Comparative testing of bycatch reduction devices in tropical shrimp-trawl fisheries

A practical guide

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Comparative testing of bycatch reduction devices in tropical shrimp-trawl fisheries

A practical guide

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World production of shrimp, both captured and farmed, is currently about 6 million tonnes per year, of which 3.4 million tonnes per year comes from capture fisheries. However, associated with this catch are significant quantities of bycatch and discards. In 2005, FAO reported that tropical shrimp-trawl fisheries have high discard rates and account for more than 27 percent of total estimated discards in all the marine fisheries of the world. Many of the discarded species are juveniles of ecologically important and economically valuable species, some of which are protected under national and international law. Given the economic and ecological importance of shrimp resources and the numerous concerns associated with tropical shrimp fishing, FAO has been engaged in a series of global and regional field projects to introduce bycatch reduction devices (BRDs) into shrimp trawl fisheries. An impediment to the rapid uptake of such devices by commercial fishing vessel operators has been the loss of marketable species and sizes of fish and diminished revenues resulting from incorrect selection and/or poor installation of BRDs in trawls. To address these issues, FAO prepared "A Guide to Bycatch Reduction in Tropical Shrimp-Trawl Fisheries". This guide was revised in 2007 and published in five languages to ensure as broad a readership as possible. Since then, FAO has received a number of requests for more detailed explanations on how to select and evaluate different BRDs on board commercial fishing vessels. To address this need, FAO has prepared this follow-up publication to provide guidance on comparative testing of BRDs in tropical shrimp-trawl fisheries. This guide includes detailed explanations of each stage of testing of a BRD, from planning and preparation for research to the execution of fieldwork, analysis of data, and reporting and extension of research outcomes.

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Abstract

This guide has been written to assist fishing technologists, fishery extension workers, resource managers and fisheries to develop effective bycatch reduction devices (BRDs) in tropical shrimp-trawl fisheries. It provides information describing the various stages of testing of a BRD, from planning and preparation for research to the execution of fieldwork, analysis of data, and reporting and extension of research outcomes. In preparing this guide, a wide variety of literature and other sources of information have been reviewed, synthesized and simplified. It should serve as a comprehensive, easy-to-read guide for anyone seeking fundamental information about testing a BRD in a tropical shrimp-trawl fishery.

A key outcome of many BRD studies is the production of selectivity curves to evaluate and compare the size selectivity of one or more BRDs. This guide provides a description of commonly used methods to prepare catch data and produce these curves. Several case studies are provided with worked examples to help the researcher understand the available options for producing these curves and their interpretation. A DVD accompanying this guide provides spreadsheets of the case studies plus blank spreadsheets that researchers can use in selectivity experiments. The production of selectivity curves in this guide is based on models using commercially available software – a simple and inexpensive means for generating such curves and analysing catch data.

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Abbreviations and acronyms

AIC	Akaike Information Criterion
ANOVA	analysis of variance
BRD	bycatch reduction device
CITES	Convention on International Trade in Endangered Species of Wild Fauna and Flora
GEF	Global Environment Facility
GLM	generalized linear modelling
GPS	Global Positioning System
IUCN	International Union for Conservation of Nature
JTED	juvenile and trash excluder device
M&E	monitoring and evaluation
MLS	minimum landing size
NMFS	National Marine Fisheries Service
NGO	non-government organization
NOAA	National Oceanic and Atmospheric Administration
PVC	polyvinyl chloride
R&D	research and development
RPM	revolutions per minute
SEAFDEC	Southeast Asian Fisheries Development Center
SELECT	share each length’s catch total (method)
SMART	specific, measurable, attainable, relevant and time-bound
SR	selection range
TED	turtle exclusion device
UNEP	United Nations Environment Programme
WWF	World Wildlife Fund / World Wide Fund For Nature

Foreword

A practical guide to assist in the design and testing of bycatch reduction devices (BRDs) is timely for several reasons. Shrimp and prawns are one of the most important internationally traded fishery products, and one of the few that can be considered a “commodity”, with a value of US$10 billion (or 16 percent of world fishery exports), which generates substantial economic benefits, especially for many developing countries. They contribute substantially to the livelihoods of poor and vulnerable communities, particularly as a source of cash.

Their “discovery” by industrial fisheries raised great economic hopes in the 1960s, followed by concern as overcapacity and economic problems increased. Many of the fisheries could be considered as a metaphor of the global fishery crisis, with their long trail of sectoral, cross-sectoral and ecosystem issues. Exploiting high-biodiversity ecosystems, specialized industrial shrimp-trawl fisheries capture large quantities of bycatch, consisting to a large extent of “low-value fish”. Having limited storage capacity, these fisheries have some of the highest levels of discards, of which a significant component consists of economically important and ecologically valuable species of fish and other animals.

One of the successes in recent years has been the development and adoption of BRDs. Although BRDs have some of their origins in reducing the capture of turtles, they have more recently been developed to reduce the unwanted capture of a variety of species and sizes of fish and other animals. Much of the rapid uptake has been spurred by three key factors. First, the inclusion and active participation of fishing captains and fishing crews in the BRD development and testing process of BRDs has ensured that approaches are practical and take advantage of the wealth of experience that can only be gathered by spending time at sea fishing. Second, specialized equipment for monitoring fishing gear and fish behaviour has improved the understanding of how trawls operate and which factors affect the catching performance of the fishing gear. Third, the application of robust testing methods (systematic fishing trials) and use of properly qualified technicians working alongside fishers has led to increased probability of successful BRD trial outcomes.

At the Twenty-ninth Session of the Committee on Fisheries (COFI) in 2011, COFI adopted the Report of the Technical Consultation to Develop International Guidelines on Bycatch Management and Reduction of Discards and endorsed the International Guidelines on Bycatch Management and Reduction of Discards contained therein, recommending that FAO provides support in capacity building and implementation of these guidelines. This guide provides information describing the various stages of testing of a BRD, from planning and preparation for research to the execution of fieldwork, analysis of data, and reporting and extension of research outcomes. In preparing this guide, a wide variety of literature and other sources of information have been reviewed, synthesized and simplified. It will serve as a comprehensive and easy-to-read guide for anyone seeking fundamental information about testing a BRD in a tropical shrimp-trawl fishery.

Executive summary

In recent decades, there has been a proliferation of attempts by researchers, fishers and others worldwide to develop effective bycatch reduction devices (BRDs) for tropical shrimp-trawl fisheries. In some of these fisheries, the introduction of BRDs has been very successful and the bycatch of many species has been substantially reduced or almost eliminated. However, these successes are not universal, particularly in developing countries where economic, social and political conditions may contribute to hampering the appropriate and effective research and development (R&D) of BRDs. Some developing countries also have a poor record of exploiting marine resources in a sustainable manner. Fishing capacity is often in excess of that required to fish sustainably without overfishing, fishing practices often include the use of poorly selective fishing gear, some of which also substantially modifies the sea bed and fish habitats, and the effective management, control, and surveillance of fishing activity is often non-existent or limited. Some of these countries also suffer from a lack of technical expertise, capacity, and infrastructure necessary to conduct appropriate and effective bycatch reduction research. These problems are all complex, and finding solutions is not an easy task. In the meantime, the development of BRDs remains relatively slow or non-existent, and the capture and mortality of bycatch in tropical shrimp-trawl fisheries remains an ongoing issue.

Recognizing a need to overcome these problems, FAO has been spearheading efforts to facilitate BRD research and development worldwide. These efforts include the execution of a five-year global project titled "Reduction of environmental impacts of shrimp trawling, through the introduction of bycatch reduction technologies and change of management". This project commenced in 2002, and was funded by the Global Environment Facility, FAO and participating countries from Latin America, West Africa, Southeast Asia and the Persian Gulf region. This project has filled vital information gaps, and provided education and training for many researchers, fishers and others with an interest in bycatch reduction in tropical shrimp-trawl fisheries. It has also served as an excellent springboard for enabling each country to continue efforts to reduce bycatch, and some countries have now made good progress towards developing their own, regionally specific, BRDs. However, despite this progress, a major limitation to more widespread R&D of BRDs in many countries has been a lack of guidelines on how to carry out BRD fieldwork.

This guide has been written to overcome this limitation and help guide efforts to develop effective BRDs. It provides information describing the various stages of testing of a BRD, from planning and preparation for research to the execution of fieldwork, analysis of data, and reporting and extension of research outcomes. In preparing this guide, a wide variety of literature and other sources of information has been reviewed, synthesized and simplified. It should, therefore, serve as a comprehensive easy-to-read guide for anyone seeking fundamental information about testing a BRD in a tropical shrimp-trawl fishery.

A key outcome of many BRD studies is the production of selectivity curves to evaluate and compare the size selectivity of one or more BRDs. This guide provides a description of commonly used methods to prepare catch data and produce these curves. Several case studies are also provided, with worked examples to help the researcher understand the available options for producing these curves and their interpretation. A DVD accompanying this guide provides spreadsheets of the case studies plus blank spreadsheets that the researcher can use in a selectivity experiment. The production of selectivity curves in this guide is based on models using commercially available software – a simple and inexpensive means for generating such curves and analysing catch data.


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1. Introduction

In recent decades, concerns have been raised worldwide over the capture and mortality of bycatch caught in tropical shrimp-trawl fisheries. In response to these concerns, substantial efforts have been made by researchers, fishers and others to improve trawl selectivity and reduce bycatch in these fisheries. These efforts have resulted in the development and testing of a variety of bycatch reduction devices (BRDs), and many are now being used successfully by commercial fishers. Arising from these efforts, a considerable body of knowledge has also been developed, and much of it has been published in general and scientific literature. A characteristic of this literature, however, reveals a high degree of variability in testing protocols, analytical procedures, and reporting and presentation of research outcomes. Some studies are overly simplistic or inflate research outcomes derived from limited fieldwork or poor experimental design. Others present highly detailed and complex analyses, reflecting the researcher's mastery of the subject, yet sometimes rendering the report difficult for emerging or inexperienced researchers to understand and replicate. All of these reports provide useful information to a greater or lesser degree, but they collectively indicate that a variety of methods can be used in BRD research. This makes it difficult for emerging or inexperienced researchers to determine which methods should be applied to their own fishery, and how to apply these methods effectively. This guide has been written to provide clarity on this issue and provide researchers with information required to effectively test a BRD and reduce bycatch in a tropical shrimp-trawl fishery.

1.1 HOW TO USE THIS GUIDE

The chapters in this guide are ordered in a way that guides the researcher through the BRD research process in a logical sequence (Table 1), and includes a description of the bycatch problem and international efforts to reduce bycatch, the preparation of a project proposal and fieldwork, experimental design, data collection and analysis, and preparation of research reports.

A DVD also accompanies this guide. It contains a copy of this guide and the datasheets used to produce the case studies in Annex 9. Blank, ready-to-use datasheets are also provided, with appropriate formulae embedded in each cell so the researcher can insert length-frequency data and produce a selectivity curve. Researchers interested in a more detailed and sophisticated evaluation of selectivity curves and associated catch data are advised to use specialized selectivity software (e.g. that available at www.stat.auckland.ac.nz/~millar/selectware/code.html or ConStat CC 2000 available at www.constat.dk).

In preparing this guide, a wide variety of literature has been reviewed, synthesized and simplified for the reader. It is assumed that readers have a basic understanding of key bycatch species in their fishery and the range of BRD designs that can help reduce the capture of these species. Readers that wish to learn more about BRD design and operation, or identify suitable BRDs to reduce specific bycatch species, may find Broadhurst (2000) and Eayrs (2007) useful. Many of the references provided in this guide are also useful to a reader seeking additional information about testing a BRD, particularly regarding fieldwork design, data collection, analysis, and reporting requirements. In a guide of this type, it is neither possible nor appropriate to describe all statistical techniques available to analyse catch data from a BRD test, and only the fundamentals of several commonly used techniques are described. A review of scientific literature describing the results of BRD tests and key statistical texts, such as Sokal and Rohlf (1995), Zar (1999), and Fowler, Cohen and Jarvis (2005), is recommended for more detailed information about appropriate statistical techniques. Finally, to gain a greater understanding of experimental methods to measure trawl selectivity, including mathematical derivations of selectivity curve parameters, readers should examine Millar and Walsh (1992), Anonymous (1995), Wileman *et al*. (1996), Tokai *et al*. (1996), and Zuur *et al*. (2001).

TABLE 1

Sequence and summary of topics covered in this guide

Chapter number	Chapter description
2	A brief description of the bycatch problem in tropical shrimp-trawl fisheries and recent efforts to reduce this problem.
3	A description of the trawl gear used to capture shrimp, including trawl design, rigging and operation.
4	A summary of bycatch reduction device (BRD) design, international efforts to reduce bycatch, and the importance of exploiting size and behavioural differences between shrimp and bycatch.
5	Details for the preparation of a project proposal and the importance of including fishers in the entire research process.
6	Preparatory steps for fieldwork, including selection of a suitable fishing boat and preparation of fishing gear and sampling equipment.
7	Practical considerations that affect successful fieldwork.
8	The advantages and disadvantages of experimental fishing methods available to test a BRD, including covered codend and paired experimental methods.
9	Basic and detailed BRD testing protocols, including fieldwork design, catch sampling techniques, data entry, and statistical analysis.
10	Identification and description of suitable models and methods to produce selectivity curves.
11	Preparation of project reports and options for the effective extension (outreach) and dissemination of results.
Annex number	
1	Illustrations and description of shrimp trawl components and terminology.
2 - 4	Blank boat and trip information log, haul log, and a catch log.
5 - 6	Blank gear log to record all relevant codend construction details, including the location of a BRD, and a blank gear log for recording all relevant turtle exclusion device construction and rigging details.
7	A description of recommended procedures to apply to a comatose sea turtle.
8	Description of the models used to construct the logistic and Richards selectivity curves.
9	Case studies of selectivity curves and their interpretation with a step-by-step explanation describing how the curves were produced.
10	Contact details of organizations with expertise in conducting bycatch reduction research.

