seal responded by moving <10 m from its original position. Deployment of a fourth cracker repelled the seal a further 10–20 m, before the fifth cracker saw it flee a further >50 m and out of the immediate fishing area.

During Interaction 23, the first cracker was deployed when the seal was feeding on fish caught in the net (Type 4 interaction). The seal exhibited no response. The second cracker deterred the seal to <10 m, however, it soon returned to the net (Type 3 interaction). Deployment of the third cracker resulted in the seal moving 10–20 m from the net, at which time the fourth cracker was deployed and repelled the animal to >50 m away and out of the fishing area.

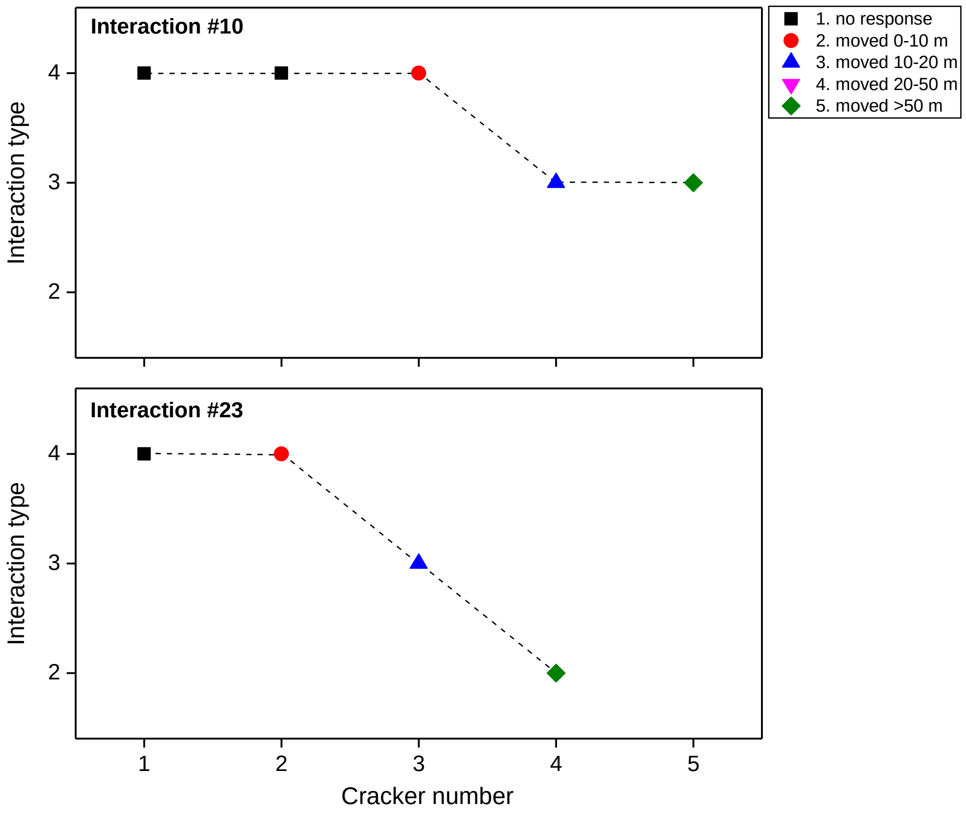


Figure 3-8. Examples of the response patterns of two Long-nosed Fur Seals whose interactions involved the use of five (top) and four (bottom) crackers by fishers in attempts to deter them from the fishing area. Symbols indicate the responses of the seals to each cracker and their behaviour (Table 3.2) at the time that each cracker was deployed.

3.3.5 Gillnet damage

Overall, seal damage was recorded for 89 of the 312 net sets (29%), with new holes observed in 20% and 38% of the net sets deployed by treatment and control boats, respectively (Table 3-4). The GLMM detected a significant difference in DPUE among the two treatments ($\chi^2(1)=5.85$, $p=0.0156$), with higher damage rates observed for the control boat than for the treatment boat (Table 3-4; Figure 3-9). Mean DPUE for the control boat (1.73 ± 0.33) was around 2.2 times higher than for the treatment boat (0.79 ± 0.19). The greater damage to control boat nets was also visually evident in trends in cumulative DPUE during most trial nights (Figure 3-10).

Table 3-4. Summary of the numbers of gillnets deployed (net sets), the percentage of net sets that were damaged by Long-nosed Fur Seals, and mean damage per unit effort (DPUE, holes.net.hr^{-1}) for the control and treatment boats each trial night.

Trial night	Control boat				Treatment boat			
	Net sets	Damaged net sets	DPUE	SE	Net sets	Damaged net sets	DPUE	SE
1	12	50%	1.49	0.62	24	21%	0.98	0.41
2	17	18%	0.40	0.23	14	29%	0.71	0.42
3	18	61%	5.54	2.05	18	11%	0.91	0.74
4	22	50%	2.15	0.88	15	27%	1.88	1.30
5	15	47%	2.32	1.27	29	3%	0.09	0.10
6	12	25%	1.01	0.61	9	11%	0.56	0.56
7	22	27%	0.80	0.35	14	29%	0.59	0.28
8	15	33%	1.24	0.49	23	30	1.1	0.49
9	21	29%	0.54	0.22	12	17%	0.39	0.21
All	154	38%	1.73	0.33	158	20%	0.79	0.19

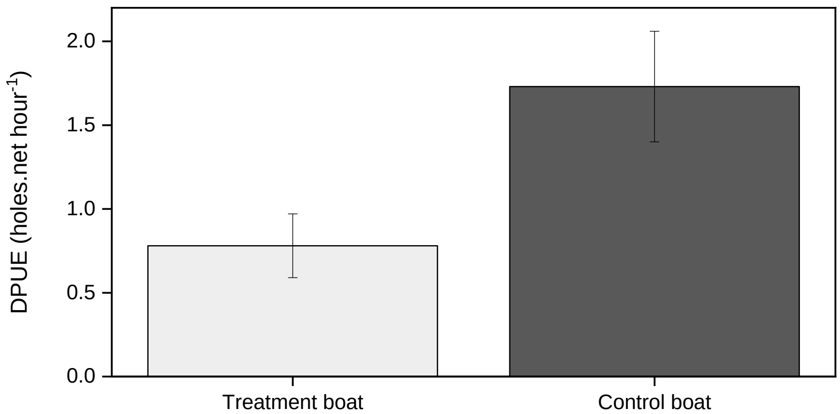


Figure 3-9. Comparison of mean net damage per unit effort (DPUE) between the treatment and control boats during the experiment.

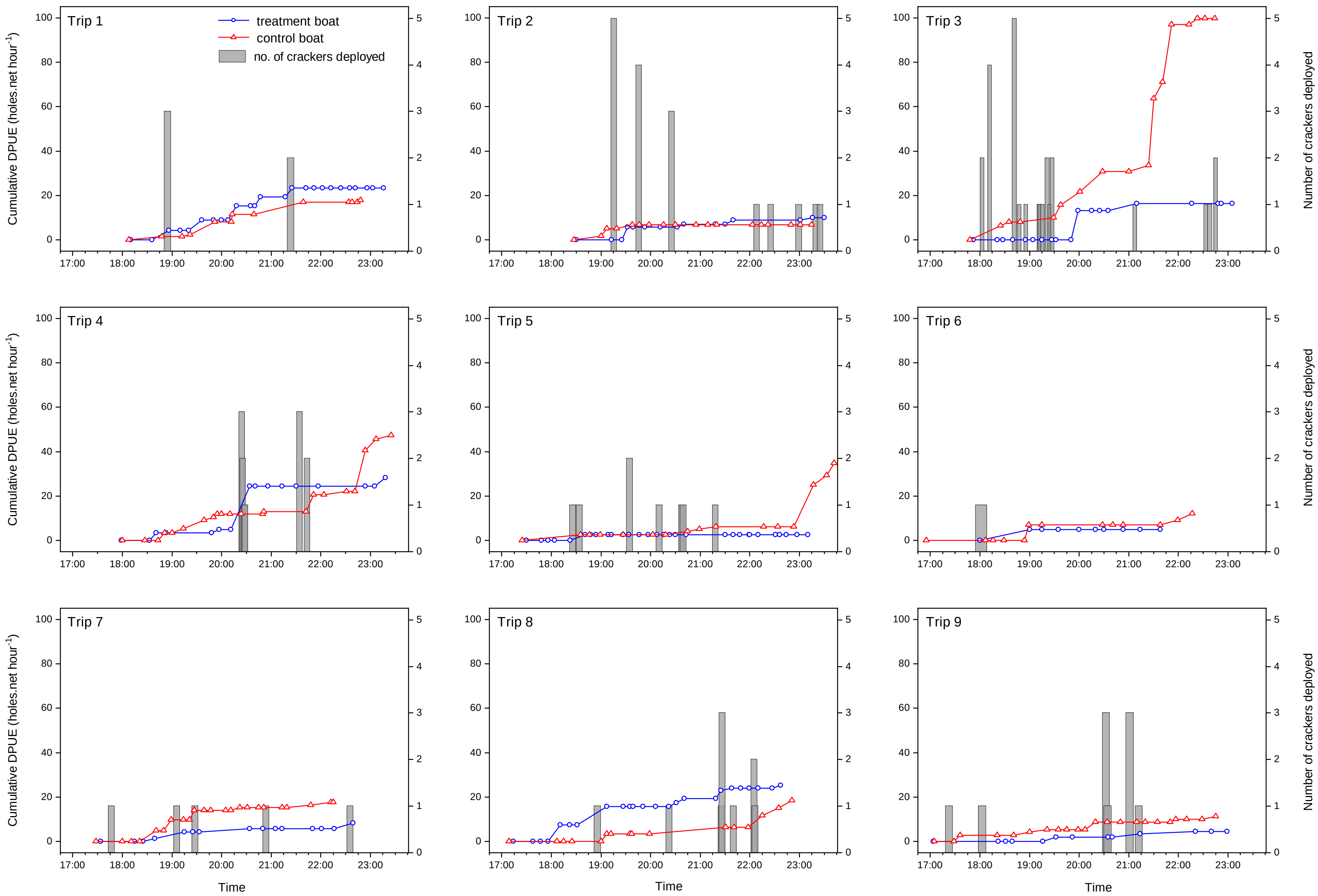


Figure 3-10. Cumulative DPUE (holes.net.hour^{-1}) for the control boat (red line) and treatment boat (blue line) during the nine trial nights. Symbols represent the inspection times of individual gillnet sets. The number of crackers deployed (bars) during each trip are also shown.

3.3.6 Mulloway catch rates

The GLMM analysis indicated that there was no significant difference in retained Mulloway CPUE between the treatment and control boats ($\chi^2(1)=3.17$, $p=0.075$) (Figure 3-11). Nightly CPUE was highly variable and ranged from 0.23–5.92 and 0.14–3.79 fish.net.hr^{-1} for the control and treatment boats, respectively (Table 3-5). Despite this variation among nights, the estimates of cumulative CPUE for the control boat during each trial night were similar to that of the treatment boat, and the two measures were linearly related (LR: $r^2 = 0.88$, $F_{1,8}=59.76$, $p<0.001$) (Figure 3-12).

Catch rates of discarded, seal-damaged Mulloway were low for both treatment (0.06 fish.net.hr^{-1} ± 0.03) and control boats (0.13 fish.net.hr^{-1} ± 0.06). No statistical testing was undertaken for discarded Mulloway CPUE due to the high number of net sets for which no seal-damaged fish were detected in the catch (i.e. no damaged fish on 8 of 9 nights for the treatment and 4 of 9 nights for the control boats, Table 3-5).

Table 3-5. Overall catch rates (CPUE, fish.net.hr^{-1}) of retained and discarded (seal-damaged) legal-sized Mulloway (i.e. > 460 mm total length) for the control and treatment boats for each trial night.

Trial night	Control boat				Treatment boat			
	Retained		Discarded		Retained		Discarded	
	CPUE	SE	CPUE	SE	CPUE	SE	CPUE	SE
1	5.92	2.76	0.27	0.20	3.79	0.94	0.00	0.00
2	2.00	0.54	0.00	0.00	2.08	0.78	0.00	0.00
3	4.22	1.68	0.63	0.42	3.09	0.79	0.00	0.00
4	2.99	1.13	0.17	0.12	1.32	0.39	0.00	0.00
5	5.17	1.65	0.04	0.04	2.79	0.51	0.34	0.17
6	0.71	0.39	0.10	0.10	0.48	0.19	0.00	0.00
7	0.72	0.30	0.00	0.00	0.53	0.22	0.00	0.00
8	0.23	0.12	0.00	0.00	0.40	0.15	0.00	0.00
9	0.77	0.29	0.00	0.00	0.14	0.10	0.00	0.00
All	2.39	0.40	0.13	0.06	1.89	0.23	0.06	0.03

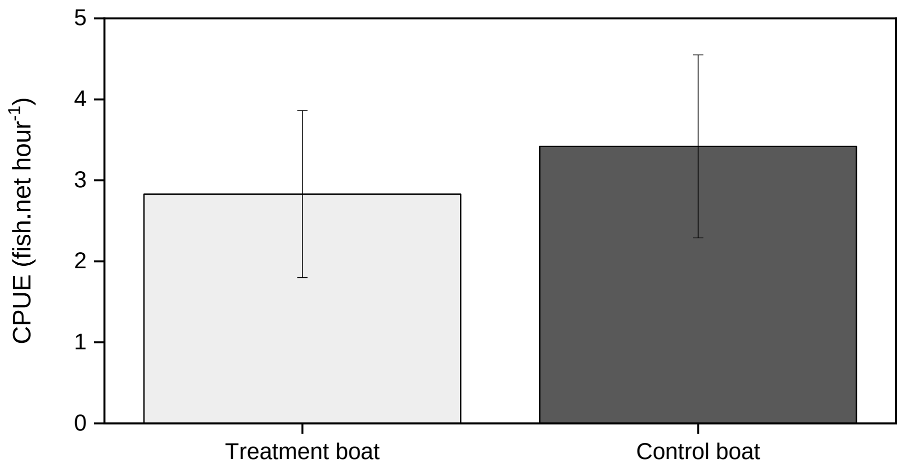


Figure 3-11. Comparison of mean catch per unit effort (CPUE) for Mulloway between the treatment and control boats during the experiment.

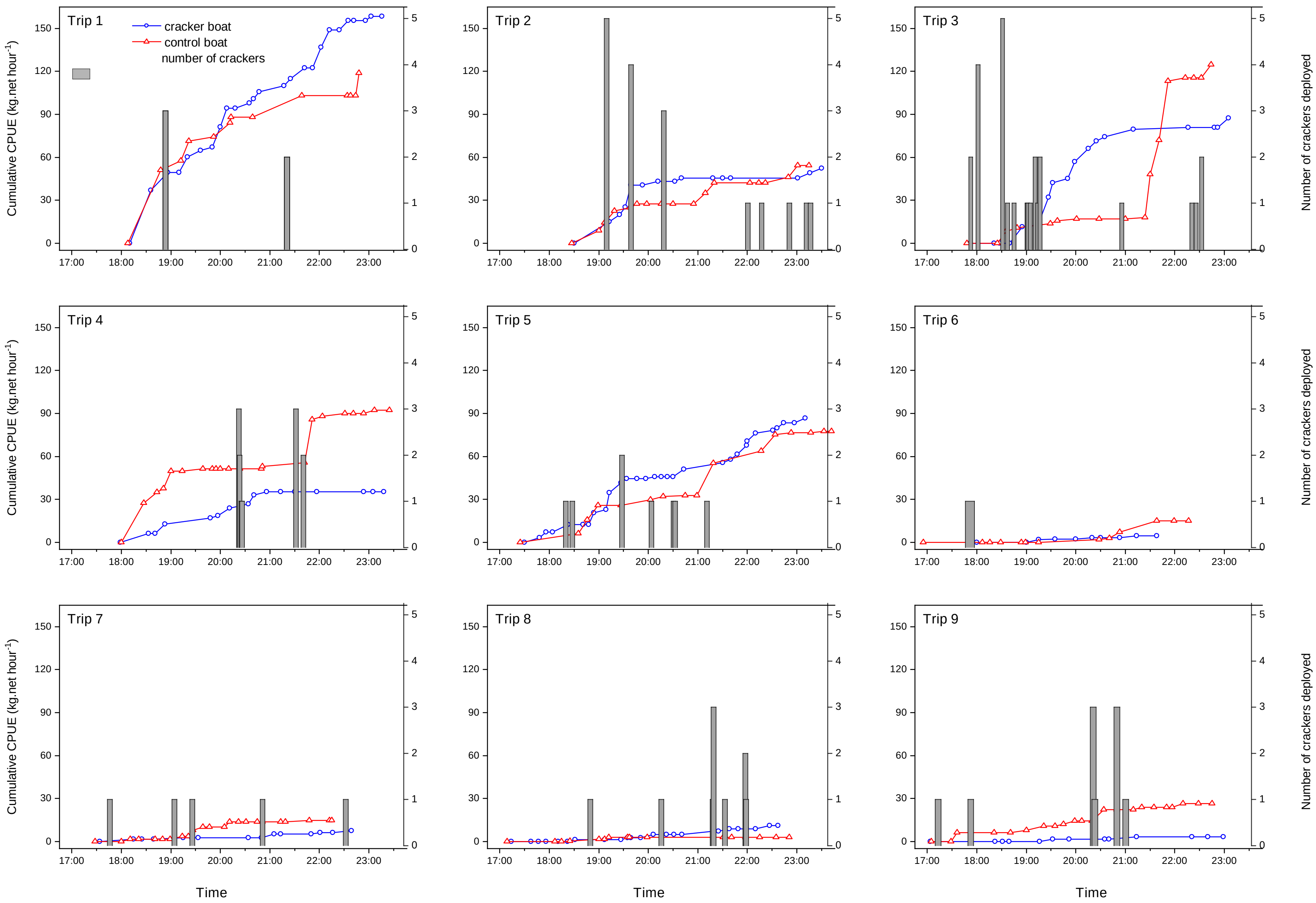


Figure 3-12. Cumulative Mulloway retained CPUE (kg.net.hour^{-1}) for the control boat (red line) and treatment boat (blue line) during the nine trial nights. Symbols represent the inspection times of individual gillnet sets. The number of crackers deployed (bars) during each trip are also shown.

3.3.7 Technical issues

Few technical problems relating to the use of crackers were encountered, although, 10% (n=11) of crackers failed to detonate. The failed detonations were not considered in the above results.

3.4 Discussion

This study provides insight into the nature of seal-fisher interactions in the LCF, and quantitative information on the effectiveness of crackers as a tool for mitigating the impacts of Long-nosed Fur Seals on gillnet fishers. Seals interacted with gillnets in a range of ways. A small proportion (7%) of seals that passed through the fishing area did not appear to be interested in the fishing activities. These seals may not have been foraging, or may not have learnt that interacting with fishing activities can provide a source of food (Kirkwood and Goldsworthy 2013). All other observed interactions involved seals that exhibited clear intent to interact with gillnets. Most seals were observed swimming back and forth along gillnets (often repeatedly), presumably in search of caught fish, while others were seen directly depredating caught fish. This ‘net-foraging’ is thought to be a learnt behaviour, reinforced with the reward of an easy meal that requires minimal energy to acquire (Cronin et al. 2016). Net foraging has been reported in gillnet fisheries world-wide (e.g. Butler et al. 2006; Königson et al. 2013; Cosgrove et al. 2015) and is thought to be typical of ‘specialist’ seals that have learnt that gillnets can provide food. The proportion of the population of Long-nosed Fur Seals that utilise the Coorong Estuary and Lower Lakes is small, and of those that do, the number that are net-foraging specialists is unknown. Those that do feed from gillnets are unlikely to do so exclusively, and probably split their time between the nets and other foraging strategies.

A key output of this study was data on the behavioural response of Long-nosed Fur Seals to crackers during commercial gillnetting operations. Analyses of these data indicated that the use of crackers elicited a startle response, of varying degrees, in targeted seals 85% of the time, while some seals did not respond at all. Further analyses revealed a possible link between the deterrent effects of crackers and the behaviour of the seals at the time the crackers detonated. Crackers were most effective when used on seals that were swimming toward but had not yet arrived at a gillnet. In such situations, the detonation of a cracker usually resulted in the targeted seal immediately diving and re-surfacing >50 m away from its original location. Crackers were also highly effective and elicited a similar response, although less often, when used on ‘net-foraging’ seals that were not feeding on caught fish. In contrast, most crackers that were used on seals actively eating caught fish failed to elicit a response (of any kind) that was visible to the observers, including sometimes when multiple crackers were thrown. These findings indicate that while crackers can be highly effective, their effectiveness is influenced, at least in part, by the motivation of the seal, and may be relatively ineffective on seals that are already plucking fish from the nets.

Motivation is the behavioural mechanism underlying an individual's assessment of the costs and benefits of a given foraging situation (Schakner and Blumstein 2013), and influences how averse seals are to underwater sounds (Götz and Janik 2010). A range of factors relating to sound perception and basic learning processes (e.g. habituation) are also likely to influence the deterrent effect of crackers, particularly with repeated exposure (Götz and Janik 2010). Elucidating the influence of such factors may help Lakes and Coorong fishers optimise their use of crackers and should be a focus of future research.

An issue that was not addressed in this study is habituation – that Long-nosed Fur Seals may, over time, learn to tolerate or avoid the noise and flash of light produced by crackers (Harris et al. 2014). The present study only documented the initial response of Long-nosed Fur Seals to crackers. At the time, crackers represented a new stimulus for the seals in the Coorong and it is difficult to predict if and, if so, how quickly seals may habituate to the crackers, especially under varying motivational conditions. It is also not known how often individual seals could be exposed to crackers, because of limited information on the foraging behaviour and residency times of Long-nosed Fur Seals that utilise the Coorong. Experience in other fisheries suggests that crackers will be effective in the short-term, but over the long-term with repeated use, seals will likely habituate to the stimulus (Geiger and Jeffries 1986; Gearin et al. 1988; Fraker 1994). If crackers are implemented as a management tool in the LCF, their effectiveness over time should be monitored.

The operational interactions between Long-nosed Fur Seals and gillnet fishers observed in this study often culminated in damage (e.g. holes) to gillnets and catch losses. Few damaged fish were observed in catches, suggesting that seals usually removed entire fish from gillnets (rather than parts of fish), often leaving only a hole in the net. There were also likely to have been hidden losses that went unseen, e.g. whole fish taken from nets with no evidence (Fjälling 2005; Königson et al. 2007). Nevertheless, it is important to point out that the frequency at which these impacts occurred may not accurately represent those experienced by LCF fishers during their usual fishing activities. There are several key reasons for this. First, this study was undertaken in areas where interactions between seals and fishers regularly occur. Usually, fishers would avoid these areas during periods of high seal abundance. Second, the gillnets used were left in position for the duration of each fishing night, regardless of whether seals were present. Normally, if seals moved into a fishing area, attending fishers would retrieve and shift their gear to areas less exposed to seals or stop fishing all together. Finally, not all LCF fishers attend their gillnets. Thus, it is possible that the presence of fishers in the vicinity of gillnets during this study may have in some way affected the behaviour of foraging seals and the way they interacted with gillnets. That is, some seals may have been alerted to the presence of the nets by the presence of the vessel (they would recognise noises from the engines and net handling) and approached, while others may have been deterred by the presence of the vessel.

Although the use of crackers did not fully prevent seal depredation in this study, it did reduce the damage to fishing gear. Gillnet damage rate was around 55% lower for the vessel that used crackers compared to the control vessel. Furthermore, the comparison of estimates of retained Mulloway CPUE for the control and treatment boats indicated that crackers had no effect on the Mulloway catches. These results suggest there may be an economic benefit for fishers who are willing to defend their nets using crackers, at least in the short-term, as a result of a reduction in the amount of time and materials required to repair and replace seal-damaged gear. However, crackers cost around AU$3.50 each, and this additional expense would need to be considered when weighing up the potential economic benefits associated with their use. Furthermore, additional time spent by fishers attending their nets may reduce the time available to attend to other aspects of their businesses and the costs of doing so should also be considered.

While this study assessed the deterrent effect of crackers on Long-nosed Fur Seals, there is potential for them to impact other animals. From an ecological perspective, one taxon of concern in the Lower Lakes and Coorong Estuary is the Australian Pelican (*Pelecanus conspicillatus*), which often interacts with fishery operations in the region (Goldsworthy and Boyle 2019). During this study, it was common for at least one and sometimes several pelicans to be observed loitering around the gillnets, including immediately after crackers were deployed, suggesting little or no effect of crackers on their presence.

From a fishery perspective, it is also important to consider the potential effect that crackers may have on the behaviour of fish around gillnets, particularly target species. In the 1970s, purse-seine fishers reported that while crackers temporarily deterred seals from fishing gear, they also dispersed schools of fish (Wickens 1996). A simple comparison of retained Mulloway CPUE between the treatment and control boats in this study indicated that the use of crackers had no effect on the number of legal-sized Mulloway in the catch, implying that crackers did not affect the behaviour of this species around gillnets. However, such an assessment should also consider the number of holes in gillnets, because it may be that each hole represented a caught Mulloway that was subsequently removed from the net by a seal. Therefore, if we combine the total numbers of fish landed and holes in gillnets and calculate an "adjusted" catch rate, the estimates of CPUE for the treatment and control boats are quite different. In fact, the adjusted CPUE for the treatment boat (2.6 fish.net hour^{-1}) was 36% lower that of the control boat (4.1 fish.net hour^{-1}). While it was not possible to say how many fish were removed from gillnets (Fjälling 2005; Königson et al. 2007), this finding indicates that crackers may have induced Mulloway to move away. Further research is required to investigate this possibility.

There were times during this study when a deployed cracker failed to detonate. The failed detonations were most likely due to damage to the wax-coated fuse of the cracker through which water entered and subsequently extinguished the burning fuse. This damage likely resulted from poor handling and storage practices. With more experience using crackers, this issue should be easily resolved. Also, some fishers expressed concerns about the inherent challenges and risks associated with lighting crackers whilst retrieving their gillnets. By collecting operational data on cracker usage during conventional commercial fishing operations, it should be possible to objectively assess concerns fishers have with using crackers and perhaps modify on-board storage, handling and deployment procedures so that they are safe to use and more workable for industry. If crackers are to be introduced into the LCF, consideration should be given to developing a set of protocols for fishers to ensure safe, effective and humane wildlife management outcomes.

In summary, this study has contributed important information on the usefulness of crackers for mitigating the impacts of Long-nosed Fur Seals on LCF gillnet fishers. The results demonstrate a potential for crackers to help fishers reduce seal impacts in some situations. While the deterrent effect of crackers is expected to reduce over time if used repeatedly on the same animals, our results suggest that they might be a useful tool in the management of seal-fisher interactions in the region if they are used judiciously, at least in the short term. Monitoring the effectiveness of the crackers over the long term is important, and best practice guidelines in cracker storage, handling and deployment should be developed if they are to be introduced into the fishery.

4. Trials of alternative fishing methods for use in the Lakes and Coorong Fishery

4.1 Introduction

A potential longer-term solution to the issue of Long-nosed Fur Seal depredation of gillnet catches in South Australia's Lakes and Coorong Fishery (LCF) involves the use of alternative fishing methods that are less vulnerable to seal depredation and maintain catches of target species. In 2015, the Southern Fishermen's Association agreed to collaborate with researchers to investigate the operational efficacy of two alternative fishing methods in areas of the LCF. These were: (1) fyke nets – similar to those currently used by what were formerly gillnet fisheries in the Baltic Sea to reduce seal impacts (Hemmingsson and Lunneryd 2007); and (2) hauling-nets (mechanical and manual) – similar to those currently used in South Australia's Marine Scalefish Fishery (MSF) (Steer et al. 2020). Commercial fishers agreed to work with researchers to develop and pilot three different fyke nets, and that an experienced commercial hauling-net fisher from the MSF would be contracted to carry out mechanical and manual hauling-net trials with guidance from LCF fishers.

The aim of this study was to provide preliminary information on the operational effectiveness of fyke nets and hauling-nets for targeting key fishery species in the Lower Lakes and Coorong Estuary. Such information will provide a basis from which to consider whether these methods could be used in combination with, or as alternatives to gillnets to mitigate seal impacts in the LCF. To achieve this aim, separate fishing trials were conducted for three fyke nets, as well as for the mechanical and manual hauling-net methods in areas of the fishery. The specific objectives of each trial were to: (1) determine if the method can be executed in productive fishing areas of the Lower Lakes and Coorong Estuary; (2) compare catch rates of commercial species for the method with those for conventional gillnets; and (3) evaluate the potential of the method as a commercially viable alternative to existing gillnet practices, with respect to objectives 1 and 2.

4.2 Methods

4.2.1 Fyke nets

Three fyke net configurations were field tested. These were: (1) a small double-wing (SDW) fyke net; (2) a large double-wing (LDW) fyke net; and (3) a single-wing (SW) fyke net (Figure 4-1). Each fyke net consisted of a large chamber and one or two detachable wings. The chamber was a large rectangular tube with two internal funnels designed to make entry by fish easy and exit difficult (Figure 4-2). It consisted of a single layer of blue polyethylene netting (18 ply, 40 mm mesh) supported by five rectangular frames (1.1 m high x 1.3 m wide), which were made of 35 mm diameter aluminium tubing. The chamber comprised three sections: the entrance; the fish holding compartment; and the anchor. The entrance was funnel-shaped at the inner end where it reduced to a rigid 300 mm diameter opening which would prevent seals from entering. A second funnel was fitted behind the entrance, through which fish could pass into the holding compartment. The rear of the chamber was enclosed with a drawstring, to which an anchor was attached. The design was based on that of a fyke net currently being used by commercial fisheries in the Baltic Sea (Hemmingsson et al. 2008).

The key difference between the three fyke net configurations was the number and length of the interchangeable wings that were attached to the entrance of the chamber. The SW fyke net had one wing that was 25 m long, whereas the SDW and LDW fyke nets each had a pair of wings, these were 12 m and 50 m long, respectively. The wings were constructed using the same polyethylene netting that was used for the chamber, 6 mm diameter lead rope (80 g per metre) and orange floats fitted at 1.5 m intervals, and were 50 meshes (~ 2.5 m stretched) deep. A grapnel was attached to the outer end(s) of each wing to hold it in position. The total cost of the materials and labour required to construct the chamber and wings was approximately $3,300 (incl. GST).

Fishing trials

Field-testing was conducted across a total of 24 nights during 2016 and 2017 in the Coorong Estuary and Lake Alexandrina by LCF fishers with assistance from SARDI researchers. Separate field trials were conducted for each fyke net (Table A3). Each trial was undertaken using LCF vessels in areas where, based on the skipper's experience, typical catches of Mulloway, Yelloweye Mullet (in the Coorong Estuary), and Carp, Bony Herring and Golden Perch (in Lake Alexandrina) were likely to be encountered (Figure 4-3).

Trial 1: small double-wing (SDW) fyke net

The SDW fyke net was trialled over five nights at four locations in the Coorong Estuary (Figure 4-3). At each location, the fyke net chamber was set parallel to the shoreline in a channel that was around 2 m deep, with its entrance facing into the current. The end of one wing was anchored in shallower water (<1.2 m deep) on one edge of the channel, while the end of the other wing was anchored near the centre of the channel. The ends of the wings were set approximately 10 m apart. Once deployed, the net was left to soak for between 16 and 24 h at each location (Table A3).

Trial 2: single-wing (SW) fyke net

The SW fyke net was trialled over seven nights at three locations in the Coorong Estuary (Figure 4-3). At each location, the net was set by anchoring the far end of the wing in shallow water (<0.5 m deep) on a sandbar and anchoring the chamber in deeper water (~2 m deep), so as to try and intercept fish as they moved along the edge of the bank. The net was soaked for between 15 and 25 h at each location (Table A3).

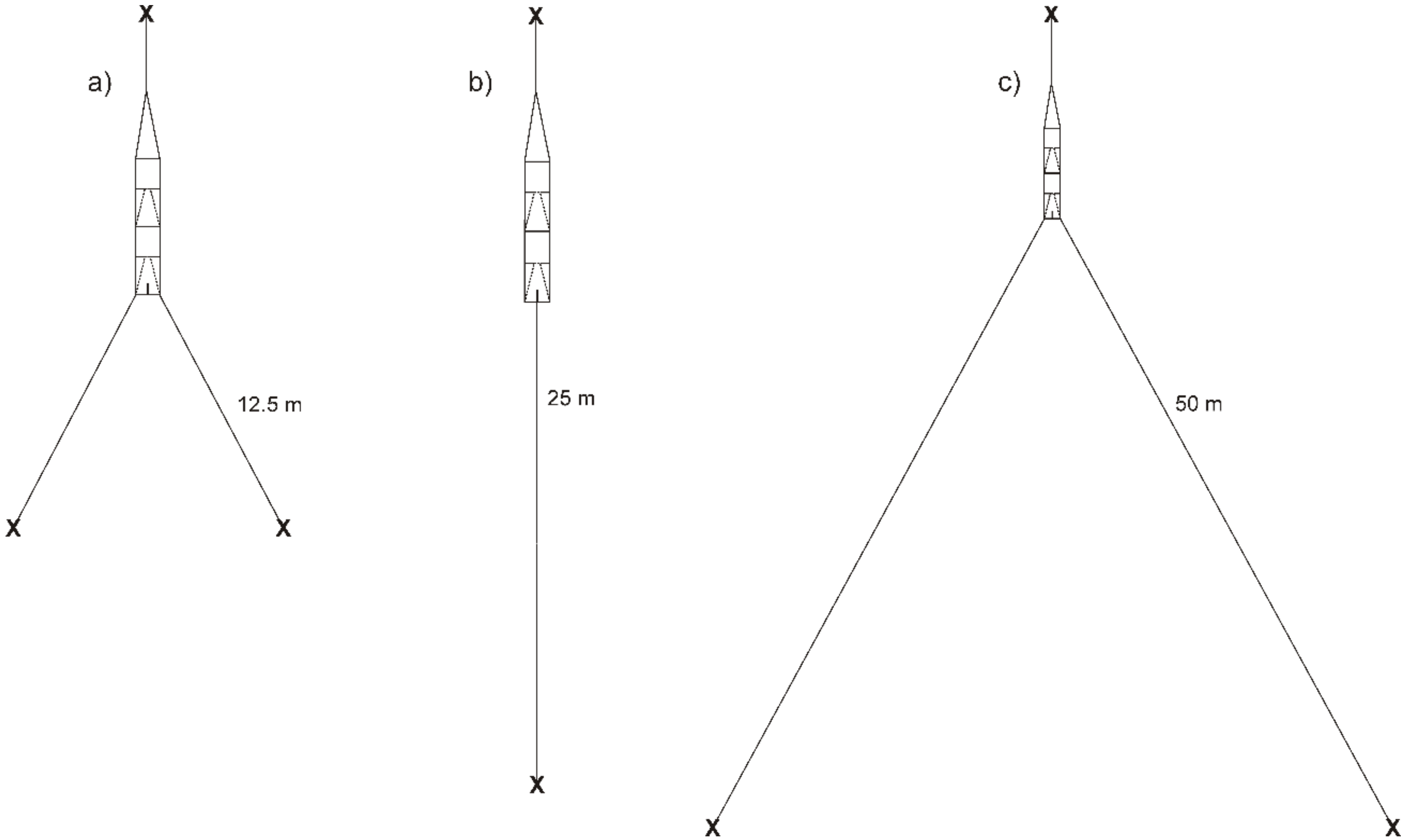


Figure 4-1. Top view of the three fyke net configurations: (a) small double-wing fyke net, (b) single-wing fyke net, and (c) large double-wing fyke net. The anchor points (X) for each configuration are also shown.