1.2 ARE TEDS A TYPE OF BRD?

There is often considerable debate regarding the consideration of a turtle exclusion device (TED) as a type of BRD. In many countries, fishery regulations draw a distinction by defining each device separately. Typically, a TED is defined based on its ability to exclude sea turtles from a shrimp trawl, and a BRD is defined based on its ability to facilitate the escape of finfish from a shrimp trawl. In essence, these regulations focus on the ability of each device to reduce the bycatch of separate species or animal groups, and they ignore the fact that TEDs can also reduce the capture of other large bycatch species, including sharks, rays, and skates, and, if suitably modified, a variety of smaller bycatch species including finfish (Plate 1). A possible explanation for this approach is that regulators wanted to ensure that concerns over threatened sea turtle populations remained separate from other bycatch concerns, as well as to focus attention on the development of effective TED designs and ensure that these efforts remained at the forefront of bycatch reduction efforts.

PLATE 1 – In many countries, TEDs are being used to exclude sea turtles and other large animals from the traw

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However, this guide draws no distinction between these devices, and a TED is considered to be a type of BRD because in addition to sea turtles it can exclude a variety of other species from the trawl. Therefore, the information in this guide should be considered as equally applicable to the testing and development of a TED as it is to other BRD designs.

COURTESY OF JOHN MITCHELL

2. The bycatch problem

In most commercial fisheries around the world, fishers have to deal with bycatch because very few fishing gear types are capable of capturing only the target species. Notable exceptions to this include spear-fishing, harpooning, hand-gathering, and perhaps the use of rakes and clamps. At the other end of the scale, trawling for shrimp in tropical waters often results in the capture of significant quantities of bycatch (Eayrs, 2007), although there are a few fisheries where shrimp can comprise almost the entire catch.

2.1 SHRIMP-TRAWL FISHERIES AND BYCATCH

According to an estimate by FAO, tropical shrimp-trawling accounts for 27 percent of the 7 million tonnes of bycatch that is discarded annually around the world, with a weighted discard rate equivalent to 62 percent of the total catch by shrimp trawlers (Kelleher, 2005). The weight of bycatch taken in these fisheries often exceeds the shrimp catch by 15:1 or more (Pender, Willing and Ramm, 1992; Brewer *et al*., 1998; FAO, 2001; Gillett, 2008), although there have been reports of bycatch-to-shrimp ratios as high as 30:1 (Abdulqader, 2000) and even 74:1 (Bishop *et al*., 2001) (Plate 2).

PLATE 2 – In some fisheries, the catch consists of both large and small fish… and relatively few shrimp

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In some shrimp fisheries, more than 90 percent of the bycatch is discarded overboard, either moribund or dead. This is usually because the bycatch is uneconomic to retain or regulations prevent it from being landed. In other shrimp fisheries, the retention and sale of large finfish such as groupers, emperors, snappers, croakers, threadfin bream, lizard fish and pompfrets is permitted, while smaller finfish such as pony fish, goat fish, and subadults of commercially important species are discarded overboard (Plate 3). Examples of these fisheries can be found in the Near East, Africa and Latin America. It is noteworthy that they are referred to as shrimp-trawl fisheries, primarily because fishing occurs using small-mesh trawl nets and shrimp may comprise a small proportion of the total catch. In reality, however, they should be referred to as multispecies trawl fisheries because a variety of finfish species dominate the catch by volume, and in some instances by value.

PLATE 3 – The larger finfish are being retained for human consumption. The smaller finfish may either be retained for human consumption, animal feed, or discarded overboard

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There are also shrimp fisheries where almost the entire catch is sold for human consumption or as feed in mariculture operations. In these fisheries, shrimp may

PLATE 4 – In some countries, bycatch is landed on shore and processed by villagers for human consumption

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comprise only a very small proportion of the overall catch by volume or value. The remainder of the catch is usually dominated by small to medium-sized finfish, including so-called low-value fish and subadults of commercially important finfish species. Examples of these fisheries can be found in Southeast Asia and Africa. In these fisheries, the capture of finfish is a valuable component of the overall catch, an important source of animal protein for people, and a vital contributor to food security in these regions (Plate 4). However, because a substantial proportion of these finfish are subadults and sexually immature, their excessive mortality may be a significant contributor to growth overfishing and failure to maximize yield per recruit. This raises conservation, ecological and economic concerns that may ultimately pose a threat to long-term food security in these regions. Reviews of shrimp-trawl fisheries by country, including descriptions of the fishery and associated bycatch problems, are provided in FAO (2001), Gillett (2008) and Davies *et al*. (2009).

2.2 BYCATCH SPECIES

The bycatch in tropical shrimp fisheries is usually dominated by a multitude of species, sometimes numbering several hundred or more (Plate 5). In Australia's Northern Prawn Fishery, Brewer *et al*. (1998) reported the capture of 250 species from shrimp trawling, while Grantham (1980) reported 150 bycatch species in the Kuwait shrimp-trawl fishery. Abdulqader (2000) reported 100 species in the Bahrain shrimp-trawl fishery, while Robins and McGilvray (1999) reported 64 species in the Queensland oceanic shrimp fishery (Australia). All studies similarly found a high proportion of the bycatch was comprised of small finfish, typically each weighing less than 300 g and measuring less than 150 mm. Many of these finfish were juveniles or subadults of species that form the basis of other commercial or recreational fisheries.

In addition to finfish bycatch, these fisheries are also responsible for the capture of protected animals such as sea turtles. In response to concerns over declining sea turtle populations, the International Union for Conservation of Nature (IUCN) Red List of Threatened Species listed in 2008 six of the world's seven species of sea turtle as vulnerable, endangered or critically endangered. These species are also currently listed in Appendix 1 of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), thus the international commercial trade of all sea turtle products, including meat, eggs and shell, is prohibited. The issue of sea turtle capture in shrimp fisheries has also had wide-ranging political and economic impacts on global shrimp trade. This is principally because of a trade embargo by the United States of America on shrimp imports from countries where approved TEDs are not a mandatory

PLATE 5 – Many species of fish, rays, sponges, and other animals are caught as part of shrimp-trawling activity

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requirement for local fishers. Many countries have responded favourably to this embargo and instituted developmental programmes leading to the mandatory introduction of these devices into the local fishery. However, some countries are still struggling with the development of TEDs that meet United States standards, while others have found alternative markets for their shrimp. Other bycatch with populations considered threatened by shrimp trawling include sharks, sawfish, dugongs, sea snakes, seahorses, coral, and some finfish species, and in some countries many of these species are now protected by law (Plate 6).

PLATE 6 – This catch consists of many small fish, including juveniles of several commercially important species, crabs, and very few shrimp

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3. Shrimp-trawl design, rigging and operation

In most tropical shrimp fisheries, the trawl is designed, rigged and operated to catch shrimp located on or near the sea bed. The trawl typically consists of a low-opening, conically shaped net that is spread open horizontally by low-aspect-ratio otter boards. A simple chain or rope ground gear is used to keep the trawl in contact with the sea bed and stimulate shrimp to rise upwards from the sea bed and enter the mouth of the trawl. With some exceptions, catch rates of shrimp are linked to the area of sea bed swept by the trawl per unit of time. This is because shrimp are dispersed across the sea bed or caught in small aggregations, and an increase in swept area should increase the number of shrimp that encounter the trawl. Swept area is typically maximized by spreading the trawl laterally to 60–85 percent of headrope length, while the trawl is towed at speeds of 1.2–1.75 m/s. A detailed description of shrimp trawl components and terminology is provided in Annex 1.

The most common indicator of the size of a shrimp trawl is headline length, although in a few fisheries the footrope length is used. In small-scale fisheries, fishers typically use trawls with a headline length of 5–20 m (e.g. Broadhurst and Kennelly, 1994, 1997; Dickson *et al*., 2004; FAO, 2001), while in industrial fisheries, headline lengths between 20 m and 30 m are more common (e.g. Aye, 2004; Bishop and Sterling, 1999; Eayrs and Prado, 1997; FAO, 2001).

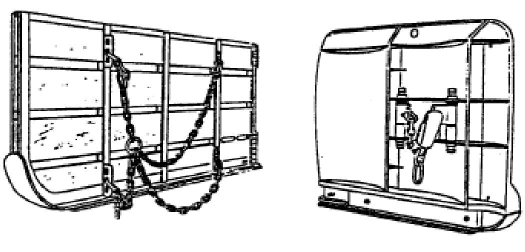
3.1 MESH SIZE

Although there is a high degree of variability in mesh size (see Annex 1 for definition of mesh size) among fisheries, shrimp trawls are almost universally constructed using small-mesh netting in the body of the trawl with even smaller-mesh netting in the codend. In Iran (Islamic Republic of) (Eayrs and Prado 1997) and some Australian fisheries (Broadhurst and Kennelly, 1994) a mesh size of 40 mm is used in the body of the trawl, while 43 mm is used in the Philippines (Dickson *et al*., 2004), 50 mm in Myanmar (Aye, 2004), 50–55 mm in the United Republic of Tanzania (FAO, 2001), 51 mm in Mexico (Quevedo, 2001), and 57 mm in northern Australia (Bishop and Sterling, 1999). In other shrimp fisheries, a relatively large mesh size is used in the wings and mouth of the trawl with smaller meshes used towards the codend. In Viet Nam, for example, a 51-mm mesh size is used in the wings and mouth of the trawl, decreasing to 25 mm near the codend (Nguyen, 2006), while in Thailand 60 mm is used in the wings and mouth of the trawl and 40 mm in the body of the trawl (Chokesanguan, 1998).

3.2 OTTER BOARDS

Otter boards are essentially underwater kites or foils that are designed to spread the trawl horizontally and help keep it in contact with the sea bed (Figure 1). They are towed across the sea bed at an angle to the towing direction (the angle of attack), which produces both an outward spreading force and a drag force. In many shrimp fisheries, particularly small-scale fisheries, the otter boards are flat and rectangular-shaped with a height-to-length ratio (aspect ratio) of about 0.4–0.5. These otter boards

FIGURE 1 – The traditional flat rectangular otter board (left) and the modern Bison otter board are two common otter board designs used in shrimp-trawl fisheries.



Source: Sterling, 2005.

PLATE 7 – Flat rectangular otter boards for shrimp trawling. The chain arrangement on each otter board is attached to the towing wire and careful adjustments of these chains influence otter board heel, tilt, and angle of attack.

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PLATE 8 – A large trawler with outriggers extended and Bison otter boards

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are usually constructed from timber, and are relatively inexpensive to purchase and simple to repair.

Since the late twentieth century, there has been a gradual increase in the use of new otter board designs that consist of several high-aspect-ratio cambered foils fitted within a single low-aspect-ratio frame. These otter boards are usually constructed entirely from steel or metal alloy and are now commonly used in many of the world's industrial shrimp fisheries. A design feature of these otter boards is superior hydrodynamic performance compared with flat rectangular otter boards, which permits the use of smaller otter boards that are easier to handle (Plates 7 and 8).

3.3 VERTICAL OPENING

Typically, the headline and footrope of a shrimp trawl are attached directly to the otter boards. With this arrangement, the vertical opening of the trawl is equivalent to the height of the otter – usually no more than 1–1.5 m. This height closely reflects the maximum vertical distribution of shrimp over the sea bed (Eayrs, 2007). In other shrimp fisheries, the trawl is attached to the otter boards via short ropes or sweeps that may measure 10 m or more in length (Plates 9 and 10). With greater distance between the otter boards, the area swept by the trawl system is increased and the vertical opening of the trawl is no longer restricted by the height of the otter board. (These sweeps may also prevent the capture of sea-bed debris that is guided by the otter boards into the path of the trawl.) With the addition of side panels or

PLATE 9 – The short sweep wires between the otter boards and trawl minimize the risk that sea-bed debris will be guided by the otter boards into the path of the trawl

CREDIT: S. EAYRS

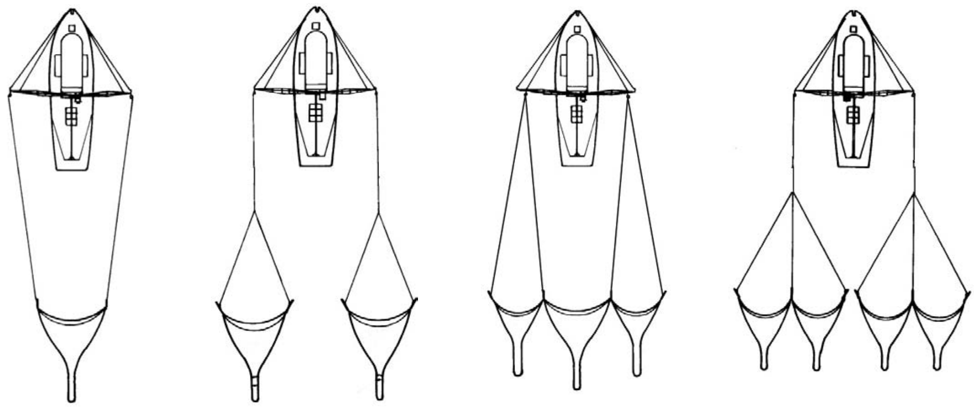
PLATE 10 – Longer sweep wires can be used to increase headline height and herd fish into the trawl. The use of floats attached to the upper sweep wires and headline also helps to increase headline height

CREDIT: B. CHOKESANGUAN AND S. CHINDAKHAN specialized taper cuts in the upper netting panel, these trawls can be used to catch semi-pelagic species of shrimp, or both shrimp and fish in a multispecies fishery. Sometimes, headline flotation is also used, and the vertical opening of the trawl may be increased to about 3 m. Another option to increase vertical opening is to remove the headline of the trawl from the otter board and attach it to a flywire, which is then attached to the towing warp ahead of the otter board. This arrangement will increase headline height by several metres, and is used to catch aggregations of swimming shrimp.