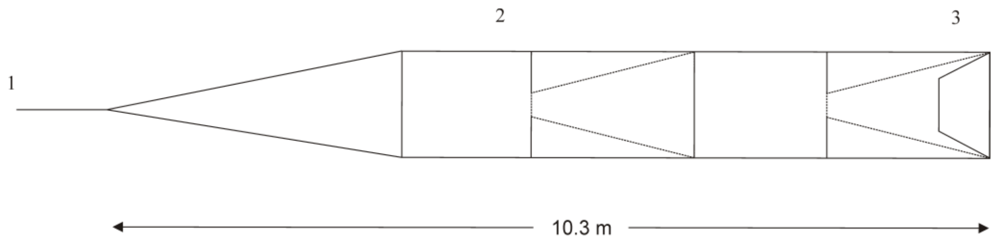


Figure 4-2. Side view of chamber system showing the entrance (3), holding compartment (2) and anchor (1).

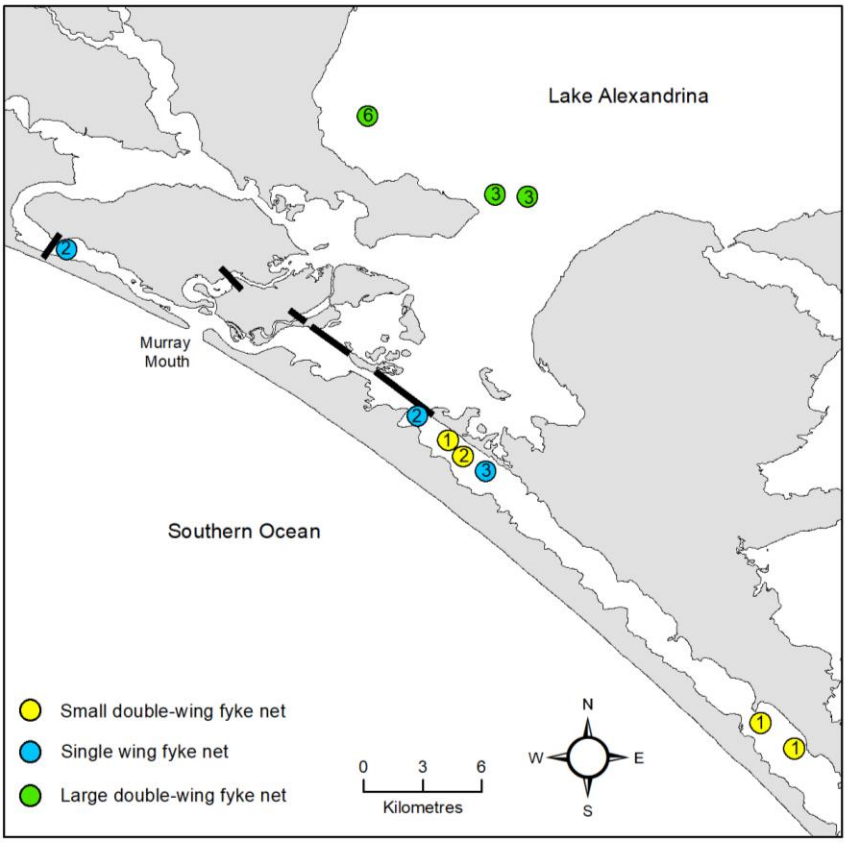


Figure 4-3. Map showing the locations of the fyke net trials in the Coorong Estuary and Lake Alexandrina. The number of trial nights undertaken at each location is shown within the coloured dots which correspond to the three fyke net configurations.

Trial 3: large double-wing (LDW) fyke net

The LDW fyke net was trialled during 12 nights at three locations in Lake Alexandrina (Figure 4-3; Table A3). The procedure to deploy the LDW fyke net was similar to that used to deploy the SDW fyke net (i.e. the chamber was set parallel to the shoreline in a deep channel, with the wings fanning out to intercept fish as they moved with the current along the edge of the channel). The ends of the wings were set approximately 50 m apart. The net was soaked for between 15 and 25 h at each location (Table A3).

Data collection and analyses

At the end of each fyke net deployment, the chamber was lifted onto the boat and all captured fish were removed, identified, counted and measured for total length (TL) to the nearest mm. In addition to these quantitative data, any debris that collected in the entrance part of the chamber was noted. In the event of an unsuccessful deployment, the likely technical reason was recorded. The presence of Long-nosed Fur Seals, and any evidence of seal damage to the net or the catch was also noted.

To evaluate the relative effectiveness of each fyke net for catching LCF species, estimates of fyke net CPUE (kg.fishing day^{-1}; by species) were plotted against those for conventional gillnets deployed by LCF fishers at the same time (same month) and in the same area (estuary or lakes). Fyke net CPUE was determined based on a standardised soak time of 24 hours. Gillnet CPUE was determined from daily catch (kg) and effort (fishing day) data that were collected by fishers completing their fishery logbooks. See Earl (2020) for descriptions of fishery logbook data reporting, storage and handling processes.

4.2.2 Hauling-nets

Two hauling-net techniques were field tested: (1) mechanical hauling, whereby a hydraulic reel fitted to a custom-built hauling vessel was used to retrieve a large hauling-net; and (2) manual hauling, whereby fishers retrieved a small hauling-net by hand. The two nets were similar in terms of their design and construction materials. Both consisted of a lateral wing and a pocket (Figure 4-4). The wings were made of polyethylene mesh (9 ply, 30–32 mm stretched mesh), cork floats fitted at 2 m intervals along an 8 mm diameter head-rope, a weighted foot-rope, and had a drop of approximately four metres (120 meshes). The sole difference between the two hauling-nets was the length of the wings. The wing on the mechanical hauling-net was 520 m long, while the wing on the manual hauling-net was 350 m long. The pocket of each net was made of polyethylene mesh (15 ply, 32 mm stretched mesh), and was 150 meshes deep and 180 meshes wide. The total cost of the materials and labour required to construct the large and small hauling-nets were approximately $7,950 and $2,950 (incl. GST), respectively.

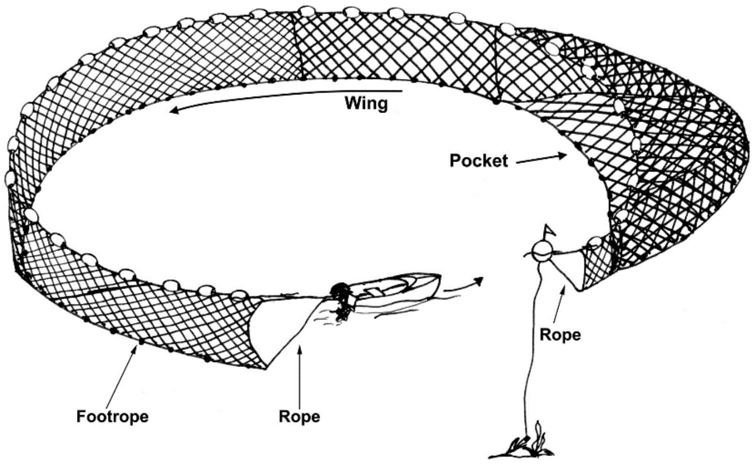


Figure 4-4. Schematic of a hauling-net shot identifying the pocket and wing sections of the net.

Fishing trials

The hauling-net trials were carried out by an experienced MSF hauling-net fisher with assistance from LCF fishers and SARDI researchers. The two hauling methods were trialled independent of each other in areas of the Lower Lakes and Coorong Estuary that were expected to be clear of rocks and other hard structures and where, based on advice from the participating fishers, commercial species were likely to be encountered (Figure 4-5).

Trial 1: Mechanical hauling

The mechanical hauling-net trial was undertaken using a chartered MSF hauling vessel (7.8 m long, fibreglass hull, inboard diesel engine; approximate value of $85,000) equipped with a hydraulic net reel, skippered by the fishing contractor and crewed by up to two LCF fishers (Figure 4-6A). The trial was conducted over six days in 2016 (three in each of October and November) and involved ten hauling shots in the Lower Lakes and nine in the estuary (Figure 4-5; Table A4). An observer vessel that was crewed by project staff and at least one other LCF fisher was present at all times.

To begin each shot, the pocket end of the net was anchored and the remaining net was deployed in a large semi-circle around an area likely to contain fish (Figure 4-7). Then, the wing end of the net was slowly towed around to the anchored pocket to form a complete circle. The wing was slowly retrieved using the hydraulic net reel, as the vessel moved astern, reducing the size of the area inside the net and herding the fish into the pocket. The pocket was then pulled up to the side of the vessel by hand, and all captured fish were brailed out with a dip net for processing. Fish enmeshed in the wings were also processed.

Trial 2: Manual hauling

The manual hauling trial was undertaken using an existing LCF vessel (4.9 m long, aluminium hull, 90 hp outboard engine; Figure 4-6B) that was skippered by its owner, and crewed by the contracted MSF hauling-net fisher. The trial was conducted over three fishing days (one in November 2016; two in March 2017) and involved two shots in the Lower Lakes and eight in the Coorong Estuary (Figure 4-5; Table A4). The hauling-net was deployed using the same methodology as that used for the mechanical hauling trial and was retrieved by hand by the skipper and crew. An observer vessel was present at all times.

Data collected and analyses

At the end of each hauling-net shot, all captured fish were identified to species level, counted, and up to 100 individuals of each species were measured for TL to the nearest mm. Each species was identified as either a prescribed or non-prescribed species (according to *Schedule 1 of the Fisheries Management (Lakes and Coorong) Regulations 2009*) (PIRSA 2016). Catches of prescribed species that were above their respective legal minimum length (LML) or saleable minimum length (SML; i.e. the approximate minimum length suitable for sale) were retained and weighed to the nearest 0.05 kg. Catches of pest species (declared under the *Fisheries Management Act 2007*) that were below their respective SML were disposed of appropriately. All other fish were released alive as soon as possible after processing.

In the event of an interrupted or unsuccessful net deployment, the technical reason was noted. The presence of seals, and any evidence of seal-inflicted damage to the net or the catch was also recorded. For comparison, estimates of CPUE (kg.fishing day^{-1}) for commercial species in the hauling-net catches were plotted against those for conventional gillnets deployed by LCF fishers in the same month and area (estuary or lakes). Daily hauling-net CPUE was standardised (1 fishing day = 3 hauling-net shots) to account for the variation in the number of shots completed on each day of the trials. Gillnet CPUE was derived from daily catch and effort data reported by fishers in logbooks. Catch rates between hauling-nets and gillnets were not compared statistically, due to the low number of fishing days completed.

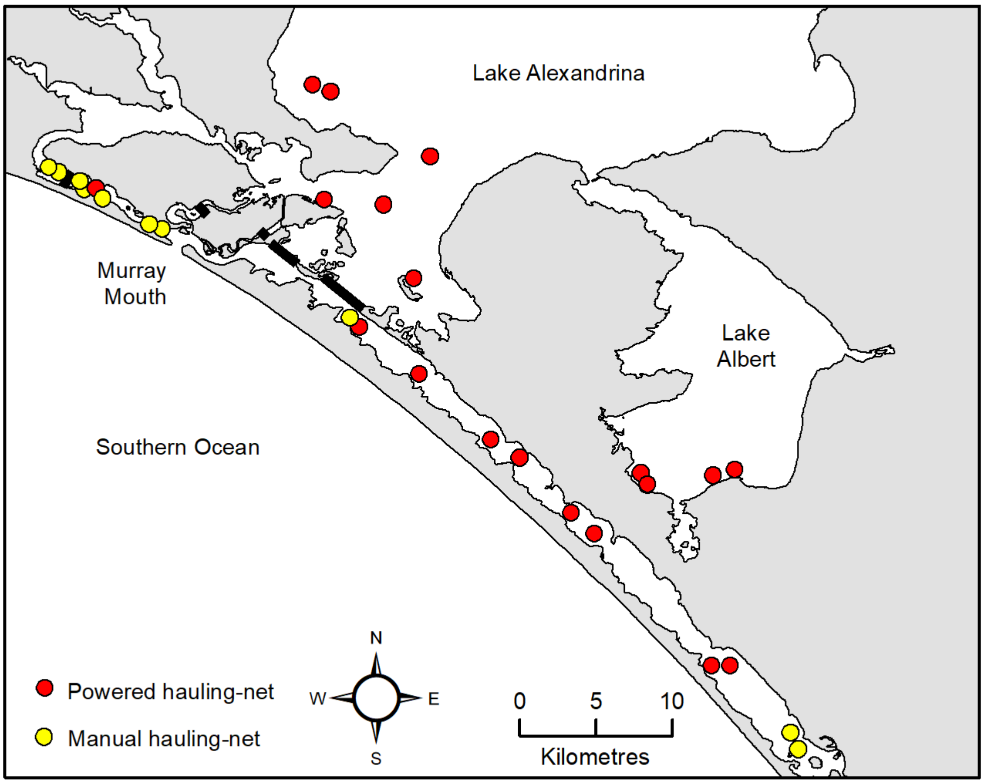


Figure 4-5. Map showing the locations of the mechanical (red dots) and manual (yellow dots) hauling-net shots completed in the Coorong Estuary and Lower Lakes during the trials. Thick black lines represent the barrages.

Figure 4-6. The two commercial fishing vessels chartered for the hauling-net trials: (A) mechanical hauling vessel from South Australia's Marine Scalefish Fishery that was used for Trial 1; and (B) LCF gillnet fishing vessel that was used for Trial 2.

Figure 4-7. Standard hauling-net shot. (A) deploy net in a large semi-circle around a school of fish, or in an area likely to contain fish; (B) join the two ends of the net to completely encircle the fish; (C and D) slowly haul (retrieve) the wing end of the net, reducing the size of the circle of the net and herding fish into the pocket; (E and F) pull the pocket (blue mesh) of the net up to the side of the vessel by hand; (G) prop open the pocket; and (H) manually brail fish out of the pocket.

4.3 Results

4.3.1 Trial fishing with fyke nets

Fishing conditions, catch summary and seal interactions

Conditions during the three fyke net trials (5–15 km.h^{-1} winds) were typical of those experienced during conventional gillnetting in the LCF. When pooled across the three trials (24 net sets), the total fyke net catch was negligible and comprised a total of 17 fish across five species (Table 4-1). This included low numbers of Bony Herring, Mulloway, Western Australian Salmon (WA Salmon; *Arripis truttaceus*), Congolli (*Pseudaphritis urvilli*) and Soldier (*Gymnapistes marmoratus*). No negative interactions with Long-nosed Fur Seals were observed, although a sub-legal-sized Mulloway in the catch was damaged by what may have been one of two seals observed near the net as it was being retrieved after trial night 4 of the SW fyke net (Table A3).

Table 4-1. Common names, scientific names and numbers (*n*) of fish caught during the three fyke net pilot trials (n_1 = small double-wing net; n_2 = single-wing net; n_3 = large double-wing net). The median and range of total lengths (TL) for each species is shown, along with the legal minimum length (LML) where applicable. (nr) = not recorded.

Common name	Scientific name	n_1	n_2	n_3	TL (mm)		LML (mm)
					Median	Range	
Congolli	*Pseudaphritis urvilli*	3	–	–	152	121–175	–
Bony Herring	*Nematolosa erebi*	–	–	3	189	172–205	–
Mulloway	*Argyrosomus japonicus*	2	1	–	230	195–231	460
WA Salmon	*Arripis truttaceus*	2	–	–	224	180–206	210
Soldier	*Gymnapistes marmoratus*	5	1	–	nr	nr	

Trial 1: Small double-wing (SDW) fyke net

Fish catches using the SDW fyke net were negligible. The total catch comprised 12 fish representing four species (Table 4-1), all of which were released because they were either sub-legal sized (Mulloway and WA Salmon) or bycatch (Congolli and Soldier). By comparison, estimates of mean CPUE for Yelloweye Mullet and Mulloway using conventional gillnets deployed near the trial area during the trial were 47.5 and 34.8 kg.fishing day^{-1}, respectively (Figure 4-8).