3.4 MULTITRAWL SYSTEMS

In many small-scale shrimp fisheries, a single trawl is towed from the stern of the fishing boat. These boats are often no more than 10–15 m in length, and may operate in other fisheries using a variety of fishing gear types when shrimp catches are uneconomic or the shrimp fishery is closed. In industrial shrimp fisheries, larger trawlers that are purpose-built for shrimp trawling are commonly used. A feature of these trawlers is that more than one trawl is towed simultaneously from booms or outriggers that extend laterally outboard from the trawler. These multitrawl systems are commonly known as twin (or double), triple, and quad trawl (rig) systems, depending on the number of trawls towed (Figure 2). They are used to optimize the area of sea bed swept by the trawl system per unit of time, and thereby optimize catches of shrimp.

FIGURE 2 – Multi-net shrimp trawl systems; a) single rig, b) twin or double rig, c) triple rig, and d) quad rig



Source: Sterling, 2005.

A twin trawl system involves towing two identical trawls, one from each boom, and each with its own pair of otter boards. With a triple trawl system, three trawls are attached together via sleds or sledges. Only one pair of otter boards is required and each otter board is attached to the outer wing of the outermost trawls. The middle trawl may be larger than the outermost trawls, and from each boom only one sled and one otter board is towed. With a quad trawl system, four trawls are used (Plate 11). Usually, each trawl is identical, although in some instances the two outer trawls may be slightly larger. Two

PLATE 11 – A United States quad-rigged shrimp trawler at anchor. Note the pair of rectangular otter boards and sled attached to each outrigger

CREDIT: J. MITCHELL

trawls are towed from each boom, connected via a sled and spread open by a pair of otter boards.

3.5 GROUND GEAR

Ground gear is used to help keep the shrimp trawl close to the sea bed. It is typically a simple design, consisting of a single length of chain. The chain is attached to the footrope of the trawl ("looped") at predetermined intervals with sufficient slack for the chain to hang loose between attachment points. This chain contacts the sea bed and drags behind the footrope when fishing (Plate 12).

An alternative option is to use a "Texas drop" system where the ground chain is attached to the footrope via numerous short chain lengths called drop chains or "droppers" (Plate 13). The ground chain should contact the sea bed along its entire length and generally measure several links shorter than the footrope. In this way, the ground chain rides over the sea bed ahead of the footrope in the bosom region and stimulates shrimp into the trawl. The dropper chains are usually a consistent length, typically 150–375 mm, and may be 600 mm or more apart. In some fisheries, the ground chain is replaced with a steel wire rope wrapped in synthetic or natural fibre rope, with perhaps with some lead weights or stones attached to aid sea-bed contact (Plate 14). This rope is often shorter than the footrope to help stimulate shrimp into the trawl.

3.6 CODEND MESH SIZE

In almost all tropical shrimp fisheries, the codend is constructed from diamond mesh netting. This mesh size (see Annex 1 for definition of mesh size) may vary substantially between fisheries, but is typically no more than 45 mm. In some fisheries, there are no codend mesh-size regulations, and fishers often select a mesh size based on the cost and availability of netting and a desire to retain the smallest commercially valuable shrimp or finfish. In these fisheries, codend selectivity is typically poor and only the smallest animals are able to escape capture. Minimum landing sizes, if they exist, are often ignored with impunity. In those fisheries where codend mesh-size regulations

PLATE 12 – The scalloped ground chain helps keep the shrimp trawl close to the sea bed. Note the headline is attached to the top of the otter boards

CREDIT: S. EAYRS

PLATE 13 – This shrimp trawl is towed from the starboard outrigger of a dual-rigged shrimp trawler. The "Texas drop" ground chain system is clearly visible

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PLATE 14 – A relatively cheap and easily replaceable option to keep the trawl mouth close to the sea bed in a small-scale fishery is to attach small stones to the footrope

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are present, the minimum mesh size will have been determined based on limiting the capture of undersized or immature shrimp or finfish, irrespective of their commercial value. A summary of codend mesh size by country is provided in Table 2.

TABLE 2
Codend mesh size in coastal tropical shrimp-trawl fisheries by country

Country/fishery	Codend mesh size (mm)	Source
Viet Nam	20	Eayrs *et al.*, 2007
Thailand	25	Chokesanguan, 1998
Bahrain	30	Abdulqader, 2000
Iran (Islamic Republic of)	30	Eayrs & Prado, 1997
Myanmar	30	Aye, 2004
Cameroon	>33	FAO, 2001
Philippines	33	FAO, 2001
Florida, United States of America	32	Steele *et al.*, 2002
Venezuela (Bolivarian Republic of)	32	FAO, 2001
Philippines	33	Dickson *et al.*, 2004
Costal Rica	38	FAO, 2001
South Africa	38	Fennessy, 1994
Trinidad	38	Maharaj, 1991
Australia, New South Wales Oceanic Prawn Trawl	40	Broadhurst & Kennelly, 1994
Mexico	44	Quevedo, 2001
Nigeria	44	Ambrose *et al.*, 2005
Australia, Gulf St Vincent, South Australia	45	Broadhurst *et al.*,1999
Australia, Queensland Otter Trawl	45	Courtney *et al.*, 2006
Australia, Northern Prawn Fishery	45	Brewer *et al.*,1998
Bangladesh	45	FAO, 2001

3.7 CODEND SKIRT AND CHAFFING GEAR

A common practice that reduces codend selectivity is the use of a skirt or chaffing net (chafer). A skirt typically surrounds the entire posterior section of the codend while a chaffing net only covers part of the lower portion of the codend. These nets are designed to protect the codend against abrasion, chaffing, attack by sharks and dolphins, and to safeguard against shrimp and other target animals escaping through codend meshes. The mesh size of a skirt or chaffing net is often similar to the codend, and it masks codend meshes to an extent that the escape of small finfish and other animals is almost impossible (Plate 15). In some fisheries, lengths of frayed rope are attached to the skirt or chaffing net to form an almost impenetrable barrier that further hinders the escape of small animals (Plate 16). Skirts are also often tied at their trailing end, thus retaining any catch that escapes through the codend. In most shrimp fisheries, the use of skirts and chafers is unregulated, but their use should be discouraged or regulated to improve codend selectivity.

PLATE 15 – The small mesh codend cover will make it almost impossible for small bycatch to escape through the meshes of the codend

CREDIT: B. CHOKESANGUAN AND S. CHINDAKHAN.

PLATE 16 – The frayed rope attached to the codend cover (white netting) helps protect the codend from damage. However, because they also block codend meshes the escape of small bycatch is almost impossible

CREDIT: S. EAYRS.

4. Bycatch reduction devices

A variety of BRDs have been developed globally to improve trawl selectivity and reduce bycatch in tropical shrimp fisheries (see Broadhurst [2000] and Eayrs [2007] for reviews). These devices can be categorized by the principal method used to reduce the capture and retention of bycatch. One method is to use BRDs that exploit differences in size between shrimp and bycatch to separate and exclude the bycatch from the trawl. The other method is to use BRDs that exploit differences in the behaviour of shrimp and bycatch and facilitate the voluntary escape of bycatch from the trawl.

The addition of a BRD to a shrimp trawl is often predicated on the notion that the trawl net and codend (and protective skirt or cover if used) are poorly selective and retain excess quantities of bycatch. While considerable effort and expense have been directed towards the development of BRDs in shrimp fisheries, relatively few resources have been directed towards evaluating the impact of increased mesh size or different mesh orientation on codend selectivity. Such a consideration applies only to very small bycatch, including small or undersized finfish and shrimp, but in many fisheries the codend is constructed from diamond mesh netting and a protective skirt or cover that prevents the escape of all but the smallest individuals. It is tempting, therefore, to consider that fishers are already using codends that have been optimized to reduce this bycatch. However, this is unlikely to be true because fishers typically select codend netting based on their desire to eliminate the possibility of shrimp loss, using netting that is inexpensive and readily available. It can also be influenced by tradition and habit, and sometimes these do not accurately reflect the conditions of the contemporary fishery. As a result, fishers have seldom optimized codend netting based on the twin goals of bycatch reduction and shrimp retention. Researchers often support this behaviour by testing BRDs to reduce small bycatch without gaining knowledge about the potential of modification to codend mesh size or geometry to achieve the same outcome. Such approaches eliminate the possible application of a cheap and simple BRD, which potentially allows the escape of large numbers of small bycatch, and which if successful may be adopted more readily by fishers than other more cumbersome and complicated BRDs.

Although a variety of other options exist to reduce bycatch that do not require modification to fishing gear, such as spatial and temporal closure of fishing grounds or controls on fishing effort, the use of BRDs is probably the most common because BRDs can be highly effective, their introduction can be relatively straightforward, and they do not limit the ability of fishers to go fishing.

4.1 BRDS TO SEPARATE SHRIMP AND BYCATCH BY SIZE

These BRDs include inclined grids or panels of netting to physically block the passage of large bycatch into the codend, such as sea turtles, rays and jellyfish, and guide it towards an escape opening in the codend. A TED is also an example of this type of BRD. The juvenile and trash excluder device (JTED) and square-mesh codend also fit into this category because they are designed to filter small bycatch passively from the codend (Plate 17).

The use of TEDs is perhaps the best example of global efforts to reduce bycatch in shrimp fisheries. Faced with rising concerns over the mortality of sea turtles from fishing activity, there have been significant global efforts to develop effective TEDs that safely exclude these animals from a trawl. Australia and the United States of America have played a key role in these efforts by being at the forefront of TED research and development (R&D), and the use of these devices is now mandatory in both countries. In addition, the United States of America has placed an

PLATE 17 – The catch on the right consists of small fish that escaped through a JTED or codend mesh. They were retained in a small-mesh cover net that surrounded a codend fitted with a JTED. These fish would normally escape capture. The catch on the left was retained in the codend

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PLATE 18 – Bycatch from shrimp trawling is usually dominated by large volumes of fish and the occasional large animal

CREDIT: S. EAYRS

embargo on shrimp imports from those countries where approved TED designs are not being used (see www.nmfs.noaa.gov/pr/species/turtles/ shrimp.htm). Only countries with an established sea turtle protection plan that provides a satisfactory level of turtle protection are exempted from this embargo. Combined with domestic pressure to protect sea turtles and minimize threats from shrimp trawling, many other countries have been actively developing, testing, and introducing TEDs into their own fisheries. As a result of this activity, many countries have now developed their own TED regulations, including the requirement for shrimp fishers to use TEDs of a specified design, size and orientation while operating in local waters.

From an ecological perspective, the introduction of TEDs in many fisheries has been highly successful and the capture of sea turtles almost entirely eliminated. An additional benefit of using TEDs is the exclusion of other large unwanted animals and sea-bed debris from the trawl. The abundance of many species, including slow-growing, poorly fecund sharks and rays, and large finfish, has been reduced dramatically in locations where shrimp trawling takes place, and the use of TEDs provides an opportunity for fishers to reduce their impact on these vulnerable species.

From an economic perspective, the introduction of TEDs (and other BRDs) can produce mixed outcomes. For example, in some instances, fishers can benefit economically from the use of TEDs because the exclusion of seas turtles and other large animals prevents them from damaging codend netting and the shrimp catch (Plate 18). Moreover, the absence of these animals in the landed catch means reduced processing times and improved shrimp quality and value. Continued or new access to seafood markets as a result of using these devices can also produce positive economic outcomes for fishers.

In other instances, however, the use of these devices can result in economic loss for fishers. The initial purchase cost of TEDs or BRDs can be particularly high if two or more nets are towed simultaneously, and cost recovery through gains in shrimp quality and value could take many years. Shrimp loss through the escape openings of the device can also be a problem. This can occur if the TED or BRD is located too close to the accumulated catch in the codend, particularly if the catch surges forward through the net during haulback. Moreover, TEDs can guide commercially valuable fish from the trawl (Eayrs, 2007; Alió, Marcano and Altuve, 2010) and cause shrimp loss if the bars of the grid become blocked with sponges or debris. Efforts to minimize such losses must be carefully considered and incorporated into any bycatch reduction research plan.

4.2 BRDS TO EXPLOIT DIFFERENCES IN BEHAVIOUR

Many strong-swimming finfish and other animals can swim forward for a considerable time and maintain station with the moving trawl, often just ahead of the accumulated catch, in an attempt to delay capture in the codend. This behaviour is principally a response to the visual stimulus of the trawl and the generation of water turbulence as the trawl is towed through the water. In contrast, shrimp have relatively poor swimming ability and they are quickly overrun by an approaching trawl and retained in the codend.

To exploit these differences in behaviour, BRDs should be located in the codend a short distance ahead – typically no more than 2 m – of the accumulated catch. This can allow fish, but not the shrimp, an opportunity to reach and swim through the escape openings of the device. Many BRDs are designed to induce water turbulence and this may further improve bycatch reduction by reducing the swimming speed required for fish to reach the escape openings of the device.