Despite the limited amount of deck space on the fishing vessel, few deployment, handling or operating issues were encountered. Floating algae wedged into the entrance part of the chamber during trial night 1 which may have restricted its effectiveness.

Trial 2: Single-wing (SW) fyke net

Fish catches using the SW fyke net were negligible, with one sub-legal sized Mulloway and one Soldier making up the entire catch (Table 4-1). By comparison, mean CPUE for Yelloweye Mullet and Mulloway using gillnets at the same time in the same area were 74.2 and 31.7 kg.fishing day^{-1}, respectively (Figure 4-8).

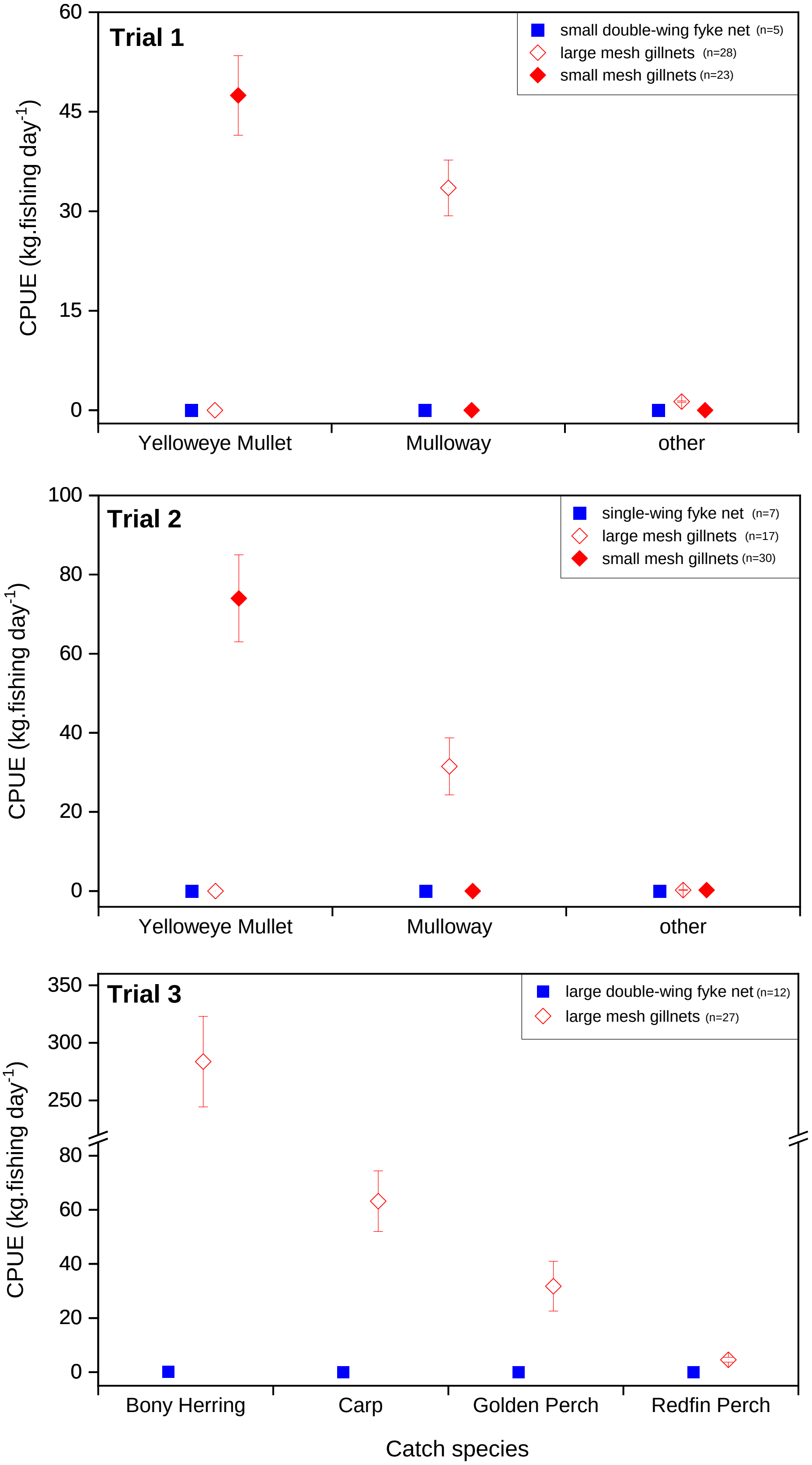


Figure 4-8. Comparison of the mean catch rates (CPUE ± S.E.) for key commercial finfish species between the small double-wing fyke net (Trial 1), single-wing fyke net (Trial 2), large double-wing fyke net (Trial 3; note the break in y-axis) and conventional gillnets used by LCF fishers in the same area during each of the three trials (data for gillnets were reported in logbooks).

No handling or deployment problems were encountered with the SW fyke net. During trial night 1, the fyke net chamber rolled onto its side due to strong currents and may not have been fishing effectively. This issue was overcome during subsequent nights by attaching a grapnel to each side of the chamber which prevented it from rolling.

Trial 3: Large double-wing (LDW) fyke net

As per Trials 1 and 2, the overall catch during the LDW fyke net trail was negligible, with only three small Bony Herring landed (Table 4-1). By comparison, estimates of mean CPUE for Bony Herring, Carp and Golden Perch using large mesh gillnets in Lake Alexandrina over the same 12-night period were 283.7, 63.2 and 31.8 kg.fishing day^{-1}, respectively (Figure 4-8). No technical issues were experienced with the LDW fyke net.

4.3.2 Trial fishing with hauling-nets

Fishing conditions, catch summary and seal interactions

Weather conditions during the two hauling-net trials (<10 $km.h^{-1}$ winds; <0.5 m waves) were typical of those required for hauling in the MSF. Water turbidity was high in the Lower Lakes and Coorong Estuary, with visibility in the surface layer of the water column <0.2 m.

Across the two hauling-net trials (29 completed shots), a total of 5,379 fish representing 14 finfish species and one Stingray species were captured (Table 4-2). Of the 14 finfish species, 11 were prescribed and three were non-prescribed. In total, 94.7% of the catch was of prescribed species. Among the prescribed species, Bony Herring accounted for 70.5% of the total number of fish caught, with most of the remaining catch made up of Yelloweye Mullet (9.9%) and Carp (6.9%). The non-prescribed River Garfish (*Hyporhamphus regularis*) was the fourth most abundant species in the catch and accounted for 5.1% of total catch (prescribed and non-prescribed).

Seventy-eight percent of all fish caught during the two trials were not retained because they were: (i) below their respective LML; (ii) below their respective SML; or (iii) a non-prescribed species (Table 4-2). All remaining fish in the catches were retained and contributed to a total retained catch of 563 kg. Carp, Bony Herring and Yelloweye Mullet collectively accounted for 87% of the total number of fish retained, and 93% of the total retained catch weight. Black Bream and WA Salmon contributed most of the remaining retained catch by number and weight. No negative interactions between Long-nosed Fur Seals and the hauling-net operations were observed.

Table 4-2. Summary of the species captured during the hauling-net trials listed in order of abundance for each species category (prescribed or non-prescribed). The table shows the common and scientific names, the commercial legal minimum length (LML), approximate saleable minimum length (SML), the numbers (*n*) of individuals caught and retained, the total weight (wt in kg) of individuals retained, and the relative contribution (%) to the total and retained catch, by number and by weight. (+) exotic species; (x) species has no LML, Non-retained catches of exotic species were binned.

Species category	Common name	Scientific name	LML (mm)	SML (mm)	Total catch *n*	Total catch %	Retained catch *n*	% total *n* retained	Retained catch wt. (kg)	% total wt. retained
Prescribed	Bony Herring	*Nematalosa erebi*	x	280	3,795	70.5	252	25.6	116.9	20.8
	Yelloweye Mullet	*Aldrichetta forsteri*	210	210	533	9.9	268	27.1	67.7	12
	Carp+	*Cyprinus Carpio*	x	260	371	6.9	353	35.8	338.4	60.2
	Redfin Perch+	*Perca fluviatilis*	x	260	163	3	9	0.9	1.5	0.3
	WA Salmon	*Arripis truttaceus*	210	210	110	2	77	7.7	15.1	2.7
	Black Bream	*Acanthopagrus butcheri*	300	300	45	0.8	29	2.9	23.2	4.1
	Greenback Flounder	*Rhombosolea tapirina*	250	250	22	0.4	–	–	–	–
	Jumping Mullet	*Gracilimugil argentea*	210	210	20	0.4	–	–	–	–
	Mulloway	*Argyrosomus japonicus*	460	460	15	0.3	–	–	–	–
	Congolli	*Pseudaphritis urvilli*	x	–	11	0.2	–	–	–	–
	Goldfish+	*Carassius auratus*	x	–	12	0.2	–	–	–	–
	Stingray	unknown	x	–	1	0	–	–	–	–
Non-prescribed	River Garfish	*Hyporhamphus regularis*	230	–	273	5.1	–	–	–	–
	Common Toadfish	*Tetractenos hamiltoni*	x	–	5	0.1	–	–	–	–
	Smooth Toadfish	*Tetractenos glaber*	x	–	3	0.1	–	–	–	–
		Total			5,379		988		562.8	

Trial 1: Mechanical hauling

Few technical problems were encountered during the deployment phase of the mechanical hauling operations, although snagging of the net during the retrieval phase was a major issue, particularly in the Coorong Estuary. Retrieval of the net was stalled during six (67%) of the nine shots attempted in the estuary due to the net snagging on submerged masses of calcareous tubes formed by the tubeworm, *Ficopomatus enigmaticus*, which were not visible from the surface due to the high turbidity (Table A4). On each occasion, the net was released by the observer vessel which enabled the shot to be completed. Snagging was less of an issue in the Lower Lakes, with 90% of the attempted shots completed without interruption.

Lower Lakes

In the Lower Lakes, ten mechanical hauling-net shots were completed (four in Lake Albert; six in Lake Alexandrina) across three days (Table A4). When pooled across all shots, the total catch comprised 1,278 fish, most of which were Bony Herring (59.3%), Carp (27.2%) and Redfin Perch (11.4%) (Table 4-3). Small numbers of Congolli, Goldfish, Yelloweye Mullet and River Garfish were also caught.

Of the total number of fish caught, less than half (43%) contributed to the total retained catch of 427 kg, which was dominated by Carp (78%) and Bony Herring (22%) (Table 4-3). All other fish in the pooled catch were not retained because they were either below their respective LML or SML, or a non-prescribed species (e.g. River Garfish). This included 65% (n=563) and 98% (n=135) of all Bony Herring and Redfin Perch in the catch, respectively. Length frequency distributions for the dominant catch species are provided in Appendix 3 (Figure A1).

Retained mechanical hauling catch-rates of Carp and Bony Herring (i.e. the dominant retained catch species) in the Lower Lakes varied considerably among trial days, ranging between 11–167 kg.fishing day^{-1} and 2–81 kg.fishing day^{-1}, respectively (Figure 4-9). Overall, mean CPUE for Carp (92 kg.fishing day^{-1} ± 45) was three times higher than for Bony Herring (31 kg.fishing day^{-1} ± 45).

Compared to conventional large mesh gillnets used by LCF fishers in the Lower Lakes during the trial, estimates of mean mechanical hauling retained CPUE for Carp and Bony Herring were considerably lower, by 40% and 81%, respectively (Figure 4-9). Legal-sized Golden Perch were taken in low quantities using gillnets, but were absent from mechanical hauling catches. Retained catch rates for Redfin Perch were low for both methods.

Table 4-3. Summary of the species captured using the mechanical hauling-net in the Lower Lakes and Coorong Estuary (Trial 1). The table shows the common names, the numbers (*n*) of individuals caught and retained, the total weight (wt) in kg of individuals retained, and the relative contribution (%) to the total and retained catch, by number and by weight. Non-prescribed species are shown in italics. (+) exotic species. Retained catch per unit effort (CPUE in kg.fisher day^{-1}) is also shown.

	Lower Lakes (10 shots)							Coorong Estuary (9 shots)						
Common name	Total *n*	Total %	Retained *n*	Retained %	Retained wt. (kg)	Retained wt. (%)	CPUE ($kg.fd^{-1}$)	Total *n*	Total %	Retained *n*	Retained %	Retained wt. (kg)	Retained wt. (%)	CPUE ($kg.fd^{-1}$)
Bony Herring	758	59.3	195	35.4	93	21.8	30.8	55	6.8	–	–	–	–	–
Yelloweye Mullet	5	0.4	–	–	–	–	–	374	46.4	125	61.9	31.6	67.7	9
Carp+	347	27.2	347	63	332.4	77.9	92.3	–	–	–	–	–	–	–
Redfin Perch+	146	11.4	9	1.6	1.5	0.4	0.5	–	–	–	–	–	–	–
WA Salmon	–	–	–	–	–	–	–	83	10.3	77	38.1	15.1	32.3	3.4
Greenback Flounder	–	–	–	–	–	–	–	16	2	–	–	–	–	–
Congolli	7	0.5	–	–	–	–	–	1	0.1	–	–	–	–	–
Goldfish+	12	0.9	–	–	–	–	–	–	–	–	–	–	–	–
River Garfish	*3*	*0.2*	–	–	–	–	–	*270*	*33.5*	–	–	–	–	–
Common Toadfish	–	–	–	–	–	–	–	*4*	*0.5*	–	–	–	–	–
Smooth Toadfish	–	–	–	–	–	–	–	*3*	*0.4*	–	–	–	–	–
Total	1,278		551		426.9			806		202		46.7		

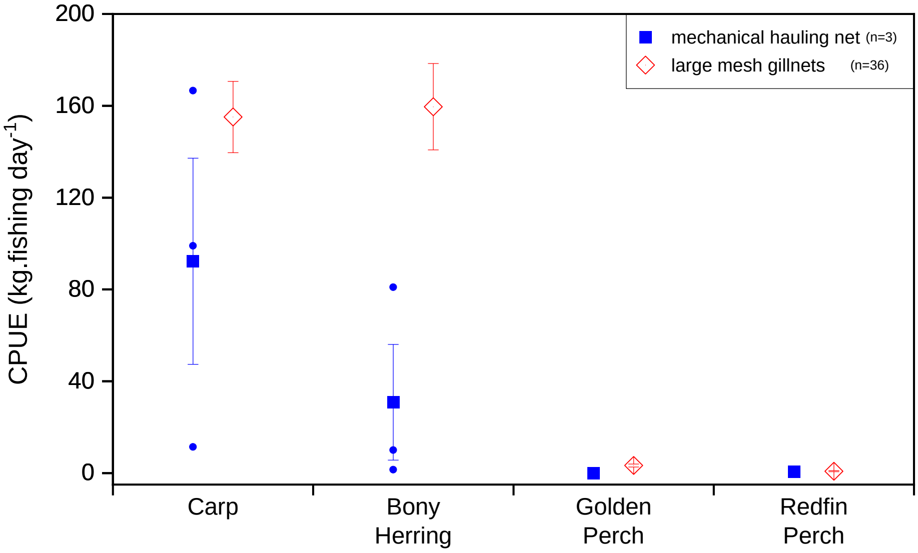


Figure 4-9. Mean retained catch rates (CPUE ± S. E.) of key commercial species using the mechanical hauling-net and conventional large mesh gill nets in the Lower Lakes during Trial 1 (n = number of fishing days). For each species, hauling-net CPUE for each trial day is also shown (small blue dots).

Coorong Estuary

In the Coorong Estuary, nine mechanical hauling-net shots were completed over four days (Table A4). A total of 806 fish were captured, with Yelloweye Mullet (46%) and River Garfish (34%) dominating the catch (Table 4-3). WA Salmon (10%) and Bony Herring (7%) were moderately abundant, while low numbers of Greenback Flounder, Toadfish and Congolli were also recorded.

Seventy-five percent of the total number of fish in the catch were discarded. The remaining fish in the catch contributed to a total retained catch weight of 46.7 kg, which comprised Yelloweye Mullet (31.6 kg) and WA Salmon (15.1 kg). Length frequency distributions for the dominant catch species are provided in Appendix 3 (Figure A2).

Mechanical hauling-net CPUE for retained commercial species in the estuary were negligible compared to those using conventional gillnets (Figure 4-10). For Yelloweye Mullet, mean hauling CPUE was 9.1 kg.fishing day^{-1} (± 4.3; range: 3–13), whereas that using small mesh gillnets was 142.9 kg.fishing day^{-1} (± 12). No Mulloway were landed using the mechanical hauling-net, yet the species dominated large mesh gillnet catches with a mean gillnet CPUE of 26.5 kg.fishing day^{-1} (± 3.1). Hauling-net CPUE for the non-prescribed River Garfish that were above the current LML of 230 mm TL for Garfish in SA ranged from 3.3–42.5 kg.fishing day^{-1} (mean: 15.4 kg.fishing day^{-1} ± 9.1) (Figure 4-10).

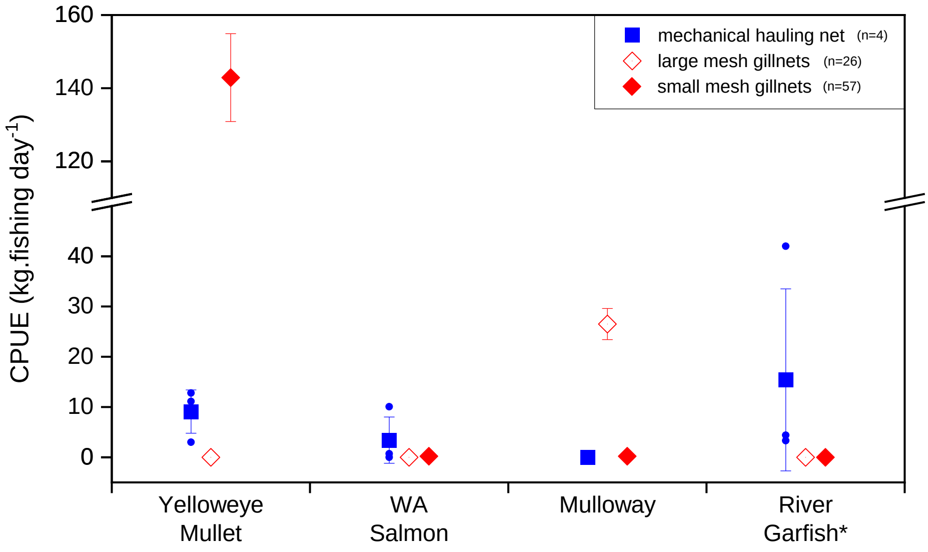


Figure 4-10. Mean retained catch rates (CPUE ± S.E) of key commercial finfish species using the mechanical hauling-net and conventional large mesh gill nets in the Coorong during Trial 1 (n = number of fishing days). For each species, hauling-net CPUE for each trial day is also shown (small blue dots). Note the break in y-axis.

Trial 2: Manual hauling

Few deployment issues were encountered during the manual hauling-net trial. Snagging of the net was a major issue. Retrieval of the net was stalled during six (75%) of the eight shots attempted in the Coorong Estuary due to the net snagging on submerged tubeworm reefs (Table A4). On each occasion, the net was released by the observer vessel which enabled the shot to be completed.

Lower Lakes

Due to time constraints, only two manual hauling-net shots were completed in the Lower Lakes, both of which were undertaken near the Goolwa Barrage (Figure 4-5; Table A4). Overall, a total of 2,940 fish were caught, of which 98% were Bony Herring (Table 4-4). The remaining catch comprised small numbers of Carp, Redfin Perch, Black Bream, Yelloweye Mullet and Congolli.

Ninety-nine percent of fish caught were released. This included 2,861 of the 2,888 Bony Herring, which were below the SML of 280 mm TL (Figure A3). Three species were represented in the total retained catch of 25 kg. These were Bony Herring (13 kg), Carp (6 kg) and Black Bream (6 kg) (Table 4-4). Length frequency distributions for these species are provided in Appendix 3 (Figure A3).

Retained catch rates of commercial species for the manual hauling-net in the Lakes were low compared to those for gillnets (Figure 4-11). For Bony Herring, the mean manual hauling-net CPUE of 19.5 kg.fishing day^{-1} (± 23.3; range: 3–36) was 83% lower than that using gillnets (119.6 kg.fishing day^{-1} ± 11.5). Similarly for Carp, mean hauling-net CPUE of 9.6 kg.fishing day^{-1} (± 7.6; range: 4.2–15) was 91% lower than the gillnet CPUE (116.2 kg.fishing day^{-1} ± 20.5). Golden Perch were absent from manual hauling catches, but were common in gillnet catches with a CPUE of 21 kg.fishing day^{-1} (± 2.4). Black Bream were absent from gillnet catches, but were relatively abundant in the retained hauling-net catch with a mean catch rate of 8.6 kg.fishing day^{-1} (± 3.4; range: 5.3–12).

Coorong Estuary

Eight manual hauling-net shots were completed in the Coorong Estuary over three days (Figure 4-5; Table A4). A total of 354 fish representing 11 species were caught, with Yelloweye Mullet (41.8%) and Bony Herring (26.3%) the most abundant, with moderate contributions of Black Bream (10.5%), WA Salmon (7.6%), Jumping Mullet (*Gracilimugil argentea*) (5.6%) and Mulloway (4.2%). Small quantities of Redfin Perch, Greenback Flounder, Congolli and Common Toadfish (*Tetractenos hamiltoni*) were also caught. Forty-five per cent of fish caught were discarded. The retained fish (n=194) weighed 64.5 kg, comprising Yelloweye Mullet (36.1 kg), Black Bream (17.5 kg) and Bony Herring (10.9 kg). Length frequency distributions for the dominant catch species are provided in Appendix 3 (Figure A4).

Compared to conventional small and large mesh gillnets, manual hauling-net catch rates for commercial species were negligible (Figure 4-12). Mean hauling-net CPUE for Yelloweye Mullet of 11 ± 5 kg.fishing day^{-1} (range: 6–16.5) was 92% lower than for small mesh gillnets (136.3 ± 24.3 kg.fishing day^{-1}). Legal-sized Mulloway were absent from manual hauling catches, but dominated large mesh gillnet catches with a mean gillnet CPUE of 85 ± 9.7 kg.fishing day^{-1}. For Black Bream, manual hauling CPUE of 4.4 ± 4.4 kg.fishing day^{-1} (range: 0–8.8) exceeded that of gillnet CPUE, but the species was not targeted by gillnet fishers during the trial.

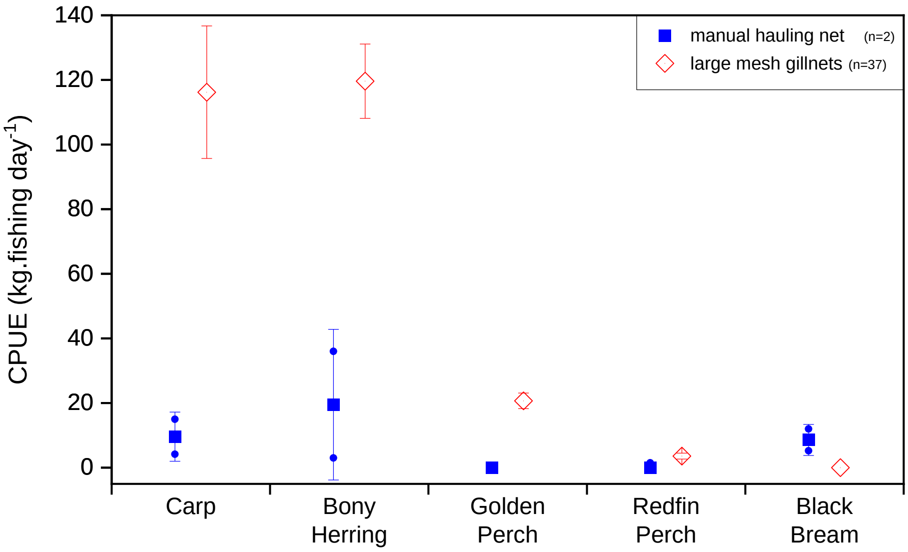


Figure 4-11. Mean retained catch rates (CPUE ± S.E) of key commercial species using the manual hauling-net and large mesh gill nets in the Lower Lakes during Trial 2 (n = number of fishing days). For each species, hauling-net CPUE for each trial day is also shown (small blue dots).

Table 4-4. Summary of the species captured using the manual hauling-net in the Lakes and Coorong Estuary (Trial 2). The table shows the common names, the numbers (*n*) of individuals caught and retained, the total weight (wt) in kg of individuals retained, and the relative contribution (%) to the total and retained catch, by number and by weight. Non-prescribed species are shown in italics. Retained catch per unit effort (CPUE in kg.fisher day^{-1}) is also shown.

	Lakes (2 shots)							Coorong Estuary (8 shots)						
Common name	Total *n*	Total %	Retained *n*	Retained %	Retained wt. (kg)	Retained wt. (%)	CPUE ($kg.fd^{-1}$)	Total *n*	Total %	Retained *n*	Retained %	Retained wt. (kg)	Retained wt. (%)	CPUE ($kg.fd^{-1}$)
Bony Herring	2,888	98.2	27	67.5	13	51.6	19.5	93	26.3	29	14.9	10.9	16.9	2.7
Yelloweye Mullet	6	0.2	–	–	–	–	–	148	41.8	143	73.7	36.1	56	11
Carp+	24	0.8	6	15	6.4	25.4	9.6	–	–	–	–	–	–	–
Redfin Perch+	14	0.5	–	–	–	–	–	3	0.8	–	–	–	–	–
WA Salmon	–	–	–	–	–	–	–	27	7.6	–	–	–	–	–
Black Bream	8	0.3	7	17.5	5.8	23	8.6	37	10.5	22	11.3	17.5	27.1	4.4
Greenback Flounder	–	–	–	–	–	–	–	6	1.7	–	–	–	–	–
Jumping Mullet	–	–	–	–	–	–	–	20	5.6	–	–	–	–	–
Mulloway	–	–	–	–	–	–	–	15	4.2	–	–	–	–	–
Congolli	1	0	–	–	–	–	–	3	0.8	–	–	–	–	–
Stingray	–	–	–	–	–	–	–	1	0.3	–	–	–	–	–
Common Toadfish	–	–	–	–	–	–	–	1	0.3	–	–	–	–	–
Total	2,941		40		25.2			354		194		64.5		

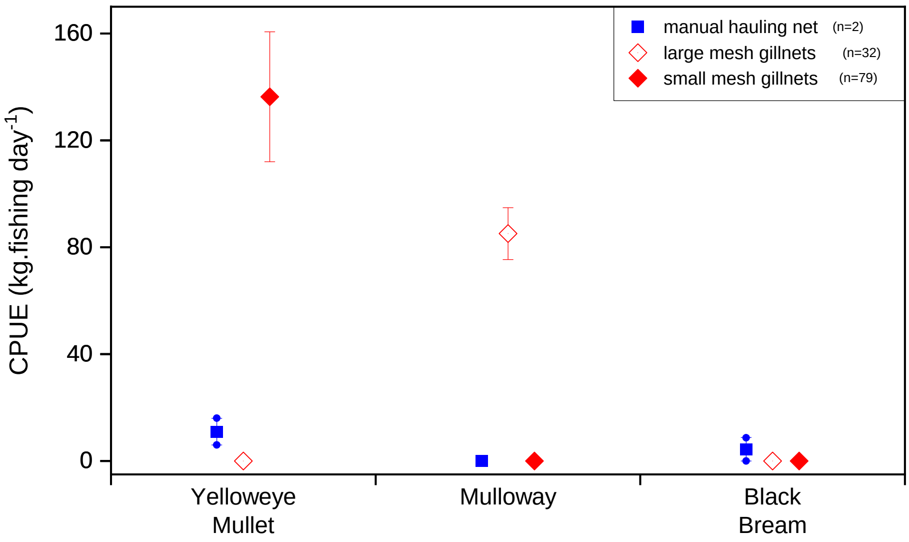


Figure 4-12. Mean retained catch rates (CPUE ± S.E) of key commercial finfish species using the manual hauling-net and large mesh gill nets in the Coorong during Trial 2 (n = number of fishing days). For each species, hauling-net CPUE for each trial day is also shown (small blue dots).

4.4 Discussion

By piloting fishing trials with commercial fishers, this study provided preliminary information on the operational effectiveness of three fyke nets and two hauling-net techniques for targeting commercially-important species in areas of the LCF. Each method was successfully executed in the Coorong Estuary and Lower Lakes, although the high turbidity, meaning schools of fish and submerged structures that might snag the net could not be sighted, created some operational impediments that limited the efficacy of the hauling-net method. The results showed substantial differences in the species composition of catches and catch rates between fyke-nets, hauling-nets and conventional gillnets. Catch rates using the three fyke nets were negligible, while those using hauling-nets were also considerably lower than those using gillnets. The findings provide a basis from which to consider whether these methods may be viable alternatives to gillnets in the LCF, as a means for reducing seal depredation.

4.4.1 Fyke nets

The first part of this study provided preliminary information on the operational effectiveness of three fyke nets in areas of the fishery. No Long-nosed Fur Seals were observed directly interacting with the fyke nets. Despite the presence of moderate abundances of LCF species in the trial areas, as confirmed by gillnet catches reported in logbooks, catches taken using all three fyke nets were negligible with no saleable fish landed.

There are a number of potential reasons for the negligible fyke net catches. The efficacy of a fyke net is largely influenced by the probability that fish will encounter its wing(s) and be guided into the chamber system (Hubert 1996). Gillnet catches taken during this study indicated that large numbers of fish were moving through the fyke net trial areas and were likely intercepted by the fyke net wing(s), and yet there is no evidence that they were effectively guided by wings into the chamber. Perhaps the fyke nets wings were too deep (2.5 m) for the depth of water in which they were set (<2 m), and so intercepted fish did not move along the "distorted" wall of mesh toward the chamber but turned away instead. Another possible reason is that intercepted fish were effectively guided into the chamber and subsequently exited. However, if fish did enter it is reasonable to assume that at least some would be retained, which was not the case. It is also possible that the fyke nets (and wings) were not appropriately positioned for the areas and conditions fished, and that with greater time and opportunity to experiment, more optimal fishing strategies could be developed. As yet, it is not possible to explain the low fyke net catches.

The results of the fyke net trials indicate that this method of fishing is unlikely to immediately prove economically viable as an alternative to gillnets for LCF fishers. However, given we could not establish the reasons why this method of fishing was ineffective in both the lakes and estuary trials, further experimentation to attempt to optimise the methods may be warranted. A first step could be to use cameras mounted above the entrance of the fyke net chamber to monitor the numbers and behaviours of fish that are guided to and through the entrance, as well as any that exit. Such information may help direct efforts to optimise trap design (e.g. mesh size, tension on the mesh, the length and depth of the wings; diameter of the entrance to the chamber).

4.4.2 Hauling-nets

The second part of this study involved field trials led by LCF fishers, which provided preliminary information on the operational effectiveness of manual and mechanical hauling-nets in traditionally productive fishing areas of the fishery. While the trials demonstrated that hauling can be executed effectively in areas of the LCF, they also revealed some technical impediments that complicated the execution of both hauling techniques. The impediments related to the turbid conditions on the fishing ground, which are characteristic of the Lakes and Coorong system (Ye et al. 2017). The high turbidity meant that it was impossible for fishers to identify fishing areas that were clear of hard bottom structures, particularly in water depths >1 m. Consequently, around 70% of the hauling-net shots attempted in the Coorong Estuary were temporarily stalled due to the net snagging. On most occasions, the snagging was caused by tubeworm reefs, which are widespread in the estuary (Dittmann et al. 2009) and often invisible to fishers. Each time the net snagged, it was released by the observer vessel – a level of technical support that is not usually available during conventional fishing operations – and the shot was completed. Without the second vessel, the "snagged" shots would have been aborted, and the time (and money) spent travelling to the fishing ground, and deploying and retrieving the gear, would have been lost. While snagging was less of an issue in the Lower Lakes, it still impacted 20% of the attempted shots. The inability of fishers to locate and avoid submerged snags in these areas casts considerable doubt over the viability of this method as a potential alternative to gillnets in the LCF.

Another consequence of the turbid conditions was that fishers were unable to visually locate aggregations of fish prior to deploying the hauling gear. This meant that each shot was undertaken over an area that was likely to contain fish, rather than where fish were known to be. The ability of fishers to locate and encircle target species is fundamental to the efficacy of this method. In the clearer marine waters of South Australia's upper gulfs, MSF fishers are often able to sight and encircle schools of target species, which substantially increases the likelihood of a commercially-viable catch (D. Wilks, personal communication). Occasionally in the Coorong Estuary, schools of Yelloweye Mullet can be seen near the surface. At such times, small beach seines are sometimes used by LCF fishers to target surface schools that are located close to a shoreline (Earl and Ferguson 2013). The ability of the Lakes and Coorong fishers to use hauling-nets from vessels would increase the size of the area over which surface schools could be targeted. Nevertheless, without the ability to locate fish on a regular basis in areas that are suitable for hauling, consistent harvesting of viable quantities of target species using this method is likely to be difficult.

Hauling-net catch rates were considerably lower than those using conventional gillnets during the trials. This result was expected given the aforementioned technical issues, and the fact that it was the first time that hauling from vessels had been tried in these areas. Nonetheless, the mechanical hauling-net occasionally produced moderate quantities of Carp and Bony Herring in the Lower Lakes, and small quantities of Yelloweye Mullet and Black Bream in the Coorong Estuary, thus demonstrating the capacity of this method for catching LCF species. While there was insufficient data to statistically compare the efficacy of the two hauling methods, mechanical hauling generally produced higher catch rates than manual hauling. This result presumably reflects the larger net used during the mechanical hauling trial rather than differences in catching efficiency.