Examples of BRDs that exploit behavioural differences between shrimp and fish include fisheyes, radial escape devices, and fish boxes. The recently developed nested cylinder device is also an example of this type of BRD (Plate 19). This device has demonstrated an ability to reduce catches of juvenile red snapper by more than 55 percent in the Gulf of Mexico Shrimp Fishery, and it was a runner-up in the 2007 World Wildlife Fund (WWF) International Smart Gear Competition (Anonymous, 2008). Researchers from the National Oceanic and Atmospheric Administration (NOAA) in the United States of America recently tested a composite panel BRD and a square-mesh panel BRD (Plate 20) fitted to the same codend and found that fish bycatch was reduced by up to 50 percent with less than 5 percent loss of shrimp (NOAA,

PLATE 19 – This nested cylinder device (designed in the United States of America) uses contrasting colours and water turbulence to aid the escape of red snapper from the codend

CREDIT: G.R. PARSONS.

PLATE 20 – BRDs such as the square-mesh codend are designed to exclude fish bycatch from the trawl

CREDIT: S. EAYRS

2010). In Australia, researchers reported that the Popeye fishbox (Plate 21) reduced fish bycatch by up to 48 percent with less than 2 percent loss of shrimp (Raudzens, 2007). Collectively, these figures are very encouraging and are generally superior to figures produced by BRDs designed to exploit size differences between fish and shrimp. These figures are a step in the right direction, and they suggest that further efforts to exploit differences in fish and shrimp behaviour should be the focus of future BRD research.

PLATE 21 – The Popeye fishbox was designed in Australia to reduce fish bycatch. The water turbulence produced by the curved foil helps fish bycatch to escape from the codend. Note that a TED is located ahead of the fishbox. The two netting panels between the TED and fishbox are part of the codend hauling arrangement

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4.3 INTERNATIONAL EFFORTS TO REDUCE BYCATCH

Australia and the United States of America have a long history of continuous development of BRDs in tropical shrimp fisheries, commencing this research in earnest in the final decades of the twentieth century. Both countries have now tested and developed a large number of BRDs in their respective fisheries, and the mandatory use of approved TED designs has dramatically reduced the impact of trawling on sea turtle populations to the extent that nearly all sea turtles that enter a trawl are subsequently excluded quickly and safely. The successful introduction of these devices took several years and required a commitment by fishers, researchers, managers and others to work collaboratively towards the common goal of sea turtle protection. A well-funded, wide-ranging extension programme for all stakeholders has been an essential ingredient in the success of these programmes.

In the United States of America, shrimp fishers are required to use either one of several variations of the fisheye, or the radial escape section or a composite square-mesh panel (Office of the Federal Register, 2008). In Australia, a range of approved BRDs are available for use, including the fisheye, radial escape section, fishbox, and square-mesh panel (Eayrs, 2007). Several other countries and regional fisheries agencies have also been tackling the bycatch issue. The Southeast Asian Fisheries Development Center (SEAFDEC), an intergovernmental organization with its headquarters in Thailand, has been working on the development of BRDs for Southeast Asian fisheries for over a decade. This work includes the development of the Thai turtle-free grid and several variations of the JTED (Plate 22), and associated testing in fisheries located in the Philippines, Thailand, Indonesia, Myanmar, Malaysia, Viet Nam, Cambodia, and Brunei Darussalam. The SEAFDEC has also proved to be especially adept at developing and producing training and promotion materials on bycatch reduction for regional fishers, researchers, and others.

PLATE 22 – The Thai JTED is designed with two grates that can be rapidly changed to alter bar spacing or orientation. Here, the grates are oriented to exclude small flat fish from the codend

CREDIT: S. EAYRS

Norway has also played a role in BRD development for tropical shrimp-trawl fisheries, primarily through the development of the Nordmøre grid and the radial escape section. Both devices were initially designed to reduce bycatch in temperate-water trawl fisheries but have been successfully adapted to fisheries in lower latitudes. Mexico also has a long history of BRD development, dating back to at least 1993 (Garcia-Cuadillo, Cisneros-Mata and Balmori-Ramírez, 2000), and the use of TEDs is mandatory in industrial shrimp-trawl fleets in the Pacific Ocean and Gulf of Mexico (Eayrs, 2007). There are also ongoing efforts in Mexico to reduce fish bycatch using a modified radial escape section, and these efforts have yielded promising results. In French Guiana, shrimp fishers are using a modified TED with a narrow bar spacing (50 mm) called a trash and turtle excluder device to exclude smaller bycatch in addition to sea turtles (WWF, 2010; Nalovic and Rieu, 2010), and in Venezuela (Bolivarian Republic of) extensive efforts have been made to evaluate the efficacy of TEDs used by industrial shrimp trawlers to exclude sea turtles (Alió, Marcano and Altuve, 2010). In the offshore shrimp fishery in Colombia, TEDs are also being used (Puentes, Madrid and Zapata, 2007). A summary of BRD performance in tropical and subtropical shrimp-trawl fisheries is provided in Table 3.

TABLE 3

Effect of BRDs on small fish bycatch and shrimp in tropical and subtropical shrimp-trawl fisheries from selected studies by country

BRD	Proportion (bold type indicates loss)		Location	Author
	Bycatch (%)	Shrimp (%)		
TED + RES	24	20	Queensland, Australia	Courtney *et al*., 2006
TED	10	12	Queensland, Australia	Courtney *et al*., 2006
RES	19	9	Queensland, Australia	Courtney *et al*., 2006
STED	32	29	Queensland, Australia	Robins-Troeger, 1994*
AusTED	11–59	9–**3**	Queensland, Australia	Robins-Troeger, Buckworth and Dredge, 1995*
AusTED	15–49	45–**27**	Queensland, Australia	Robins and McGilvray, 1999*
STED	32	1	New South Wales, Australia	Andrew, Kennelly and Broadhurst, 1993*
NG + SMP	58	41	New South Wales, Australia	Broadhurst *et al*., 1997*
CSMP	23–41	14	New South Wales, Australia	Broadhurst & Kennelly, 1997*
CSMP	40	1	New South Wales, Australia	Broadhurst & Kennelly, 1996a*
NG	90	11	New South Wales, Australia	Broadhurst & Kennelly, 1996b*
Popeye FB	29–48	2–**3**	Northern Australia	Raudzens, 2007
SS	5	0	Northern Australia	Brewer *et al*., 1998
NG	15	5	Northern Australia	Brewer *et al*., 1998
RES	20	5	Northern Australia	Brewer *et al*., 1998
FE	15	20	Northern Australia	Brewer *et al*., 1998
SMW	17–30	3–17	Northern Australia	Brewer *et al*., 1998
SS + FE	12–15	2–10	Northern Australia	Brewer *et al*., 1998
NG + FE	25–30	15–17	Northern Australia	Brewer *et al*., 1998
NG + SMW	30–40	17–38	Northern Australia	Brewer *et al*., 1998
AUSTED	27	23	Northern Australia	Brewer *et al*., 1998
FE	10	8	Northern Australia	Brewer *et al*., 1998
TED + SMW/BE	8	6	Northern Australia	Brewer *et al*., 2006
TED	8	6	Northern Australia	Brewer *et al*., 2006
RES	48	27	Brazil	

TABLE 3 – Continued

BRD	Proportion (bold type indicates loss) Bycatch	Shrimp	Location	Author
	(%)	(%)		
TED	15	1	Caribbean, Colombia	
FRD	11	1	Caribbean, Colombia	
TED + FRD	31	6	Caribbean, Colombia	
NG	58	0–20	French Guiana	
SS	6	3	French Guiana	
SS	44	19–**9**	French Guiana	
BED	58–64	27	Indonesia	
SMW + cone	28	15	Persian Gulf, Iran (Islamic Republic of)	
TED	4	6	Persian Gulf, Kuwait	
SMC	3	10	Persian Gulf, Kuwait	
FE	25	20	Persian Gulf, Kuwait	
RES	37	7	Gulf of California, Mexico	
TED	11	2	Gulf of Tehuantepec, Mexico	
FE	61	10	Atlantic, Nigeria	
TED	38	18	Papua New Guinea	
SS	0–3	0	Gulf of Thailand, Thailand	
TTFD	0–5	1	Gulf of Thailand, Thailand	
GJ	0–1	0	Gulf of Thailand, Thailand	
Thai KU	0–6	19	Gulf of Thailand, Thailand	
NMFS TED	51–53	5–**3**	Gulf of Mexico, United States of America	
TED	24–44	22–**4**	Gulf of Mexico, United States of America	
STED	24	8	Gulf of Mexico, United States of America	
TED	–	4–14	Gulf of Mexico, United States of America	
FE	28	5–14	Gulf of Mexico, United States of America	
EMF, FE	79	3	Gulf of Mexico, United States of America	
FE	17	2	Gulf of Mexico, United States of America	
Nested cylinder	55	9	Gulf of Mexico, United States of America	
CP + SMP	30–50	1–5	Gulf of Mexico, United States of America	
TED, FE	11–60	-	SE Atlantic United States of America	
TED, FE, EMF	59	12–**8**	SE Atlantic United States of America	
JTED	73	8	Sea of Viet Nam, Viet Nam	

* Data sourced from Broadhurst (2000).

Notes: All proportions represent the reported catch gain or loss (by weight) in a codend fitted with a BRD in comparison to a standard codend (no BRD fitted). Figures in bold type indicate a catch gain compared to a standard codend; all other figures indicate a reduction. AusTED – Australian TED, BED – bycatch exclusion device, CP – composite panel, CSMP – composite square-mesh panel, EMF – extended mesh funnel, FB – fishbox, FE – fisheye, FRD – fish reduction device, GJ – Georgia jumper TED, JTED – juvenile and trash excluder device, NG – Nordmøre grate, RES – radial escape section, SMW – square-mesh window, SS – super shooter TED, STED – soft TED, SMP – square-mesh panel, TED – turtle exclusion device, Thai KU – Thai Kasetsart University TED, TTFD – Thai turtle-free device.

In 2002, FAO implemented a five-year global project aimed at mitigating the impact of shrimp trawling on bycatch – the United Nations Environment Programme (UNEP)/Global Environment Facility (GEF) project titled "Reduction of environmental impact from tropical shrimp trawling through the introduction of bycatch reduction technologies and change of management" (Gillett, 2008). The objectives of this project were to reduce shrimp trawl bycatch, including turtles, non-commercial fish, and juveniles of species used for human consumption, and to increase knowledge of the impact of trawling on the marine habitat. The major outputs from the project are described in Box 1. Eleven countries – Cameroon, Colombia, Costa Rica, Cuba, Indonesia, Iran (Islamic Republic of), Mexico, Nigeria, Philippines, Trinidad and Tobago, and Venezuela (Bolivarian Republic of) – and SEAFDEC fully participated in this project by holding workshops, exchanging information, and testing BRDs at sea.

BOX 1

Major outputs from the UNEP/GEF project "Reduction of environmental impact from tropical shrimp trawling through the introduction of bycatch reduction technologies and change of management"

- Identification of appropriate BRDs for each fishery/region & tests completed in most participant countries; 30–40 percent estimated bycatch reduction.
- Revised or new legislation adopted in Nigeria and Mexico; legal review commenced in other countries; Nigeria recertified for shrimp exports to the United States of America through the reintroduction of approved TED designs.
- Recognition of the need for broader fishery management approaches to reduce bycatch, including effort controls and boat limits.
- Extensive regional and global collaboration, cooperation initialized, and steps to harmonize bycatch reduction at the subregional level.
- Knowledge of bycatch composition and quantities, and the socio-economic role of bycatch.
- Enhanced cooperation between government and industry sectors.
- Awareness of importance and usefulness of BRDs, and knowledge of possible technical solutions among various stakeholder groups
- Project Web site, training materials and FAO manual, *A guide to bycatch reduction in tropical shrimp fisheries* (Eayrs, 2007).

Source: Adapted from Gillett (2008).

4.4 REGULATORY ENVIRONMENT AND ATTITUDES OF FISHERS

Despite widespread efforts to develop effective BRDs, their performance remains far from optimized. To a large extent, this is because of a lack of support for R&D as well as ineffective regulatory frameworks. In many countries, the use of BRDs is not required by regulatory authorities; in others, they are required to be used but the authorities do not have the ability to regulate and monitor their appropriate use effectively (Gillett, 2008).

A measure often overlooked is the prescribed location of the BRD in the codend. This allows fishers to locate a BRD well ahead of the accumulated catch where the risk of shrimp loss is minimized. However, this may compromise bycatch reduction because many bycatch species are unable to swim forward and reach the escape openings of the device. However, given variation in catch volume, catch composition, codend design, and fishing practices among boats, prescribing the location of a BRD in the codend is difficult. One option that may remedy this problem is the application of bycatch reduction targets. Several countries have instituted such targets with some notable successes. For example, the development and effectiveness of the Australian fishbox BRD and the United States nested cylinder BRD occurred primarily because bycatch reduction targets provided a goal for researchers and fishers to strive towards. These devices have now been proved to be extremely effective, with superior bycatch reduction performance compared with most other BRDs. It is noteworthy that these BRDs rely upon behavioural separation of fish and shrimp, and their encouraging performance suggests that further exploitation of fish and shrimp behaviour could yield additional improvements in bycatch reduction and the development of entirely new BRD designs.

Primarily owing to fear of shrimp loss, fishers themselves are often reluctant to test BRDs and hamper their introduction. This is an understandable concern given that fishers spend considerable time ensuring there are no holes in their nets to allow the escape of shrimp and view the large escape openings of a BRD with a high degree of anxiety and foreboding. These concerns are often realized during initial testing of these devices, when the loss of shrimp is often very high. As with any new piece of fishing gear, it takes time for fishers to become experienced and capable of using the new gear efficiently. Persistence is key to fine-tuning the device for optimal performance.

In summary, bycatch regulations in many countries are absent or inadequate, and shrimp fishers are under little or no pressure from regulatory authorities to use a BRD or improve BRD performance. Until this environment is improved, the development of effective BRDs will remain severely compromised.

4.5 ASSUMED ECOLOGICAL BENEFIT OF BYCATCH REDUCTION

The introduction of BRDs in tropical shrimp fisheries is based on two key assumptions pertaining to their operation and effectiveness. The first assumption is that the capture of bycatch is too high and needs to be reduced. Although concern has been raised that using fishing gear to select (remove) preferentially a few species over a limited size range poses a greater ecological risk than selecting many species over a wider size range, adopting a precautionary approach and improving the selectivity of shrimp trawling remains a core goal of fisheries management.

The second assumption is that bycatch survives the process of temporary retention in a trawl and escape through a BRD. Many finfish and other animals physically contact trawl netting, other individuals, or the BRD prior to their escape, and the effect of this contact on their health and survival is poorly understood. For some of these animals, scale loss and bruising can be substantial and could result in their delayed mortality following escape. For others, bruises, incisions and puncture wounds following contact with other individuals could produce a similar outcome. While relatively few attempts have been made to evaluate the survival of bycatch that has escaped from a BRD, the assumption of a higher rate of survival compared with that following their discard from the deck of a boat continues to underpin BRD research.

5. Planning for BRD research

The success of an experiment at sea is largely the result of careful planning, choice of experimental method, collection of high quality data, and appropriate statistical design (Wileman *et al*., 1996). Careful planning improves the likelihood of project success because research staff and equipment are prepared well in advance of the fieldwork, potential risks and problems are identified early, and contingency plans are in place to respond appropriately. This section describes the necessary steps to plan for effective BRD research.

A research experiment should ideally be designed to provide adequate time, personnel and other resources to test a BRD under conditions that closely mimic commercial fishing conditions. Sometimes, shrimp loss is very high during the initial stages of the experiment, and resources will need to be allocated to allow for troubleshooting and fine tuning BRD performance. Once the performance of the BRD is satisfactory, the research programme should have adequate resources to enable an effective extension (outreach) programme, including additional tests and demonstrations in other locations within the fishery, and resources for fine tuning BRD performance in these regions.

It should also be noted that a successfully tested BRD in one fishery (or perhaps in another country) is not guaranteed similar success in another. There is a high probability that the position of the BRD will need to be modified and tested in several locations in the codend, and across a variety of conditions and locations within the fishery, before bycatch reduction performance is optimized.

5.1 INVOLVING THE FISHING SECTOR IN THE PLANNING PROCESS

Every effort should be made to ensure that representatives of the fishing industry are involved in the entire development process, from initial research planning to fieldwork to reporting and extension of results. This may be difficult if fishers are not enthusiastic about reducing bycatch. Common reasons for lack of enthusiasm include:

- a fear of shrimp loss (or other commercially valuable species) through the escape openings of a BRD;
- a distrust or lack of familiarity of working with researchers;
- concerns about a possible increase in fuel consumption following the installation of a BRD;
- concerns over crew safety, particularly when using a large, rigid TED;
- a lack of awareness regarding the impact of shrimp trawling on ecosystem health.

A failure to address these concerns will hamper the development of efficient BRD designs, delay the uptake and adoption of these devices by fishers, encourage poor compliance with regulations, and compromise bycatch reduction. Essential steps to improve the enthusiasm of fishers and encourage their participation in bycatch reduction research are described in Box 2.

Involving fishers in R&D provides an opportunity to access their knowledge and experience, including identification of suitable fishing grounds and timing of the research, knowledge of expected catch volume and composition, and knowledge of fishing gear design and preparation. It also provides access to their boats to conduct the fieldwork, helps to build their trust, and enables them to provide an essential contribution to BRD development based on their fishing knowledge and experience. In this way, the fishing gear and sampling protocol can be adapted to suit the expected conditions of the fishery. In addition, potential handling issues associated with a BRD onboard a commercial fishing boat can be identified and overcome early in the testing programme, and other concerns by fishers over the use of these devices can be considered and addressed in the testing programme.

BOX 2

Improving enthusiasm and participation of fishers in bycatch reduction research

There are several essential steps that a researcher can take to improve the enthusiasm of fishers and encourage their involvement in bycatch reduction research. They include:

- Providing fishers with a rationale and need for reducing bycatch. Fishers need to understand why some species require protection and the impact that fishing has on these species, even if they are personally seldom encountered, and the potential threats bycatch may pose to their livelihood.d.
- Giving fishers an opportunity to contribute and co-own the research process. This includes:
  - asking fishers to contribute ideas to reduce bycatch;
  - inviting fishers to contribute to the research activity, from research planning to gear design and construction, from fieldwork to outreach activities;
  - conducting research onboard their own trawlers, making them familiar with the work from the onset, and when not in conflict with the research, giving them an opportunity to improve on BRD design;
  - seeking their advice and assistance regarding outreach opportunities, preparation of reports, co-authorship of reports and papers, and presentation of results to fishers and other stakeholders.
- Providing timely feedback to all fishers on research progress and results, from identification of the bycatch problems, to descriptions of research methodology, including BRDs to be tested, to results and consequences.
- Addressing the fears and concerns of fishers associated with the use of BRDs. This includes ensuring that minimizing shrimp loss or other valuable species is an important research priority and will be reduced to the greatest extent practicable.
- Including bycatch that fishers would like to catch less frequently as a research priority. This might include dangerous or poisonous species, or those that damage the catch or delay catch processing.
- Taking the time to evaluate the potential economic benefits to fishers from reduced bycatch, such as improved trawl performance and catch quality, reduced trawl damage, and opportunity to access preferential markets.
- Providing fishers public recognition and credit for their contributions.

Exploring the benefits of reduced bycatch to fishers is vital to their enthusiasm and involvement in bycatch reduction research. It also influences their continued involvement once the research has been completed, including the uptake of BRDs on a permanent basis and their ongoing refinement to suit variable operating conditions. Even a mandatory requirement to use these devices will not guarantee full compliance with the regulations if fishers are not interested in reducing bycatch. This will lead to higher compliance costs and the prospect of suboptimal bycatch reduction performance. If all efforts fail and fishers cannot be convinced to contribute to this research, initial efforts may have to commence without their involvement, perhaps on a research vessel. This is usually a far less desirable option, but efforts must still be made to keep them informed of all research progress and developments. It may take considerable time and effort to establish a working relationship with fishers and gain their trust and involvement, but their role in bycatch reduction is ultimately essential. Once the performance of these devices has been initially tested, it may be possible to convince some fishers of the benefits of bycatch reduction and demonstrate that some fears are unfounded. Then, they may be more inclined to participate in further research. Persistence is key.

5.2 PROPOSED RESEARCH

A project proposal is a document that describes important details about the proposed research programme (Box 3). It is essential that a project proposal is prepared well in advance of the intended fieldwork because it serves as a guide for all project personnel and a focal point describing the agreed development process. If the research requires funding by an external agency, adequate time is required for the agency to complete a review of the proposal and award funding. In those instances where external funding is sought, care should be taken to review the terms and conditions associated with project proposal submission as these vary between funding agencies.

BOX 3

Contents of a project proposal

A project proposal should be carefully and thoroughly written to provide reviewers with a full and complete understanding of the proposed research. The proposal should contain the following information:

- cover page with project title, names of principal investigators, and project start and finish dates;
- introduction, including description of the bycatch problem, key issues, project background, and rationale;
- project impact, outcomes, outputs and activities;
- research methods, including experimental methods and statistical design;
- research time frames and milestones;
- research feasibility, risks and contingency planning;
- beneficiaries of the research;
- extension of results;
- project staff;
- budget and budget narrative.

Before seeking external funding or approval of a project proposal, a review of the proposal by other researchers is useful because it provides an opportunity to receive fresh ideas and technical comments, particularly on the appropriateness of the proposed research methodology. If changes are suggested or required by the reviewers, they can be made prior to commencing the research, thus minimizing costs and risks to a successful research outcome.

5.2.1 Cover page

The project proposal should contain a cover page containing project title, name and affiliation of principal investigators, and the proposed start and finish dates of the research programme. This information highlights what the project is about, who is leading the research, and when the research will commence and be concluded. The project title requires careful consideration because it must precisely and succinctly reflect the content and intent of the proposal. Information that can be included in the title includes the gear modifications to be tested, the fishery or locations where the research is to be conducted, and the bycatch that is a focus of the research. A review of titles from peer-reviewed scientific papers and their references is a good way to learn how to write an appropriate project title.

5.2.2 Introduction

This part of the project proposal describes the rationale and importance of the intended research. It is important to describe in some detail the nature, extent and frequency of the bycatch problem, and how or to what extent the intended research will address this problem.

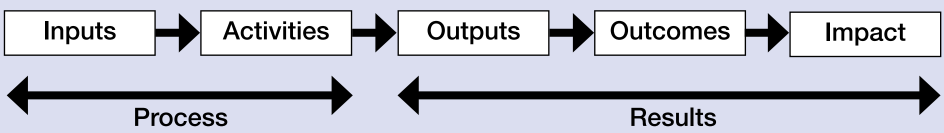
The introduction is also an opportunity to provide a history of the bycatch problem in the fishery of interest and other similar fisheries, including reviews of relevant research and literature, and the implications of failing to reduce adequately or eliminate the bycatch problem. This detail provides the proposal context and enables assessment of the merits of the intended research programme, and is particularly important if the proposal is to be used to attract research funding.

5.2.3 Project framework

The project framework is a systematic, results-based approach (Box 4) to research that articulates clearly how project inputs will lead to project outcomes and impact on the fishery and wider environment. Project researchers must clearly understand the difference between each section of the framework and the associated information needs.

BOX 4

Project Framework



The project framework is comprised of the following processes and results:

Inputs – all personnel, finances and material resources that contribute to project activities.

Activities – the coordination of inputs, training, and programmatic tasks and actions organized and carried out by project personnel, including fieldwork. In a proposal, these activities are described using verbs or adverbs such as analyse, evaluate, measure, train, test, demonstrate, consult, and raise awareness.

Outputs – the immediate products of one or more project activities, for example, the production of a project report, usually within a predefined timeline.

Outcomes – the intermediate results due to the preceding project outputs.

Impact – the ultimate result or end-point attributable to the combination of outcomes achieved by the project.

Project outputs and outcomes should be formulated in very clear terms that are qualitatively and quantitatively verifiable using relevant performance indicators for monitoring and evaluation purposes. The success or failure of the project will be judged mainly on its ability to reach project outcomes, and it is important therefore to identify the specific problem to be solved and ensure that project outcomes are realistic and not overly ambitious. Similarly, outputs should be realistically achievable given the context in which the project will operate and limitations in terms of financial resources and project extent. Examples of potential outputs and outcomes are provided in Table 4.

The impact of the project should be formulated in terms of a desired end-state following completion of the project. This will help ensure the project is oriented towards the production of meaningful results, including those that contribute to bycatch reduction and the sustainable utilization of marine resources.

5.2.4 Monitoring and evaluation: use of SMART indicators

Monitoring and evaluation (M&E) is an integral part of the project design and management process from the outset. It allows for reflection and provides a reporting system for project staff

TABLE 4

Examples of possible outputs and outcomes for a bycatch reduction project

Outputs	Outcome	Impact
Broader stakeholder (fishers, researchers, resource managers, environmental NGOs, and others) collaboration and coordination Increased understanding and awareness of the needs and aspirations of each stakeholder group Greater awareness of bycatch related issues through workshops, meetings, and mass media, contributing to wider support for regional and national project activities	Increased understanding and awareness of fisheries resources, ecosystem management, and the impacts of fishing processes Greater multistakeholder participation in the work of the national and regional institutions with respect to fisheries management	Marine resources and stocks are protected, and biodiversity maintained through the application of effective bycatch management measures
Three BRDs jointly developed, tested, and evaluated in pilot areas by fishers and researchers	A cost-effective, safe, and reliable BRD that reduces two priority bycatch species by 80 percent in pilot regions under controlled conditions	
Three BRDs thoroughly tested in diverse locations and times within the fishery using appropriate indicators and performance measures	At least one BRD meets science and industry performance criteria and is approved for fleet-wide implementation and integrated into management planning processes	
Targeted initiatives in the fishing fleet to promote and support best practice guidelines for fishing operations using BRDs	80 percent of the vessels in the fleet implement BRDs and adopt best practices for bycatch management	
Legal arrangements and compliance mechanisms strengthened and implemented in the fishery for the use of BRDs by fishers Fishery monitoring, control, surveillance, and enforcement programmes effectively strengthened at sea, dockside and in the courts through training of legal and fisheries protection officers to implement conservation management measures and national laws	Effective monitoring and environmental protection services in the fishery reduces illegal, unreported and unregulated fishing by 90 percent and contributes to long-term sustainability of target stocks and bycatch species	
Comprehensive set of practical conservation and management measures at national levels, consistent with regional and global instruments Strategy for long-term capacity development in fisheries management and environmental protection formulated and implemented	Innovative on-the-water conservation and management measures implemented and in line with ecosystem-based management and in compliance with national targets	

and stakeholders. Monitoring (including setting baseline performance indicators and gathering data), evaluation and reporting must be planned for, managed and resourced. These tasks are an essential part of good project management.