River Garfish was an unexpected bycatch during the trials. This species is not a prescribed species for the LCF and rarely appears in gillnet catches due to its slender body being narrower than the smallest gillnet mesh currently permitted in the fishery (PIRSA 2016). The pockets of the hauling-nets used in this study were made of 32 mm stretched mesh and are designed for targeting Southern Garfish (*Hypohamphus melanochir*) in the MSF. If River Garfish was a prescribed species, it would have been the most abundant species in the retained mechanical hauling-net catch from the estuary. Given the high market value of Southern Garfish compared to some LCF species (EconSearch 2019b), adding River Garfish to the prescribed species list for the LCF (if hauling is implemented in the fishery) should be considered.

Long-nosed Fur Seals did not interact with the hauling-net operations undertaken in this study. This was expected given it was likely to have been the first time the seals in the region had seen hauling operations. Over time and with repeated use of hauling-nets, seals may learn how to catch fish caught in the pocket. Nevertheless, a key advantage of hauling over gillnetting is that fishers are always in attendance of their gear and so crackers or another deterrent tactic could be used to try and ward off approaching seals. An alternative approach to prevent seal depredation of hauling-net catches could be to physically protect fish caught in the pocket by installing an external seal-proof sock around the pocket of the net using Dyneema® mesh which is four times stronger than nylon mesh. A lightweight seal exclusion device could also be installed near the entrance of the pocket to prevent seals entering the pocket.

The catch dynamics of the tested mechanical and manual hauling-nets suggest that an immediate economic benefit is unlikely to accrue for LCF gillnet fishers who transition to hauling-nets, as a result of the investment required to purchase new nets and the difficulties associated with landing viable quantities of target species. However, manual hauling from vessels may be worthwhile when fishers can sight aggregations/schools of target species over areas suitable for hauling (i.e. that are clear of submerged snags), although it is difficult to predict how often such opportunities may arise. Acknowledging this, the next phase of this work could be to determine the most appropriate hauling-net mesh sizes for targeting LCF species to minimise bycatch of unwanted sizes of commercial species. Other areas of research that may warrant investigation (if hauling is implemented in the fishery) include mapping of areas suitable for hauling, or designing bobbins or some other means for the bottom of the net to bounce over potential snags; and the potential utility of remote sensing technologies for locating aggregations/schools of target species in areas of the fishery.

4.4.3 Summary

This study has contributed important information on the operational effectiveness of three fyke nets and two hauling-net methods for targeting key fishery species in areas of the LCF. While each of the test methods was effectively executed in areas of the fishery, the catch dynamics associated with each method suggest that their use as alternatives to existing gillnets is unlikely to be immediately economically viable for LCF licence holders. Ideally, any costs associated with using a new fishing method, as well as any losses in catches incurred by fishing less efficiently (i.e. by not using the preferred gillnet methods), should be less than the current (and future) costs being incurred due to seal depredation.

5. Conclusions

The objectives of this project were achieved as indicated by the key results and outcomes below.

Objective 1*: Review global seal-fisher interactions, and mitigation and management options relevant to the LCF*.

This objective was addressed by reviewing relevant peer-reviewed scientific literature to better understand the nature and extent of seal-fisher interactions globally and identify practical mitigation options relevant to the LCF that could be investigated in this project (Chapter 2).

- Interactions between seals and small-scale fisheries occur globally and often involve seals depredating fish caught in fishing gear, which can result in catch losses and gear damage.
- To reduce seal impacts, fishers typically first adjust their fishing practices (e.g. reduce soak times of fishing gear) and/or use deterrents to try to scare seals away from their fishing operations. Deterrents often provide short-term/temporary relief.
- Seal crackers are among the most commonly used deterrents by small-scale fisheries because they are inexpensive compared to other deterrents and easy to deploy.
- In some fisheries, seal depredation has been successfully mitigated by modifying existing fishing gear to protect caught fish. This approach has proven difficult for gillnet fisheries, which have generally had to modify techniques or transition to alternative fishing methods. In some European fisheries, gillnets have been replaced by seal-proof fyke nets.
- Switching to more active fishing methods (equipment moves or is towed) may also help reduce seal depredation in static fisheries (equipment left still to catch moving target species). Haul-netting is one such method that is used in small-scale fisheries globally, including in South Australia.
- Based on the review findings and consultation with industry, seal crackers were identified as a potential mitigation method for short-term and targeted reduction of seal depredation in the LCF. Two fishing methods were identified as potential alternate fishing methods to further mitigate seal impacts in the LCF. These were fyke and hauling-nets.

Objective 2*: Assess operational changes to current practices, including the use of seal deterrent methods to reduce the rates of seal depredation on caught fish and damage to gear*.

This objective was addressed by undertaking field trials with commercial fishers to obtain quantitative information on the effectiveness of seal crackers for reducing the impacts of Long-nosed Fur Seals on LCF gillnet fishers. An overview of the key results and outcomes of the deterrent trials, and management implications is provided in the Discussion section of Chapter 3.

- The use of crackers elicited a positive behavioural response of varying degrees in targeted Long-nosed Fur Seals around 85% of the time.
- Crackers were most effective when used on seals that were approaching gillnets. In such situations, the detonation of a cracker usually resulted in the seal diving and re-surfacing >50 m away.

- Crackers elicited a similar response, although less often, when used on seals that were patrolling a gillnet, presumably searching for caught fish.
- Crackers failed to elicit a detectable response on seals that were feeding on fish caught in gillnets.
- Results indicate that crackers can be highly effective in some situations and their effectiveness appears to be influenced, at least in part, by the motivation of the targeted seal.
- Although crackers did not reduce depredation rates, they did reduce the damage to fishing gear. Gillnet damage rate was 55% lower for the vessel that used crackers than for the control.
- There was limited evidence that crackers affected the behaviour of targeted Mulloway around gillnets, although further research is required.
- While the deterrent effect of crackers on Long-nosed Fur Seals is expected to reduce over time if used repeatedly on the same animals, our results suggest that if used judiciously, they may help reduce seal-fisher conflicts in the LCF at least in the short-term.

Objective 3*: Develop and trial alternative fishing methods based on best practice that are less vulnerable to seal depredation of catches and gear damage, and may provide practicable alternatives to current practices*.

This objective was addressed by piloting fishing trials with commercial fishers to obtain preliminary information on the operational effectiveness of three fyke nets (small double-wing fyke net; large double-wing fyke net; and single-wing fyke net) and two hauling techniques (manual and mechanical) for targeting commercial species in areas of the LCF. An overview of the key results and outcomes of the gear trials, and implications for the fishery is provided in the Discussion section of Chapter 4.

- Each fyke net was ably deployed using existing LCF vessels. Catches using each fyke net were negligible, with no saleable fish landed. Results suggest that the fyke net method is unlikely to be immediately economically viable as an alternative to gillnets for LCF fishers.
- Because elsewhere fyke nets do successfully catch fish and exclude seals, further testing to adapt the method to local conditions may prove useful. However, due to the extreme low success of the present trials, it could be expected that local fishers would be reluctant to persist with such trials.
- The turbid conditions created some technical impediments that limited the efficacy of hauling-net techniques. Fishers found it difficult to identify areas suitable for hauling (i.e. that were clear of submerged snags) and were also unable to sight fish prior to deploying the hauling gear.
- Both hauling techniques produced considerably lower catch rates than conventional gillnets.
- Results suggest that an immediate economic benefit is unlikely to accrue for LCF fishers who transition to hauling, as a result of the investment required to buy new gear and the difficulty in consistently harvesting viable quantities of fish. Nevertheless, manual hauling-nets may be a viable alternative to gillnets at times when schools of target species can be located in suitable areas.

Successful methods for reducing seal-fisher conflict need to be cost effective, where the benefits from mitigation initiatives outweigh their costs. To properly assess the potential benefits of using seal crackers, alternate fishing gear and other mitigation options in reducing the impacts of seal depredation on the LCF, an objective assessment of the economic impacts that seal depredation is currently having on fishers is needed. This is the focus of a new FRDC project (2018-036), currently underway.

6. Implications and Recommendations

Developments made during this project have already been adopted as part of the South Australian Government's integrated approach to managing the impacts of Long-nosed Fur Seals on the LCF. Fishers are now permitted to use crackers in any area of the fishery, subject to a range of permit conditions, training requirements and attainment of appropriate police clearances. Permit conditions require fishers to submit data returns to monitor usage and effectiveness of crackers, which will enable assessment of the short- and long-term benefits of crackers to industry.

Preliminary information on the operational efficacy of fyke nets and hauling-nets in areas of the LCF has been conveyed to the LNFSWG and PIRSA Fisheries and Aquaculture. While cost-benefit evaluations of these methods in areas of the LCF have not been undertaken, there was consensus among stakeholders that the results of this project have demonstrated that further investment in developing fyke nets and hauling-nets as alternate fishing methods is unwarranted, and that other potential solutions to seal depredation need to be explored.

It is recommended that this report be disseminated to LCF licence holders, the DEW, PIRSA Fisheries and Aquaculture, national and international fisheries scientists, and the general public. The results are also likely to be of interest to other fisheries, and aquaculture industries being impacted by seals.

Based on the conclusions of this project, it is recommended that:

- Seal crackers continue to be made available to fishers and instructions provided on how their careful use may improve catches and reduce net damage (and their over-use may habituate seals).
- Uptake of crackers by fishers be monitored. Attention should be paid to situations when crackers are used and opinions of the fishers on their efficacy.
- Alternative adaptations to fishing practices that reduce seal interactions be investigated and documented – such as changes to soak times, fishing times, net haul times, seasonal adaptations.
- Consideration be given to adding River Garfish to the prescribed species list if hauling is implemented in the fishery.

6.1 Further development

Reports from industry suggest that the seal-fisher conflict and associated economic impacts on LCF gillnet fishers continued during this study. While previous temporary initiatives by the South Australian Government (e.g. the waiving of net licence fees; more flexible management arrangements) to alleviate the financial strain on fishers caused by seals have been welcomed by industry, it is not clear whether the current level of support for fishers is adequate, or how to evaluate the costs and benefits of alternative mitigation options or management interventions in the absence of reliable information on the economic impacts seals are having on the industry. Goldsworthy et al. (2019) reported that there is also growing industry and community concern about the potential impact that Long-nosed Fur Seals are having on the broader Lakes and Coorong ecosystem (native fish populations, waterbirds), with some sectors advocating for seal numbers to be managed to mitigate these perceived impacts.

There is a need for reliable, quantitative information on the nature and extent of the economic and ecological impacts of Long-nosed Fur Seals in the Lakes and Coorong region. Such information is needed to support processes undertaken by the LNFSWG to identify, prioritise and develop practical and cost-effective long-term policy and management strategies to manage the impacts of Long-nosed Fur Seals in the region. To address these needs, FRDC project 2018-036 'Seal-fisher-ecosystem interactions in the Lower Lakes and Coorong: understanding causes and impacts to develop longer-term solutions' commenced in June 2019 and is due to be completed in 2022.

The objectives of FRDC project 2018-036 are to:

(1) Assess the direct economic impact of seal interactions on Lakes and Coorong gillnet fishers;

(2) Assess the ecological impacts of seals on the Lower Lakes and Coorong ecosystem;

(3) Assess the spatial and temporal use of the Lower Lakes and Coorong region by seals to identify key haul-outs, movement corridors, foraging areas and overlap with fishing effort; and

(4) Identify options to manage seal numbers and evaluate their costs and benefits to mitigate their impacts.

7. Extension and Adoption

This study has been a standing agenda item at meetings of the LNFSWG. Project updates were provided to the LNFSWG by Prof. Simon Goldsworthy (Senior Research Scientist, SARDI; co-investigator). Dr Jason Earl (Principle Investigator) presented preliminary findings of the seal deterrent (on 14 July 2016) and gear trials (on 19 July 2017) to the LNFSWG as soon as they became available. Project updates were disseminated to the general public through communiqués of the LNFSWG (https://www.environment.sa.gov.au/topics/plants-and-animals/Living_with_wildlife/seals). Progress reports were also provided at quarterly meetings of the Lakes and Coorong Consultative Committee (LCCC), which includes representatives from the SFA, PIRSA Fisheries and Aquaculture, Natural Resources South Australian Murray-Darling Basin and SARDI Aquatic Sciences. Meetings of the LNFSWG and LCCC will continue to be the primary fora for extending the results of this study and identifying potential strategies to reduce seal impacts on the LCF.

A presentation titled "*Assessing the effectiveness of underwater crackers for reducing seal impacts in South Australia's Lakes and Coorong Fishery*" was provided to marine and fisheries scientists from Australia and overseas at the 55th Annual Conference of the Australian Marine Sciences Association, in Adelaide during 1–5 July 2018.

The final report will be provided to DEW, PIRSA Fisheries and Aquaculture, licence holders of the LCF through the SFA, and members of the LNFSWG and LCCC to inform development of strategies to manage seal-fisher conflict in the LCF.

7.1 Project coverage

Relevant media and government articles during the course of the study:

- 22 July 2015: ABC Online: http://www.abc.net.au/news/2015-07-22/seal-scarer-explosives-considered-to-address-coorong-animals/6638346
- 3 October 2015: ABC Online: http://www.abc.net.au/news/2015-10-03/no-protections-for-fur-seals-mp-says/6825246
- 9 March 2016: ABC Online: http://www.abc.net.au/news/2016-03-09/firecrackers-used-to-scare-seals-away-from-coorong-fishers/7233066
- 10 March 2016: The Australian: https://www.theaustralian.com.au/national-affairs/state-politics/scheme-to-scare-away-coorong-seals-is-just-crackers-say-fishers/news-story/ece043a54d45d65248366717ba7dfaf3
- 7 June 2016: ABC Online: http://www.abc.net.au/news/2016-06-07/trials-protect-coorong-fishing-area-from-fur-seals-not-working/7483458?section=sa
- 23 August 2017: ABC Online: http://www.abc.net.au/news/2016-08-23/underwater-fire-crackers-tackle-river-murray-seals/7777750?section=sa

8. Appendices

8.1 Appendix 1. Project staff

Authors

- Dr Jason Earl (SARDI)
- Dr Alice Mackay (SARDI)
- Prof. Simon Goldsworthy (SARDI)

Project staff

- Neil MacDonald (Southern Fishermen's Association)
- Prof. Steve Kennelly (IC Independent Consulting)
- Renate Velzeboer (DEW)
- Mike Greig (DEW)
- Dr Belinda McGrath-Steer (PIRSA)
- Dr Michael Drew (SARDI)
- Dr Matthew Heard (SARDI)
- Mike Greenwood (DPIPWE)
- Justin Febey (DPIPWE)
- David Wilks – commercial hauling-net fisher (MSF)

Industry members that participated in field activities

- Garry Hera-Singh
- Zane Skryprek
- Roderick 'Dingles' Dennis
- Perry Robinson
- Glen Hill
- Nathan Mammone
- Scott Alexander
- Trevor Lucieer
- Duncan Lucieer
- Christine Jackson

8.2 Appendix 2. Intellectual Property

No intellectual property identified. This report and resulting manuscripts are intended for wide dissemination and promotion.

8.3 Appendix 3. Supplementary information

Table A1. Generalised linear mixed model results and model factors for the best three models. No significant difference between models (∆AIC < 2). Therefore, most parsimonious model used (No.1).

Gillnet damage per unit effort (DPUE, new holes.net.hr^{-1})			
No.	Model	AIC	∆AIC
1	Damage ~ Trial + offset(log(Soak_time)) + (1 | Night_ID)	712.09	0
2	Damage ~ Trial + offset(log(Soak_time)) + (1 | FisherID)	713.49	1.4
3	Damage ~ Trial + offset(log(Soak_time)) + (1 | Night_ID/ FisherID)	714.06	0.57

Table A2. Generalised linear mixed model results and model factors for the best three models for Mulloway catch per unit effort. Interaction term is the best fitting model (∆AIC > 2).

Mulloway catch per unit effort (CPUE, fish.net.hr^{-1})			
No.	Model	AIC	∆AIC
1	MullowayCPUE ~ Trial + offset(log(Soak_time)) + (1 | Night_ID/ FisherID)	678.03	0
2	MullowayCPUE ~ Trial + offset(log(Soak_time)) + (1 | FisherID)	708.88	30.85
3	MullowayCPUE ~ Trial + offset(log(Soak_time)) + (1 | Night_ID)	748.14	39.26

Table A3. Details of fyke net trials, including dates, GPS coordinates (GDA94) and soak time for each net set.

Fyke net configuration	Trial	Trial night	Date	Latitude	Longitude	Soak time (hrs)
Small double-wing	1	1	13/01/16	-35.6131	139.0419	16
	1	2	14/01/16	-35.6131	139.0419	23
	1	3	15/01/16	-35.6076	139.0333	24
	1	4	01/02/16	-35.7366	139.2185	17
	1	5	02/02/16	-35.7442	139.2351	22
Small single-wing	2	1	03/02/16	-35.5942	139.0204	25
	2	2	04/02/16	-35.5942	139.0204	24
	2	3	16/02/16	-35.6143	139.0559	15
	2	4	17/02/16	-35.6143	139.0559	23
	2	5	18/02/16	-35.6143	139.0559	22
	2	6	28/03/17	-35.5284	138.8109	15
	2	7	29/03/17	-35.5284	138.8109	23
Large double-wing	3	1	21/06/17	-35.4933	139.0799	16
	3	2	22/06/17	-35.4933	139.0799	23
	3	3	23/06/17	-35.4933	139.0799	24
	3	4	24/06/17	-35.4984	139.0645	24
	3	5	25/06/17	-35.4984	139.0645	24
	3	6	26/06/17	-35.4984	139.0645	24
	3	7	27/06/17	-35.4579	138.4579	21
	3	8	28/06/17	-35.4579	138.4579	24
	3	9	29/06/17	-35.4579	138.4579	24
	3	10	30/06/17	-35.4579	138.4579	24
	3	11	01/07/17	-35.4579	138.4579	24
	3	12	02/07/17	-35.4579	138.4579	22

Table A4. Details of hauling-net trials, including dates, time each shot commenced, GPS coordinates (GDA94) and duration of each net shot. (*) hauling-net became snagged and was released by the observer vessel.

Hauling method	Habitat	Trial	Shot no.	Date	Time (hrs)	Latitude	Longitude	Shot duration (min)
Power	Lakes	1	1	11/10/16	0745	-35.685908	139.309234	90
		1	2	11/10/16	0925	-35.689175	139.233192	74
		1	3	11/10/16	1115	-35.677424	139.236932	65
		1	4	11/10/16	1340	-35.689567	139.318602	79
		1	5*	7/11/16	1040	-35.443427	139.000386	98
		1	6	7/11/16	1240	-35.450889	138.985000	60
		1	7	7/11/16	1405	-35.500635	139.079984	66
		1	8	8/11/16	0750	-35.530638	138.991389	69
		1	9	8/11/16	0917	-35.535036	139.010161	70
		1	10	8/11/16	1044	-35.563946	139.061045	49
	Estuary	1	1*	12/10/16	0819	-35.706080	139.185472	53
		1	2*	12/10/16	0935	-35.675863	139.143666	70
		1	3	12/10/16	1105	-25.713327	139.193656	45
		1	4*	12/10/16	1236	-35.713361	139.193944	44
		1	5	13/10/16	0815	-35.795830	139.301574	45
		1	6*	13/10/16	0915	-35.802026	139.289989	39
		1	7	13/10/16	1040	-35.662981	139.108754	35
		1	8*	7/11/16	0715	-35.534252	139.844116	105
		1	9*	9/11/16	0909	-35.606226	139.027487	53
Manual	Lakes	2	1	28/03/17	0701	-35.521264	138.806079	47
		2	2*	29/03/17	0821	-35.522450	138.807373	71
	Estuary	2	1*	9/11/16	2215	-35.840107	139.346545	58
		2	2*	9/11/16	2305	-35.843237	139.342000	54
		2	3*	28/03/17	0722	-35.548901	138.868183	50
		2	4*	28/03/17	0819	-35.547361	138.871022	59
		2	5	28/03/17	1001	-35.523504	138.816075	50
		2	6*	28/03/17	1115	-35.527477	138.813239	62
		2	7*	28/03/17	2105	-35.529012	138.820805	54
		2	8	28/03/17	2210	-35.547361	138.871022	50

Figure A1. Length frequency distributions for the three dominant finfish species in the catch taken using the mechanical hauling-net in the Lakes during Trial 1. No legal minimum lengths currently apply to these species. Green lines indicate the approximate saleable minimum length for each species.

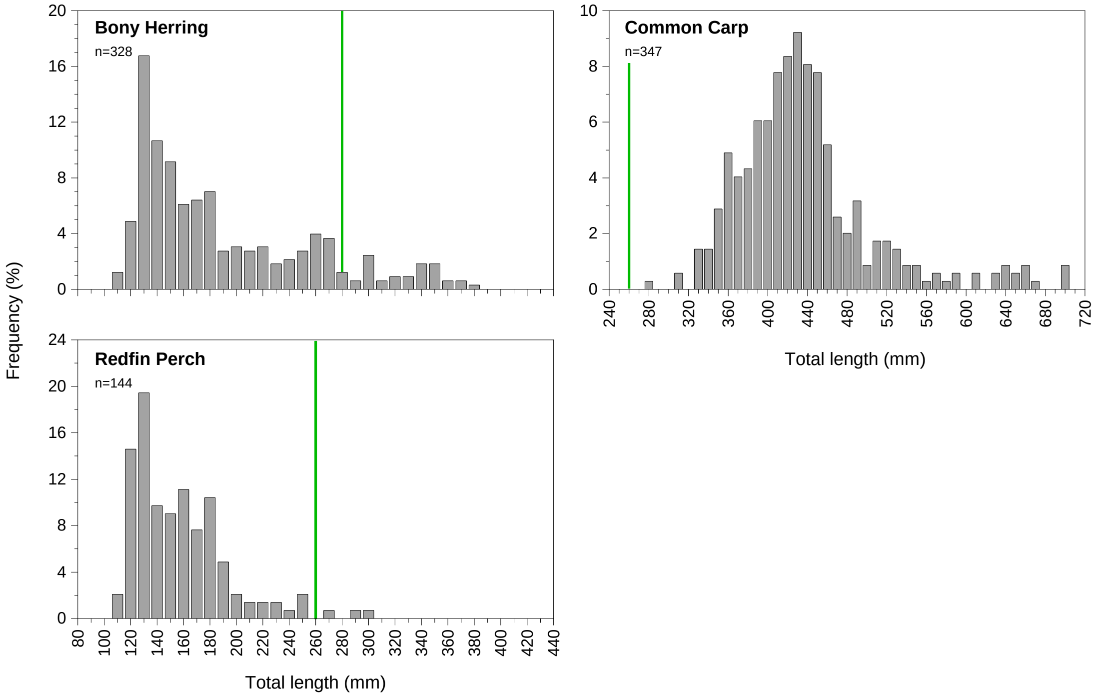


Figure A2. Length frequency distributions for the four dominant finfish species in the catch taken using the mechanical hauling-net in the Coorong Estuary during Trial 1. Where applicable, red lines indicate legal minimum length. For species not currently subject to a legal minimum length, green lines indicates the approximate saleable minimum length. River Garfish (non-prescribed species) were measured from the tip of the upper jaw to the tip of the tail.

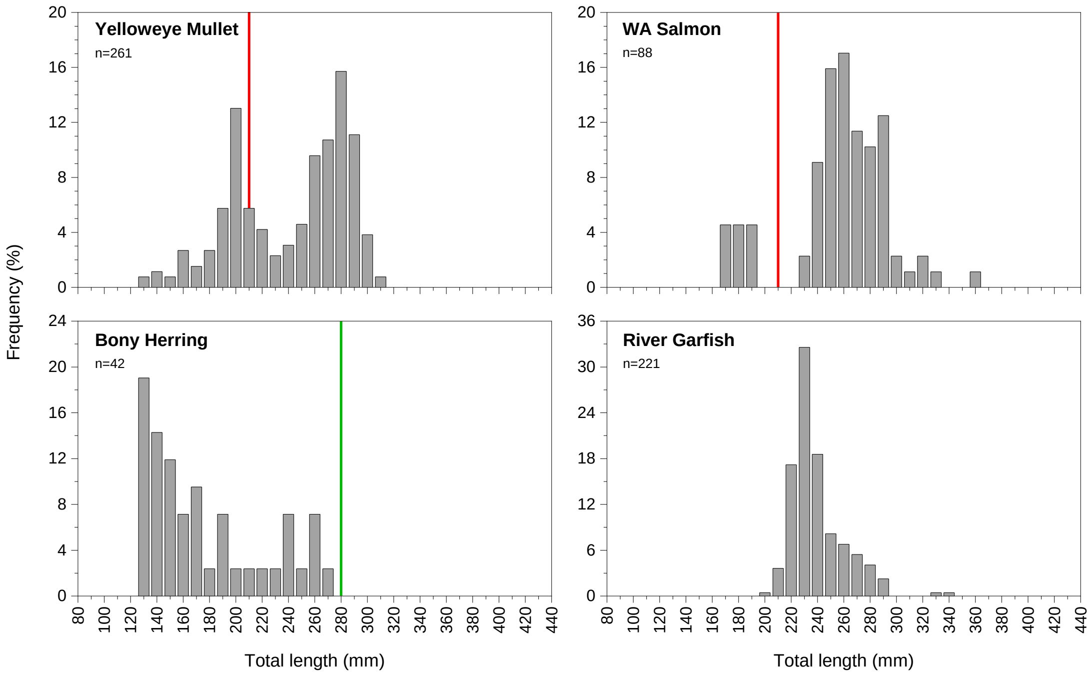


Figure A3. Length frequency distributions for the dominant finfish species in the catch taken using the manual hauling-net in the Lakes during Trial 2. Where applicable, red lines indicate legal minimum length. For species not currently subject to a legal minimum length, green line indicates the approximate saleable minimum length.

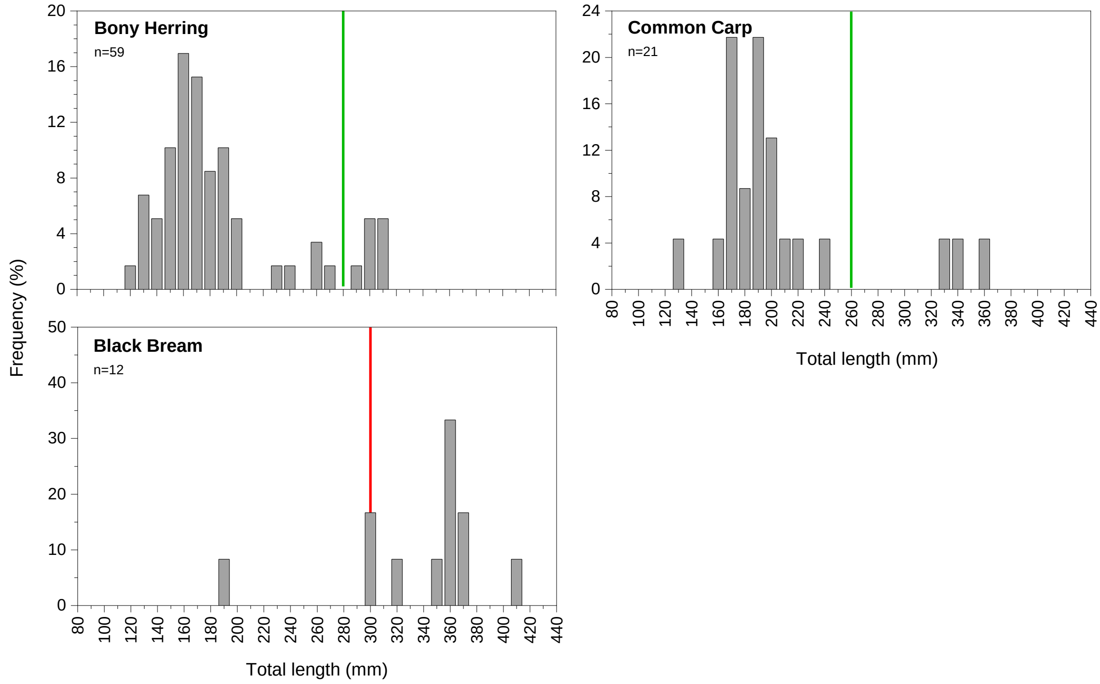
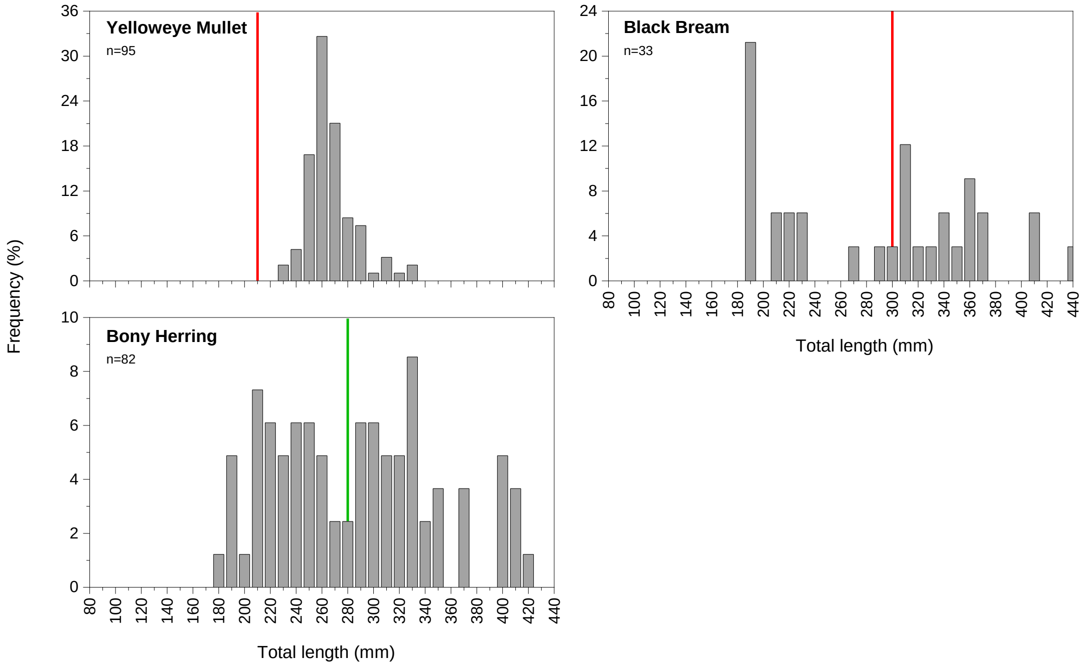


Figure A4. Length frequency distributions for the dominant finfish species in the catch taken using the manual hauling-net in the Coorong Estuary during Trial 2. Where applicable, red lines indicate legal minimum length. For species not currently subject to a legal minimum length, green line indicates the approximate saleable minimum length.



8.4 Appendix 4. References

Barlow, J. and Cameron, G. A. (2003) Field experiments show that acoustic pingers reduce marine mammal bycatch in the California drift gill net fishery. *Marine Mammal Science* **19**(2), 265-283.

Brooks, M. E., Kristensen, K., van Benthem, K. J., Magnusson, A., Berg, C. W., Nielsen, A., Skaug, H. J., Maechler, M. and Bolker, B. M. (2017) Modeling Zero-Inflated Count Data With glmmTMB. *bioRxiv*.

Brown, R., Jeffries, S., Hatch, D., Wright, B. and Jonker, S. (2011) Field Report: 2011 pinniped research and management activities at and below Bonneville Dam. *Oregon Department of Fish and Wildlife* **7118**.

Butler, J. R., Middlemas, S., Graham, I. M., Thompson, P. M. and Armstrong, J. (2006) Modelling the impacts of removing seal predation from Atlantic Salmon, *Salmo salar*, rivers in Scotland: a tool for targeting conflict resolution. *Fisheries Management and Ecology* **13**(5), 285-291.

Carleton, R. G., McCormick-Ray, J. and Smith, R. L. (2013) 'Marine Conservation Science, Policy and Management.' (Wiley: Hoboken, United States)

Cosgrove, R., Gosch, M., Reid, D., Sheridan, M., Chopin, N., Jessopp, M. and Cronin, M. (2015) Seal depredation in bottom-set gillnet and entangling net fisheries in Irish waters. *Fisheries Research* **172**, 335-344.

Cronin, M., Gerritsen, H., Reid, D. and Jessopp, M. (2016) Spatial overlap of grey seals and fisheries in Irish waters, some new insights using telemetry technology and VMS. *PLoS ONE* **11**(9).

Culik, B. M., Koschinski, S., Tregenza, N. and Ellis, G. M. (2001) Reactions of harbor porpoises *Phocoena phocoena* and herring *Clupea harengus* to acoustic alarms. *Marine Ecology Progress Series* **211**, 255-260.

Dawson , S., Northridge , S. P., Waples , D. and Read , A. (2013) To ping or not to ping: the use of active acoustic devices in mitigating interactions between small cetaceans and gillnet fisheries. *Endangered Species Research* **19**(3), 201-221.

Deecke, V. B., Slater, P. J. and Ford, J. K. (2002) Selective habituation shapes acoustic predator recognition in harbour seals. *Nature* **420**(6912), 171.

De María M., Barboza, F. R., Szteren, D. (2014) Predation of South American sea lions (*Otaria flavescens*) on artisanal fisheries in the Rio de la Plata estuary. Fisheries Research **149**, 69-73.

Dittmann, S., Baring, R., Baggalley, S., Cantin, A., Earl, J., Gannon, R., Keuning, J., Mayo, A., Navong, N., Nelson, M., Noble, W. and Ramsdale, T. (2015) Drought and flood effects on macrobenthic communities in the estuary of Australia's largest river system. *Estuarine, Coastal and Shelf Science* **165**, 36-51.

Dittmann, S., Rolston, A., Benger, S. N. and Kupriyanova, E. K. (2009) Habitat requirements, distribution and colonisation of the tubeworm *Ficopomatus enigmaticus* in the Lower Lakes and Coorong. Report for the South Australian Murray-Darling Basin Natural Resources Management Board, Adelaide.

DPIPWE (2012) Combined Protocols for the Mitigation of Seal Interactions with Aquaculture staff and Infrastructure. Department of Primary Industries, Water and Environment (DPIPIWE), Tasmanian Government. Accessed at https://stors.tas.gov.au/store/exlibris3/storage/2014/07/30/file_1/1263531.pdf on 12 September 2017.