A performance indicator is a quantitative or qualitative factor or variable that provides a simple and reliable means to measure achievement or progress of an activity. Performance indicators must be SMART: specific, measurable, attainable, relevant and time-bound.

5.2.5 Research methods

This is a very important part of the research project because it describes how the work is to be carried out. It provides a detailed description of the proposed research methods to assess BRD performance, as well as the specific hypotheses to be tested and the level of required statistical certainty. It should also include a detailed description of the BRDs to be tested, the fishing gear and boat to be used, and the location and duration of the fieldwork. A description of the sampling protocol is essential, including details describing the sampling methods and the proposed statistical design to test the hypotheses.

5.2.6 Project time frames and milestones

The time frame of all key research activities that comprise the intended research should be identified and clearly articulated. Key activities include review of the relevant literature, planning meetings with key stakeholders, submission of permits, identification of appropriate boats, construction or purchase of fishing gear and BRDs, fieldwork, analysis, and completion of all relevant reports. As the timing and duration of each of these activities varies, it is often convenient to use a Gantt chart to display this information (Table 5). The time frames indicated in a Gannt chart should be reasonable and allow sufficient flexibility should unforeseen problems arise.

TABLE 5

An example of a Gantt chart for a twelve-month project

	Month											
Activity	1	2	3	4	5	6	7	8	9	10	11	12
Planning meetings	X	X			X			X			X	X
Permit application	X											
Literature review	X	X	X									
Boat identification		X										
Gear construction/purchase		X	X									
Fieldwork			X			X			X			
Data analysis				X	X		X	X		X	X	
Milestone report					X			X			X	
Final report												X

Milestones mark the end of an important phase, section or component of the research programme. They may indicate the completion of fieldwork or the end of a year's work in a multiyear research programme, and are often recognized by the completion of a milestone report. These reports may be requested by funding agencies because they indicate research progress and flag potential problems that may affect final project outcomes.

5.2.7 Project risk assessment

While every attempt should be made to follow the details outlined in the proposal, the best prepared plans may need to be adjusted because of unforeseen circumstances.

This part of the project proposal serves to identify possible risks to a successful project outcome and provide a contingency plan should such events occur. Examples include poor weather, lost or damaged fishing gear, inadequate catch data to compare BRD performance, and inappropriate data analysis. While it is not possible to identify all risks, this part of a proposal is an important first step towards being prepared to identify potential threats to the project and how they may need to be addressed. For each risk identified, two questions should be asked:

1. What is the likelihood that the risk will occur?
2. What is the consequence or impact on the project if the risk occurs?

The answers to these questions can then be ranked based on their likely level of impact and consequence using a numerical scoring system, which in turn enables a fuller assessment of risks to project success (Box 5).

BOX 5
Risk assessment scoring system

A risk assessment can be based on a numerical scoring system (see tables below) that considers the likelihood of an identified risk becoming a reality and the associated consequence. For example, if fieldwork is timed for the monsoon season, the risk of rough seas may be sufficiently certain that the level of risk scores a 6. If a small boat is used for fieldwork, this weather may have a major consequence on the ability of researchers to collect data, and the level of impact may be at least a 4. The product of these two numbers is 24 and the associated risk ranking category is extreme. Serious consideration should therefore be given to planning the fieldwork for another time.

By repeating this process, it becomes possible to rank and prioritize all identified risks and then take steps to minimize the likelihood of them becoming a reality. Risks that have a catastrophic level of impact should always be prioritized highly irrespective of their likelihood level of risk. For example, while the risk of losing fishing gear is usually rare (score of 2) the consequence could be catastrophic (score of 5) and produce a total ranking that is moderate (10). Despite this low score, lost fishing gear may bring a sudden end to the project, perhaps for days or even weeks as replacement gear is sought.

Likelihood levels of risk

Likelihood	Score	Definition
Likely	6	It is expected to occur
Occasional	5	May occur
Possible	4	Some evidence that is may occur
Unlikely	3	Uncommon, but has been known to occur
Rare	2	May occur in exceptional circumstances
Remote	1	Never heard of, but not impossible

Consequence levels of impact

Consequence	Score	Definition
Negligible	0	Insignificant project impact; no delay to completing the project
Minor	1	Minimal project impact; delay measured in minutes
Moderate	2	Maximum acceptable level of impact; delay measured in hours
Severe	3	Long term impact, delay measured in days
Major	4	Very serious impact; delay measured in weeks or months
Catastrophic	5	Project immediately stops or ends with no hope of repeating

Risk ranking category

Score		Category
0	=	Negligible risk
1 – 6	=	Low risk
8 – 12	=	Moderate risk
14 – 18	=	High risk
19 – 30	=	Extreme risk

Sources: Tables adapted from Fletcher (undated).

5.2.8 Project stakeholders and beneficiaries

Stakeholders are best defined as people, groups or organizations that have a direct or indirect stake in the project because they can affect or be affected by the activities and outcomes of the project. The key benefits of having stakeholders include:

- Valuable opinions, views and suggestions of the stakeholders can help shape the project while it is still in its developmental stage. This can significantly improve the quality of the project.
- With stakeholder support, access to useful resources may be more readily available. This will increase the chance of the project reaching a successful outcome or attaining even greater success.
- The active participation of stakeholders will make them understand the nature of the project and they can then contribute by actively supporting the project.
- By envisaging in advance the reaction of stakeholders to the project, activities including outreach can be built into the project to accommodate their reaction and win their support.

It is important to prioritize stakeholders and identify which are affected by the project and to what extent. A useful starting point is to classify them by their interest in the project and potential power to influence project performance and outcomes (Table 6). The final and most important stage is to ascertain what exactly motivates the stakeholders and then adopt the best way to win them over. It is necessary to take into consideration what kind of approach would be required and what information would the stakeholders need. Successfully conducting a stakeholder analysis in the early stages of planning can greatly improve the quality of a project.

It is also important to identify the beneficiaries and key actors in the project as this helps provide a focus for the activities to be completed. Fishers will be beneficiaries of the project if it reduces their workload, improves catch value, reduces operating costs, or allows continued access to fishery resources. Identifying other key beneficiaries of the research, including the fishery management authority, other government bodies, environmental non-government organizations (NGOs), or other groups, can be useful as a way to source appropriate research funding.

5.2.9 Extension of results

A project proposal should include an extension or outreach plan that clearly identifies how fishers, fishery managers and key actors will be informed of project progress, results and outcomes. The extension plan should identify the media that will be used to provide project information and the timing of media releases. For example, suitable media to present project outcomes to fishers includes direct conversation, port meetings, brochures, pamphlets and general literature using attractive imagery, charts and photography. Videos are also an excellent option for information transfer, particularly if they contain underwater video of fishing gear and BRDs in operation. Suitable media for fishery managers and others includes all the above options as well as e-mail, scientific or peer-reviewed articles, workshops and conferences.

5.2.10 Project staff

The principal investigators and all key project staff involved in the research should be listed in the project proposal. Other important details include the affiliation of all staff members and a brief description of their qualifications and expertise in relation to the intended research. This information is essential so that funding agencies and other stakeholders know who to contact for further project information and in order to evaluate the credentials and ability of the research staff.

5.2.11 Budget and budget narrative

Considerable effort should be spent developing a budget that accurately reflects the expected costs of the research. The budget should be arranged in several categories, including the salaries and wages of all project staff (including fringe benefits, if applicable), fishing gear and sampling equipment, travel, supplies and materials, contracts (including boat charter if applicable), and any indirect costs for administration, utilities, etc. The cost of any outreach activity should also be included in the budget.

A budget narrative describes in detail how the budget in each category will be spent. The purpose of the narrative is twofold. First, it encourages researchers to think very carefully about the proposed research and associated costs, and minimizes the likelihood that the project will be underfunded. Second, it provides proposal reviewers with necessary information to understand adequately how and where the budget will be spent. It also gives them confidence that the researchers have carefully thought about the proposed research.

6. Preparing for fieldwork

This section describes the steps necessary to prepare for fieldwork. Failure to adopt these steps may stop or limit fieldwork, result in the collection of suboptimal or inappropriate data, and prevent hypotheses from being properly testing and evaluated.

6.1 PERMITS

Before commencing fieldwork, it is essential that all necessary permits are obtained from the appropriate regulatory authorities. This is especially important where the intent is to use or modify fishing gear that are not permitted in the fishery, where sampling is planned in locations usually closed to fishing activity, where work is going to involve protected species, or where catch samples are required to be retained for future analysis. As the application process may take several months, it is vital that a permit application is submitted to the authorities well in advance of the intended fieldwork. This will minimize possible delays to the fieldwork, and allow time to modify the research plan should this be required by the regulatory authorities. Even if no changes to the research plan are required, a permit obtained well in advance of the fieldwork means that preparations can continue with confidence while providing a buffer to deal with any unforeseen delays or problems.

6.2 SELECTION OF A FISHING BOAT FOR FIELDWORK

To test the performance of a BRD, a commercial shrimp trawler should be selected that normally operates in the area of intended fieldwork. This will provide access to a captain and crew experienced in handling and operating the trawler and fishing gear, as well as access to their knowledge of local fishing locations, shrimp and bycatch behaviour, and the availability of these species to the trawl (Wileman *et al*., 1996). Using a commercial trawler also ensures efficient operation and handling of the trawl gear, and processing and holding of the catch. The handling and performance of a BRD is also likely to mirror closely the handling and performance of the device when used by the fishing fleet under normal commercial operating conditions. A key point in using a shrimp trawler is that other fishers are more likely to be accepting of fieldwork results rather than results that come from a research vessel, particularly if the research vessel bears little or no resemblance to the trawler.

It is important to inspect the shrimp trawler prior to commencing the research to ensure it is a suitable and capable platform to conduct the research (Plate 23). It will also help guide the researchers in the development of an appropriate experimental design and sampling protocol based on available deck space and fishing gear. The trawler must have all necessary fishing gear, crew, and deck and safety equipment to enable the research to be completed efficiently and safely. It must have suitable deck space for scientific sampling and measurement of the catch (Plates 24–27) and an appropriate location for data entry and processing (Anonymous, 1995). It must also have sufficient accommodation for research staff and crew, and appropriate wheelhouse equipment to enable the safe operation and navigation of the trawler and the collection of important environmental

PLATE 23 – This trawler has limited deck space for crew, researchers, and fishing gear, and thus catch sampling will be difficult

CREDIT: B. CHOKESANGUAN AND S. CHINDAKHAN

PLATE 24 – A large, spacious back deck is essential for safe and productive research

CREDIT: J. MITCHELL

PLATE 26 – A commercial shrimp trawler rigged to tow a single trawl from the stern

CREDIT: S. EAYRS

PLATE 25 – With adequate deck space, the catch from each trawl can be separated and sampled by two teams of researchers. Otherwise, the catch will need to be bagged and frozen and returned to the laboratory for later sampling. Note the deck is covered to protect the crew and catch from the sun

CREDIT: B. CHOKESANGUAN AND S. CHINDAKHAN

PLATE 27 – With the outriggers extended outboard and the trawls in the water, this shrimp trawler has adequate deck space and accommodation for multigear fieldwork

CREDIT: B. CHOKESANGUAN AND S. CHINDAKHAN

information. If the trawler does not meet these requirements then another trawler may need to be sought.

The use of a research vessel for fieldwork may be an alternative option if a shrimp trawler is unavailable or unsuitable. A research vessel may provide additional benefits in terms of space for catch sampling and measurement, data entry and processing, as well as accommodation for research staff. This vessel may be larger than or different from typical shrimp trawlers in the fishery, which may be fine providing the fishing gear is identical to that used by local fishers and similarly operated. If multiple fieldwork trips are planned during a fishing season, a research vessel may be a preferable option to ensure the same vessel is available for each trip, particularly if the trips overlap with the peak fishing season when a trawler may not be available. A research vessel also helps ensure maximum control over research activities, and provides specialist facilities not available on a commercial trawler (Wileman *et al*., 1996).

6.3 RESEARCH STAFF AND SKILL SETS

The number of individuals that are required to participate safely and effectively in the research will to a large extent be determined by the objectives of the research, as well as the size and design of the fishing boat. Adequate personnel are required to complete various tasks, including gear handling, catch sampling and measurement, data collection and logging. Too few staff will delay or compromise completion of these tasks. They also risk being overburdened and fatigued, and less alert to potential risks to personal safety. On the other hand, too many staff will result in crowded conditions and inefficient utilization of funds (Anonymous, 1995), and reduce their ability to maintain a safe distance from moving deck machinery and other safety hazards.

All personnel should be selected based on their experience and ability to complete specified research tasks. They should be familiar with selectivity research and handling of fishing gear (Anonymous, 1995) and be suitably trained in appropriate sea safety procedures.

A worthwhile consideration in any experiment is the involvement of a statistician to avoid the risk of project failure owing to inadequate data collection and analysis. The statistician should be involved from the start of the project in order to be able to contribute effectively to project design and development. The statistician should be able to conduct an initial power analysis to determine the number of tows required to test project hypotheses (the data from preliminary tests may be useful here), identify appropriate statistical techniques to test project hypotheses, determine the amount or type of data to be collected in order to apply the identified statistical techniques, and then apply the statistical techniques to the data and contribute to project reports.

6.4 ALLOCATION OF WORK BETWEEN TEAM MEMBERS

All members of a research team must contribute to the fieldwork and have an equal or appropriate workload (Plate 28). Ideally, each member should have similar or comparable skills so that the workload can be shared and tasks completed in an equitable and efficient manner. It may be useful for the workload to be rotated among research staff so that each individual spends time measuring and weighing catch samples, recording data and any other related tasks. Care is required, however, that data collection is not compromised by variable measurement techniques among staff.

While working long hours at sea collecting catch data is a normal part of at-sea research, it is essential that opportunities are provided to rest and sleep. If the fieldwork is ongoing both night and day, it may be necessary to divide the research team into two groups with each group working for a predetermined period of time or shift. Typical shifts may be 8 or 12 hours in duration before replacement by researchers from the next shift.

PLATE 28 – All members of a research team must contribute to the fieldwork and participate in allocated tasks

CREDIT: S. EAYRS

6.5 PREPARATION OF FISHING GEAR, MATERIALS AND EQUIPMENT

A well-prepared research team ensures that research activity is fully coordinated, commences on time, runs smoothly, collects all required data, and reduces the potential for lost fishing time through gear loss or damage, poor weather, or other unforeseen incidents. Prior to the fieldwork, all fishing gear should be carefully checked and measured (Plate 29). If more than one trawl is used, efforts are required to ensure that all trawl dimensions are as similar as possible, including headline and footrope length, ground gear material, design, construction, and rigging, and mesh size, hanging ratio, and tapers in each part of the trawl. For each codend, the mesh size, the number of meshes in length and circumference, and their rigging should be checked to ensure they are identical. The otter boards should be identical in design, area, weight and rigging, and all wires (warp wires, sweeps and bridles) should be checked to ensure there are no differences between port and starboard sides. It is also essential that all length marks on the warp wires are clearly marked.

PLATE 29 – Prior to fieldwork, all fishing gear should be carefully checked and measured

CREDIT: S. EAYRS

6.6 PLANNING FOR GEAR DAMAGE

It is essential to be prepared for the risk of damaged or lost fishing gear during fieldwork. Collaborating with local fishers that trawl in the proposed testing location or using the fishing boat to survey trawl runs acoustically (perhaps as fishing gear is being readied) prior to the experiment should substantially reduce the risk of gear damage. Repairing or replacing damaged gear at sea is likely to be a less timely and costly exercise than having to return to port for replacement gear. It is essential that adequate netting material, twine, chain, shackles and other spare trawl components are purchased before the fieldwork and stowed onboard. The expense of chartering a shrimp trawler or research vessel, preparing fishing gear and sampling equipment, and bringing research staff together, only to be unable to complete the fieldwork due to poor planning or inadequate fishing gear is unacceptable.

While possibly not an option onboard small shrimp trawlers, industrial trawlers should have the space onboard to carry spares of large fishing gear components, such as otter boards, trawls and wires, so that a seriously damaged trawl can be totally replaced if necessary.

6.7 SAMPLING EQUIPMENT

The sampling equipment required for fieldwork can be divided into three groups: equipment for measuring the fishing gear (trawl, codend and BRD); equipment for measuring the catch; and equipment for measuring environmental variables (Wileman *et al*., 1996).

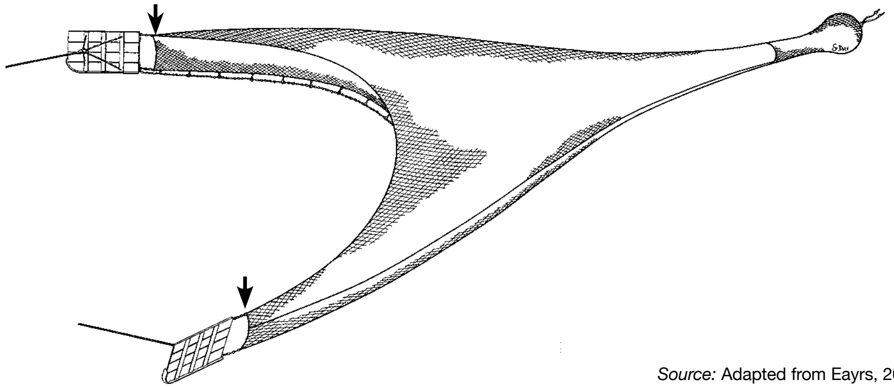
Equipment for measuring the fishing gear includes a mesh-measuring gauge approved by the International Council for the Exploration of the Sea or other body to measure the mesh opening (inside stretched mesh distance between opposing knots) in the trawl net and codend. Where such a gauge is not available, a tape measure or ruler provides a useful but less accurate option. Typically, a tape measure is used to measure mesh size between opposing knots rather than the actual mesh opening (Box 6), although care is required as regulations usually refer to mesh opening and not mesh size. A tape measure is also useful for measuring important lengths including otter

BOX 6

Measurement of mesh size

If an approved mesh-measuring gauge is unavailable, an option is to measure the length of ten consecutive meshes with a tape measure. The measurement of a single mesh is the distance from the centre of a knot to the centre of the opposing knot. To measure 10 meshes, 10 meshes are pulled taut and the distance between the first centre of knot to the last centre of knot is measured and then divided by 10 to calculate the average size of a single mesh. As mesh size may vary by as much as 10 percent across a panel of netting, this procedure should be repeated in several locations to calculate the average mesh size across the entire panel. At a minimum, it is recommended that measurements are taken from at least five locations.

FIGURE 3 – Headline length is the distance between the first and last twine hangings used to attach the netting to the headline (indicated with arrows)



Source: Adapted from Eayrs, 2007.

board height and length, and the lengths of the headline (Figure 3), footrope, sweep, bridle, ground chain and dropper chains. The tape measure will also be required to measure the dimensions of the BRD, such as mesh size, escape opening dimensions, or bar spacing.

PLATE 30 – Sampling equipment includes a measuring board to measure fish length. Typically, fish length is measured between the tip of the snout to the caudal fork

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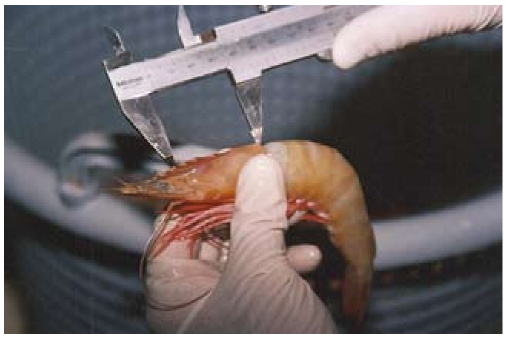
PLATE 31 – The measurement of shrimp requires carapace length to be measured using calipers. Carapace length is measured immediately behind the eye socket to the posterior edge of the carapace



CREDIT: S. EAYRS

Equipment to measure the catch includes calipers for measuring the carapace length of shrimp, and measuring boards for the measurement of fish and other animals (including shrimp if calipers are unavailable) (Plates 30 and 31). Scales that can weigh up to 50 kg are required to weigh baskets of shrimp, fish and other animals, while smaller scales that can weigh up to 1 kg or 5 kg are required to record weights of smaller numbers of animals (Plate 32).

Most equipment to record environmental variables can be obtained from the captain of the boat, from electronic equipment in the wheelhouse (it is necessary to check prior to the

PLATE 32 – Weighing scales to weigh the catch are essential equipment for catch sampling

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research that this equipment is operational) or from visual observations. This information includes the water temperature, wind speed and direction, sea and swell height and direction, tide and current direction, towing speed and direction, water depth, warp-to-depth ratio, and time of day or night. This information is particularly useful when trying to identify similar tows for comparison, or help explain reasons for variable trawl performance and associated catch variability.

Additional equipment that is useful during fieldwork includes a digital camera, underwater video camera, and in some instances, a portable Global Positioning System (GPS) unit or propeller log. A digital camera is useful to record deck operations and fishing gear for inclusion in research reports and presentations, and to collect images of fish that require identification in the laboratory. An underwater camera is useful to observe the trawl and BRD in operation, and the behaviour of fish in response to BRD. These observations can then be used to fine-tune the BRD to improve bycatch reduction, and stimulate ideas for further development, particularly by fishers. These observations are also extremely useful during the extension phase of the project, in particular to promote the effectiveness of a BRD, and they can be a useful tool to encourage attendance and participation of fishers at meetings and workshops. While many shrimp trawlers are equipped with a GPS unit, some are not, and a portable GPS unit is useful to provide important information about the location of the vessel, particularly the location of each tow. The GPS unit can also provide a measure of vessel speed over the ground, although a portable propeller log to measure vessel speed through the water can be used if a GPS is unavailable.

6.8 RECORD-KEEPING

It is essential that thorough and accurate records of all research activities are kept for future reference and analysis (Plate 33). Ideally, sufficient information needs to be collected to allow the complete replication of the research using identical fishing gear and operating conditions.

During the fieldwork, attention to detail is essential, and data need to be collected into four separate logs: trip log, haul log, catch log, and gear log. A trip log provides an overview of the fieldwork by describing the boat, area of operation, date, fishing gear, and timing of the fieldwork (Annex 2). Usually, only one trip log needs to be completed during the fieldwork, even if the fieldwork extends over several days.

A haul log contains specific information about each haul or tow, including the fishing gear and BRD used, haul location, depth, direction and duration, weather details, towing speed, warp length, and the total weight of each species caught (Annex 3). A haul log is specific to a particular haul or tow, so the number of haul logs reflects the number of hauls that were completed. If a problem is encountered with a particular haul, such as a damaged or fouled trawl, these details should also be recorded in the haul log. In most instances, the catch from this haul cannot be used to assess BRD performance; however, it is still important to record details of the haul. This will be useful for future reference and to explain reasons for lost fishing time during the research period. It is important that an accurate note of the fishing gear used, including type of BRD, is made for each haul.

PLATE 33 – Weighing the catch and recording data. It is essential that data are recorded with accuracy and care

CREDIT: S. EAYRS

A catch log contains species-specific catch details including length-frequency data and weight of the measured sample (Annex 4). If all fish of a particular species are measured, the documented weight in the catch and haul logs will be identical. If the catch is large, it may be necessary to subsample the catch, and for each species only the weight of the subsample is documented in the catch log. The total weight of each species must still be entered into the haul log.

The fishing gear log is where details of the codend and BRD are included, and one gear log must be completed for each codend or BRD tested in the fieldwork (Annexes 5 and 6).

It may be wise to print the data sheets on waterproof paper, particularly if sampling is expected in heavy weather or rain. While this paper is more expensive than traditional paper, and may need to be ordered well in advance of fieldwork owing to scarcity of demand and availability, it does eliminate the risk of data loss from data sheets damaged by water.

6.9 PRE-FIELDTRIP EQUIPMENT CHECKLIST

During planning and preparation for fieldwork, it is useful to prepare a pre-fieldtrip checklist of all equipment necessary to sample and process the catch successfully. This checklist should be regularly reviewed to ensure that all identified equipment and other items are available and ready for use. Then, as the equipment is placed on board the boat, it should be checked off to ensure that no equipment is left ashore.

It is essential that the checklist also contains a list of necessary sea safety equipment. This will include a list of mandatory safety equipment that should be carried onboard the boat, including fire extinguishers, life rafts and buoys, first-aid kit, and flares, and it is the responsibility of the principal investigator to ensure that all items are carried onboard, stowed correctly, and meet appropriate survey or licensing requirements. If any of this equipment is missing or not compliant with survey requirements, the fieldtrip should be postponed until this problem is rectified. The checklist should also include a list of safety equipment and other items that each individual should bring on board, which may include a personal flotation device or life jacket, wet weather gear, hat, sunglasses, sun screen, and gloves to handle the catch.

Prior to the fieldwork, all fishing gear should be accurately measured. At a minimum, a plan of the trawls needs to be produced, including headline and footrope length, mesh size, diameter and length of all netting panels, all tapers, joining round rates, ground gear construction details, and flotation. Codend details are essential, including mesh size and twine diameter, codend length and circumference, single or double braided or twisted twine, codend skirt or chaffing gear, and location of drawstrings. The details of BRD construction, including construction material, dimensions, and location in the codend, must also be recorded. Additional information that should be collected includes warp wire construction and diameter, otter board type, surface area, rigging and weight, backstrop length and construction, sweep length and construction (if used), ground gear and trawl rigging details.

Measuring a trawl system accurately is time-consuming and will need the services of two qualified persons for several hours. Measurements recorded in the field should be transferred into a permanent fishing gear log and checked against the original plan for consistency. If there are variations, the master fishers should be consulted as they may have made important adjustments to the fishing gear to ensure operational effectiveness. In such cases, the master fisher and principal investigator should agree on the measurements recorded in the master plan. In the event of damage, repairs will be made to return the fishing gear to the dimensions in the master plan.

6.10 SAFE WORKING PRACTICES

To reduce the risk of injury at sea or worse (and avoid lost fishing and sampling time), and ensure that all fieldwork staff respond appropriately in an emergency, they should receive formal training in

PLATE 34 – While standing on otter boards to work on a trawl is not uncommon for fishers, it is inherently dangerous and should never be attempted by fieldwork staff. Winches and hauling equipment should also never be used by these staff, and they should stand well clear of such equipment when in operation

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safety at sea, including emergency response in case of fire, sinking, or person overboard, as well as safe working practices, including identification and handling of dangerous or poisonous animals, first aid, and radio telephony. In some countries, research staff are required to receive sea safety training by recognized instructors at specialized training facilities, and must pass both written and practical examinations before being cleared for work. In other countries, research staff receive little or no formal training. If all goes well, trained individuals will not be called upon to respond to an accident or emergency at sea; however, with the passage of time, knowledge and skills may be lost, and refresher courses are advisable on a regular basis.