Earl, J. (2020) Assessment of the South Australian Lakes and Coorong Fishery in 2018/19. Report to PIRSA Fisheries and Aquaculture. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2020/000208-01. SARDI Research Report Series No. 1059. 81pp.

Earl, J. and Ferguson, G. (2013) Yelloweye Mullet (*Aldrichetta forsteri*) Stock Assessment Report 2011/12. Report to PIRSA Fisheries and Aquaculture. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2007/001048-1. SARDI Research Report Series No. 737. 54pp.

EconSearch (2019a) Economic and social indicators for the South Australian Lakes and Coorong Fishery 2017/18. A report to PIRSA Fisheries and Aquaculture, prepared by BDO EconSearch, Adelaide. 91pp.

EconSearch (2019b) Economic and social indicators for the South Australian Marine Scalefish Fishery 2017/18. A report to PIRSA Fisheries and Aquaculture, prepared by BDO EconSearch, Adelaide. 75pp.

Eyo, J. and Akpati, C. (1995) Fishing gears and fishing methods. Proceedings of the UNDP assisted Agriculture and rural development programme (Ministry of Agriculture Awka, Anambra State). Training course on Artisanal Fisheries development, held at University of Nigeria Nsukka, 143-167.

Ferguson, G. J., Earl, J. and Ye, Q. (2018) The History of Fisheries in the Lower Lakes and Coorong. In Natural History of the Coorong, Lower Lakes, and Murray Mouth Region (Yarluwar-Ruwe). (Eds. L. Mosley, Q. Ye, S. A. Shepherd, S. Hemming and R. Fitzpatrick) pp. 452-476. (University of Adelaide Press: Adelaide, South Australia).

Ferguson, G. J., Ward, T. M., Ye, Q., Geddes, M. C. and Gillanders, B. M. (2013) Impacts of Drought, Flow Regime, and Fishing on the Fish Assemblage in Southern Australia's Largest Temperate Estuary. *Estuaries and Coasts* **36**(4), 737-753.

Fjälling, A. (2005) The estimation of hidden seal-inflicted losses in the Baltic Sea set-trap Salmon fisheries. *ICES Journal of Marine Science* **62**(8), 1630-1635.

Fjälling, A., Wahlberg, M. and Westerberg, H. (2006) Acoustic harassment devices reduce seal interaction in the Baltic Salmon-trap net fishery. *ICES Journal of Marine Science* **63**(9), 1751-1758.

Fraker, M. A. (1994) A description and assessment of the interaction between California sea lions and steelhead trout at the Chittendon Locks, Seattle, Washington. Draft report to the U.S. Marine Mammal Commission.

Gearin, P., Pfeifer, R., Jeffries, S. J., DeLong , R. L. and Johnson, M. A. (1988) Results of the 1986-87 California sea lion - Steelhead Trout predation control program at the Hiram M. Chittenden Locks, Northwest and Alaska Fisheries Centre, Natl. Mar. Fish. Serv. NWAFC Processed Report. 111pp.

Geiger, A. and Jeffries, S. (1986) Evaluation of seal harassment techniques to protect gillnetted Salmon. Report to Washington Department of Fish and Wildlife. Contract 83-ABC-00133. 27pp.

Goldsworthy, S. D., Bailleul, F., Nursey-Bray, M., Mackay, A., Oxley, A., Reinhold, S.-L. and Shaughnessy, P. D. (2019) Assessment of the impacts of seal populations on the seafood industry in South Australia. Final report for FRDC Project 2013-011. South Australian Research and Development Institute, Aquatic Sciences. Adealide. pp334.

Goldsworthy, S. D. and Boyle, M. (2019) Operational interactions with Threatened, Endangered or Protected Species in South Australian Managed Fisheries: 2017/18. Report to PIRSA Fisheries and Aquaculture. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2009/000544-9. SARDI Research Report Series No. 1032. 39pp.

Götz, T. and Janik, V. M. (2010) Aversiveness of sounds in phocid seals: psycho-physiological factors, learning processes and motivation. *The Journal of Experimental Biology* **213**(9), 1536-1548.

Götz, T. and Janik, V. M. (2013) Acoustic deterrent devices to prevent pinniped depredation: efficiency, conservation concerns and possible solutions. *Marine Ecology Progress Series* **492**, 285-302.

Hamer, D. J. and Goldsworthy, S. D. (2006) Seal-fishery operational interactions: Identifying the environmental and operational aspects of a trawl fishery that contribute to by-catch and mortality of Australian fur seals (*Arctocephalus pusillus doriferus*). *Biological Conservation* **130**(4), 517-529.

Harris, R. N., Harris, C. M., Duck, C. D. and Boyd, I. L. (2014) The effectiveness of a seal scarer at a wild Salmon net fishery. *ICES Journal of Marine Science* **71**(7), 1913-1920.

Hemmingsson, M., Fjälling, A. and Lunneryd, S.-G. (2008) The pontoon trap: Description and function of a seal-safe trap-net. *Fisheries Research* **93**(3), 357-359.

Hemmingsson, M. and Lunneryd, S. G. (2007) Pushup traps in Sweden - introduction of a new seal-proof fishing gear. Finfo Informer **8** (in Swedish with English summary).

Hubert, W. A. (1996) 'Passive capture techniques. In Murphy, B.R.; Willis, D.W. (Eds): Fisheries techniques. 2nd edition. American Fisheries Society, Bethesda, Maryland.'

Jefferson, T. A. and Curry, B. E. (1996) Acoustic methods of reducing or eliminating marine mammal-fishery interactions: do they work? *Ocean & Coastal Management* **31**(1), 41-70.

Kauppinen, T., Siira, A. and Suuronen, P. (2005) Temporal and regional patterns in seal-induced catch and gear damage in the coastal trap-net fishery in the northern Baltic Sea: effect of netting material on damage. *Fisheries Research* **73**(1), 99-109.

Kemper, C. M., Pemberton, D., Cawthorn, M., Heinrich, S., Mann, J., Wursig, B., Shaughnessy, P. and Gales, R. (2003) Aquaculture and marine mammals: co-existence or conflict. *Marine mammals: fisheries, tourism and management issues*, 208-225.

Kennelly, S. J. (2015) Initial consultancy regarding seal depredation in the South Australian Lakes and Coorong Fishery. IC Independent Consulting. 18pp.

Kirkwood, R. and Goldsworthy, S. (2013) 'Fur seals and sea lions.' (CSIRO Publishing: Collingwood, Victoria).

Kirkwood, R., Pemberton, D., Gales, R., Hoskins, A. J., Mitchell, T., Shaughnessy, P. D. and Arnould, J. P. Y. (2010) Continued population recovery by Australian fur seals. *Marine and Freshwater Research* **61**(6), 695-701.

Königson, S. (2011) Seals and fisheries - a study of the conflcit and some possible solutions. PhD thesis, Gothenburg university, Gothenburg, Sweden.

Königson, S., Fjälling, A., Berglind, M. and Lunneryd, S.-G. (2013) Male gray seals specialize in raiding Salmon traps. *Fisheries Research* **148**, 117-123.

Königson, S., Fjälling, A. and Lunneryd, S. (2007) Grey seal induced catch losses in the herring gillnet fisheries in the northern Baltic. *NAMMCO Scientific Publications* **6**.

Konigson, S., Lunneryd, S. G., Stridh, H. and Sundqvist, F. (2009) Grey Seal Predation in Cod Gillnet Fisheries in the Central Baltic Sea. *Journal of Northwest Atlantic fishery science* **42**, 41-47.

Königson, S. J., Fredriksson, R. E., Lunneryd, S.-G., Strömberg, P. and Bergström, U. M. (2015) Cod pots in a Baltic fishery: are they efficient and what affects their efficiency? *ICES Journal of Marine Science* **72**(5), 1545-1554.

Königson, S. J. and Lunneryd, S.-G. (2013) Development of alternative fishing gear in the Swedish small-sclae coastal fisheries. Progress in marine conservation in Europe 2012 BfN skripton 339. 217-227.

Lundstrom, K., Lunneryd, S.-G., Konigson, S. and Hemmingsson, M. (2010) Interactions between harbour seals (*Phoca vitulina*) and coastal fisheries along the Swedish west coast: an overview. *NAMMCO scientific publications* **8**, 329-340.

Lunneryd, S. G., Fjälling, A. and Westerberg, H. (2003) A large-mesh Salmon trap: a way of mitigating seal impact on a coastal fishery. *ICES Journal of Marine Science* **60**(6), 1194-1199.

Mate, B. R., Brown, R., Greenlaw, C., Harvey, J. and Temte, J. (1986) An acoustic harassment technique to reduce seal predation on Salmon. *Acoustical Deterrents in Marine Mammal Conflicts with Fisheries*, 23-36.

Mate, B. R. and Harvey, J. T. (1987) Acoustical deterrents in marine mammal conflicts with fisheries. Oregon State Grant Publication ORESU-W-86-001. Sea Grant Communications, Oregon State University, Corvalis, Oregon.

Mate, B. R. and Miller, D. J. (1983) Acoustic harasssment experiments on harbor seals in the Klamath River, 1981. Southwest Fisheries Center Administrative Report. LJ-83-21C: 51-56.

Natale, F., Carvalho, N. and Paulrud, A. (2015) Defining small-scale fisheries in the EU on the basis of their operational range of activity The Swedish fleet as a case study. *Fisheries Research* **164**, 286-292.

Oksanen, S. M., Ahola, M. P., Oikarinen, J. and Kunnasranta, M. (2015) A novel tool to mitigate by-catch mortality of Baltic seals in a coastal fyke net fishery. *PLOS ONE* **10**(5), e0127510.

Olsen, A. M. and Evans, D. (1991) The Coorong. a multi-species fishery. SA Department of Fisheries, No. 22, Adelaide.

Pemberton, D. (1989) The interaction between seals and fish farms in Tasmania. Department of Lands, Parks and Wildlife, Tasmania. Unpublished report, 96pp.

Pemberton, D. and Shaughnessy, P. D. (1993) Interaction between seals and marine fish-farms in Tasmania, and management of the problem. *Aquatic Conservation: Marine and Freshwater Ecosystems* **3**(2), 149-158.

Petras, E. (2003) 'A review of marine mammal deterrents and their possible applications to limit killer whale (*Orcinus orca*) predation on Steller sea lions (*Eumetopias jubatus*).' (Alaska Fisheries Science Center, National Marine Fisheries Service, National Oceanic and Atmospheric Administration).

Phillips, W. and Muller, K. (2006) Ecological character of the Coorong, Lakes Alexandrina and Albert wetland of international significance. South Australian Department for Environment and Heritage, Adelaide.

PIRSA (2016) Management Plan for the South Australian Lakes and Coorong Fishery. PIRSA Fisheries and Aquaculture, Adelaide. South Australian Fisheries Management Series Paper No. 72. 116 pp.

Quick, N. J., Middlemas, S. J. and Armstrong, J. D. (2004) A survey of antipredator controls at marine Salmon farms in Scotland. *Aquaculture* **230**(1), 169-180.

Rafferty, A. R., Brazer, E. O. and Reina, R. D. (2012) Depredation by harbor seal and spiny dogfish in a Georges Bank gillnet fishery. *Fisheries Management and Ecology* **19**(3), 264-272.

Reeves, R. R., Hofman, R. J., Silber, G. K. and Wilkinson, D. Acoustic deterrence of harmful marine mammal-fishery interactions. In 'Proceedings of a Workshop held in in Seattle, Washington, 20-22 March 1996. U.S. Department of Commerce, NOAA Technical Memorandum NMFS-OPR-10'.

Riedman, M. (1990) 'The pinnipeds: seals, sea lions, and walruses.' (University of California Press: Berkley, Los Angeles, USA).

Ríos, N., Drakulic, M., Paradinas, I., Milliou, A. and Cox, R. (2017) Occurrence and impact of interactions between small-scale fisheries and predators, with focus on Mediterranean monk seals (*Monachus monachus* Hermann 1779), around Lipsi Island complex, Aegean Sea, Greece. *Fisheries Research* **187**, 1-10.

Robinson, S., Terauds, A., Gales, R. and Greenwood, M. (2008) Mitigating fur seal interactions: relocation from Tasmanian aquaculture farms. *Aquatic Conservation: Marine and Freshwater Ecosystems* **18**(7), 1180-1188.

Sara, J. K., Karl, E. L., Hemmingsson, M. M. B., Sven-Gunnar, L. and Håkan, W. (2006) Feeding preferences of harbour seals (*Phoca vitulina*) specialised in raiding fishing gear. *Aquatic Mammals* **32**(2), 152-156.

Schakner, Z. A. and Blumstein, D. T. (2013) Behavioral biology of marine mammal deterrents: a review and prospectus. *Biological Conservation* **167**, 380-389.

Sepúlveda, M., Pérez, M. J., Sielfeld, W., Oliva, D., Durán, L. R., Rodríguez, L., Araos, V. and Buscaglia, M. (2007) Operational interaction between South American sea lions *Otaria flavescens* and artisanal (small-scale) fishing in Chile: Results from interview surveys and on-board observations. *Fisheries Research* **83**(2), 332-340.

Shaughnessy, P., Kirkwood, R., Pemberton, D. and Cawthorn, M. (2003) Pinnipeds, cetaceans and Australian fisheries; a review of operational interactions. In '*Marine mammals and humans: Fisheries, Tourism and Management Issues*' (ed Gales N, Hindell M & Kirkwood R), CSIRO Publishing, Melbourne, 136-152.

Shaughnessy, P. D., Goldsworthy, S. D. and Mackay, A. I. (2015) The long-nosed fur seal (*Arctocephalus forsteri*) in South Australia in 2013–14: abundance, status and trends. *Australian Journal of Zoology* **63**(2), 101-110.

Shaughnessy, P. D., Semmelink, A., Cooper, J. and Frost, P. G. H. (1981) Attempts to develop acoustic methods of keeping cape fur seals *Arctocephalus pusillus* from fishing nets. *Biological Conservation* **21**(2), 141-158.

Steer, M. A., Fowler, A. J., Rogers, P. J., Bailleul, F., Earl, J., Matthews, D., Drew, M. and Tsolos, A. (2020) Assessment of the South Australian Marine Scalefish Fishery in 2018. Report for PIRSA Fisheries and Aquaculture. South Australian Research and Development Institute (Aquatic Sciences). SARDI Publication No. F2017/000427-3. SARDI Research Report Series No. 1049. 214pp.

Suuronen, P., Chopin, F., Glass, C., Løkkeborg, S., Matsushita, Y., Queirolo, D. and Rihan, D. (2012) Low impact and fuel efficient fishing—looking beyond the horizon. *Fisheries Research* **119**, 135-146.

Suuronen, P., Siira, A., Kauppinen, T., Riikonen, R., Lehtonen, E. and Harjunpää, H. (2006) Reduction of seal-induced catch and gear damage by modification of trap-net design: design principles for a seal-safe trap-net. *Fisheries Research* **79**(1), 129-138.

Team, R. C. (2017) R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

Trippel, E. A., Strong, M. B., Terhune, J. M. and Conway, J. D. (1999) Mitigation of harbour porpoise (*Phocoena phocoena*) by-catch in the gillnet fishery in the lower Bay of Fundy. *Canadian Journal of Fisheries and Aquatic Sciences* **56**(1), 113-123.

Varjopuro, R. and Salmi, P. (2006) Complexities in keeping the seals away from the catch: building a 'seal-proof'fishing gear. *Maritime Studies* **5**, 61-86.

Vincent, C., Ridoux, V., Fedak, M. A., McConnell, B. J., Sparling, C. E., Leaute, J.-P., Jouma'a, J. and Spitz, J. (2016) Foraging behaviour and prey consumption by grey seals (*Halichoerus grypus*)—spatial and trophic overlaps with fisheries in a marine protected area. *ICES Journal of Marine Science* **73**(10), 2653-2665.

Wartzok, D. and Ketten, D. R. (1999) Marine mammal sensory systems. *Biology of marine mammals* **1**, 117.

Westerberg, H., Lunneryd, S. G., FjAlling, A. and Wahlberg, M. (2008) 'Reconciling fisheries activities with the conservation of seals throughout the development of new fishing gear: a case study from the Baltic Fishery-Gray Seal conflict.' (American Fisheries Society, 5410 Grosvenor Ln. Ste. 110 Bethesda MD 20814-2199 USA) 11-1291.

Wickens, P. (1996) Conflict between Cape (South African) fur seals and line fishing operations. *Wildlife Research* **23**(1), 109-117.

Ye, Q., Bucater, L. and Short, D. A. (2017) Coorong Fish Condition Monitoring 2015/16: Black Bream (*Acanthopagrus butcheri*), Greenback Flounder (*Rhombosolea tapirina*) and smallmouthed hardyhead (*Atherinosoma microstoma*) populations. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2011/000471-5. SARDI Research Report Series No. 943. 89pp., Adelaide.

Ye, Q., Earl, J., Bucater, L., Cheshire, K., McNeil, D., Noell, C. and Short, D. (2013) Flow related fish and fisheries ecology in the Coorong, South Australia. *SARDI Research Report Series*(698), 000014-2.