The captain of the fishing boat should discuss sea safety with fieldwork staff prior to departure to sea or early in the fishing trip. This should include identification of potential safety hazards on deck, including winches and lifting gear, and locations on deck from which catch sampling can be accomplished safely without hampering crew movements and operation of the fishing gear. Research staff should not operate winches or hauling machinery (Plate 34). The captain should also ensure that fieldwork staff are familiar with the location of the muster station, life boats, life jackets, fire extinguishers, and first-aid kits, as well as emergency alarms such as fire or abandon ship. The boat's crew should be aware of the location of these safety items and their operation; however, time lost seeking out the crew in an emergency could result in loss of life. Although the captain is ultimately responsible for the safety of all personnel onboard the boat, the principal investigator is responsible for fieldwork staff and should not hesitate to raise safety concerns with the captain, or abandon the fieldwork should there be concerns regarding unsafe boat handling or deck practices, or if it becomes unsafe to continue sampling in heavy weather.

7. Fieldwork

7.1 LOCATION OF FIELDWORK

The location of fieldwork will be influenced by project objectives and available finances. Normally, fieldwork should be located where shrimp and bycatch abundance mirrors that normally encountered by the commercial fishery. This will help ensure that fieldwork results accurately represent expected BRD performance under commercial fishing conditions.

If shrimp and bycatch abundance is low during fieldwork it may not be possible to statistically compare catches between experimental and control codends, and evaluate the effectiveness of a BRD unless a large number of tows are completed. To prevent this problem, knowledge of the natural behaviour and distribution of shrimp and bycatch is essential, including their seasonal and regional abundance (Anonymous, 1995). This knowledge can be sourced from previous fieldwork, port landings, historical databases, discussions with fishers and other researchers, and reviews of both scientific and popular literature. Other factors that may influence the location of fieldwork includes the size of the fishing boat and likely exposure to poor weather, distance to and from port or safe anchorages, and the presence of other fishing activity.

Once the location of fieldwork has been established, many researchers will divide the fishing location into identically sized, numbered cells and randomly select the timing and cell number of each individual tow or haul. (They may also randomize fishing with the experimental and control codends within each cell.) This is a randomized block design that ensures the selection of towing location is independent – an important consideration for some statistical analyses such as analysis of variance (ANOVA). Randomly selecting fishing locations avoids possible problems with localized depletion of shrimp and bycatch and catch bias in favour of selected species, which in turn could lead to an inaccurate assessment of BRD performance.

The size of each cell will usually be determined by the researchers. If each cell is too large, valuable fishing time may be lost moving the boat between cells. If each cell is too small, shrimp and bycatch that avoid capture in one cell may migrate to adjacent cells. These animals will be more fatigued than those already present within the cell, and their subsequent capture could affect catch rates, catch composition, and bycatch reduction performance to an extent greater than otherwise expected. This bias should be avoided, particularly if the objective of the research is to gain an insight into BRD performance under controlled conditions (and serve as a baseline to gauge the impact of future performance).

Once fieldwork has been completed in cells unaffected by recent fishing or research activity, an additional step that can be applied is to test repeatedly a BRD within cells. This step is appropriate where there are concerns of variable bycatch reduction owing to heavy fishing activity, or to assess performance at heavily fished locations.

7.2 TIMING AND DURATION OF FIELDWORK

It is important that fieldwork is timed to coincide with the commercial shrimp fishing season and the time of day that the fishery operates. This may mean that fieldwork is timed for night-time, when many species of shrimp are most active. Shrimp and bycatch abundance can also change dramatically during the fishing season, and it is important to factor this in to the research plan.

Careful timing of fieldwork is also important to avoid abnormally high abundances of shrimp or bycatch unless their encounter is a specific project objective and does not negatively influence the experimental design of the project. Huge catches will quickly reduce the swept area performance and catching efficiency of the trawl. They may also affect the ability of fish and other animals to escape from the trawl, delay processing of the catch, damage the trawl or codend, and hamper re-deployment of the trawl. Ultimately, huge catches may force a reduction in towing duration and bias catch composition in favour of small, poor-swimming fish and other animals.

If the annual fishing season extends for an entire year, it may be necessary to repeat the fieldwork at several predetermined times throughout the year. In tropical latitudes, the monsoon season will have a dramatic impact on catch composition and sea conditions, and it may be necessary to conduct fieldwork before, during and after this season.

The duration of fieldwork must be sufficient to allow multiple tows (replication) of all BRDs and controls that are part of the testing programme. This will be affected by the project budget and a range of operational factors, including boat availability, travelling time, and the number of planned tows per day. Consideration should also be given to the effect of adverse weather conditions and the possible need to delay completion of the fieldwork.

Because the abundance and periodicity of both shrimp and bycatch species has a strong influence on the timing and duration of fieldwork, every effort should be made to obtain relevant knowledge well in advance of the fieldwork.

7.3 REQUIRED NUMBER OF TOWS

A typical sampling programme requires each BRD to be tested repeatedly in a controlled manner and catch data collected from each tow. This should result in a catch sample that is suitable for statistical analysis, accounts for between-tow variability, and enables the researcher to make defendable statements regarding the performance and efficacy of each device.

There is no agreed minimum number of tows (or replicates) required to test and evaluate BRD performance satisfactorily because this number depends upon the objectives of the research, the variability of the data collected, and the experimental design and statistical tests used. A range of operational factors, including funding, availability of the boat, staff and other resources, type of experimental fishing gear, volume and composition of the catch that enters the trawl, and the performance of the BRD, can also affect the possible level of replication.

Frequently, the researcher is faced with having to balance the needs of the experiment and the number of tows that will satisfy these needs with available project funding. An additional consideration is that there may be a legislative requirement to complete a designated minimum number of tows, particularly if a BRD is tested to evaluate its ability to meet (or surpass) certain bycatch reduction targets. For example, at least 30 successful tows are required in order to evaluate statistically BRD performance in the United States southeastern shrimp fishery (NMFS, 2008). As an approximate guide, a review of literature indicates that at least 15–30 tows per treatment or device have been used in the past to obtain sufficient replication (Table 7).

If a BRD has been previously tested in the same fishery, or in a similar study elsewhere using the same experimental fishing gear, the number of tows completed in that study can be a guide to the number of tows required in the current study. Catch data from the previous study may also be used to conduct a power analysis and explore the relationship between sample size and the probability of achieving a desired level of statistical significance. A description of this relationship is provided in Sokal and Rohlf (1995), and most statistical software packages are capable of conducting a comprehensive power analysis.

Because the power of a test increases as variance or deviation decreases, a relatively simple analysis involves plotting the relationship between the standard deviation of the difference in bycatch between experimental and control trawls (squared if necessary to avoid negative values)

TABLE 7

Total number of tows and tow duration by experimental gear

No. tows	Tow duration (h)	Experimental gear	Reference	Comments
120	0.5	Dual rig	Brewer *et al.*, 1998	2 TEDs, 6 BRDs & control codend tested in paired combinations; catches between codends compared; average 24 tows per treatment (device)
120	0.8	Triple rig	Courtney *et al.*, 2006	1 TED/BRD combination, 1 TED, 1 BRD, & 1 control codend tested simultaneously over 10 nights; catches from outside trawls compared; 15 tows per treatment per side
87	2.0	Dual rig	Brewer *et al.*, 1998	8 TED/BRD combinations & control codend tested in paired combinations; catches between codends compared; average 18 tows per treatment
82	3.0	Twin rig	Raudzens, 2007	1 BRD & control codend tested under commercial conditions over 21 nights; catches between codends compared
80	0.5	Twin rig	Broadhurst *et al.*, 2004	4 treatment codends tested in covered codend experiment; 20 tows per treatment over 10 days
74	0.5	Dual rig	Blaber *et al.*, 1997	2 square-mesh codends & control codend tested in covered codend experiment; 33 and 41 paired tows per experimental codend respectively
59	0.8	Quad rig	Courtney *et al.*, 2008	1 TED/BRD combination, 1 TED, 1 BRD, & 1 control codend tested simultaneously over 8 nights; catches between codends compared
54	0.7	Twin trawl	Broadhurst & Millar, 2009	3 treatment codends & control codend tested in paired combinations; 18 tows per treatment catches between codends compared
47	4.0	Quad rig	Garcia *et al.*, 2008	1 TED/BRD combination, 1 TED, 1 BRD, & 1 control codend tested simultaneously over a 5 month period; catches between codends compared
42	0.4	Single rig	Broadhurst & Kennelly, 1995	Two treatment codends tested over 7 days using trouser trawl (21 tows per treatment at 6 tows per day)
38	4.5	Single rig	Guijarro & Massuti, 2006	1 codend tested in covered codend experiment; 18 tows during sampling period 1, and 20 tows in sampling period 2
30	0.5	Twin rig	Warner *et al.*, 2004	1 TED/BRD combination & control codend tested using paired skimmer trawls over two sampling periods; catches between codends compared
15	3.0	Single rig	Eayrs, Nguyen & Ley, 2007	JTED tested under commercial conditions over 5 nights; cover net placed over JTED escape opening

and the number of completed tows. For example, if 30 tows were completed in a previous BRD study, the standard deviation of the first 3 tows could be calculated, then the standard deviation of the first 6 tows, then the first 9 tows, and so forth until the standard deviation of all 30 tows is calculated. Each of these calculated deviations can then be plotted to produce an exponential decay curve, and the approximate number of tows required to minimize the standard deviation occurs where the slope of the curve is minimized and approaches zero. Because additional tows have little effect on the slope of the curve and the standard deviation remains similar, they represent unnecessary additional effort and expense. While this approach is fairly straightforward, it only represents a historical "snapshot" of BRD performance at that time and place because species composition and volume is variable and the experimental conditions and protocols can never be exactly replicated. This test is also sensitive to infrequent but very large catch differences between trawls, which may influence the shape of the curve and hamper the determination of sample size. Such an analysis can therefore only be considered a guide to the number of tows required to evaluate BRD performance.

7.4 TOWING DURATION

The duration of a tow should ideally replicate that used by commercial fishers because it influences catch composition and the volume and proportion of shrimp and bycatch that escape from the trawl (Eayrs, 2007). In many fisheries, tow duration may be three hours or more, and replicating these times during fieldwork limits the number of tows that can be completed each day. Unless fishing occurs during both night and day, the ability to collect adequate samples may be compromised unless the fieldwork extends over a sufficient number of days (although differences in catch composition and volume between night and day may preclude this as an option anyway).

There is currently no agreed standard tow duration to test BRD performance in a shrimp fishery (Plate 35). A review of published papers indicates a wide diversity in towing duration, from less than 30 minutes to 4.5 hours (Table 7). In the United States southeastern shrimp-trawl fishery, where bycatch reduction targets and guidelines for testing BRDs have been established, towing duration is not prescribed but must be standardized and usually representative of the commercial towing duration (NMFS, 2008). As a guide, a standardizing towing duration of 30 minutes or 1 hour generally provides sufficient catch for sampling and analysis while substantially increasing the number of tows that can be completed during the available fieldwork period. Such short towing periods are also generally sufficient for fishers and others to observe BRD performance during at-sea demonstrations of BRDs.

To determine whether catches from short tows adequately represent longer tows, an option is to compare catch composition between short and long tows using identical trawls and determine if some species are under-represented in the short tows. As shrimp and most bycatch species have limited swimming capability and ability to escape from an approaching trawl, a one-hour tow will probably be adequate to retain a representative sample of these species. However, large, strong-swimming species are likely to be under-represented in catches from shorter tows as they may out-swim the trawl. This may not be a serious problem if these animals rarely encounter the trawl irrespective of tow duration, although if BRD performance on these species is a key project objective, longer-towing duration will be appropriate for each replicate tow. This approach was used by Brewer *et al*. (1988) to test a large number of TEDs and BRDs in a short time. Initially, the authors used 30-minute tow durations to identify those with most potential before retesting them using 2-hour tow durations in a subsequent research trip. This approach allows clearly unsuitable BRDs to be quickly discarded from the study; however, a flaw in this approach is that it assumes BRD performance from shorter tows is a suitable indicator of likely performance from longer tows. If this assumption is incorrect, a BRD could be discarded in error.

While catch composition between trawls may be similar irrespective of tow duration, the location of a BRD in a trawl could introduce an additional problem. This is because the location of these devices relative to the accumulated catch in the codend has a major influence on bycatch reduction performance (Eayrs, 2007). If tow duration is short, fish swimming ahead of the accumulated catch may be unable to reach the BRD, and the performance of this device could be different during longer tows when the catch is greater. This means that the catch composition from a codend fitted with a BRD during a short tow may poorly reflect the catch composition fishers will observe when using longer, commercial-length tows.

PLATE 35 – Would the catch composition from a 1-hour tow be similar to a commercial-length tow? What about a 30-minute tow

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The researcher faces a difficult decision: Conduct the experiment with a large number of short tows or a small number of long tows? The researcher will need to evaluate the trade-offs of one option over the other given project objectives and limited project resources.

7.5 TOWING SPEED

The towing speed selected for a comparative experiment must replicate the speed used by commercial fishers. Towing speed can greatly influence the performance of BRDs that are designed with escape openings for fish to swim through voluntarily. This is because fish need to swim faster than the trawl to reach the BRD and pass through the escape openings; and if a non-commercial towing speed is used during the research, the performance of the BRD will not accurately reflect its performance under normal commercial fishing conditions.

Fishers commonly use engine revolutions per minute (RPM) as a proxy for towing speed. However, as the RPM to produce a given speed can differ considerably owing to wind, tide and sea conditions, the research requires a more precise means to measure towing speed and ensure consistency between tows or boats. Options include a portable GPS unit or propeller log. Nowadays, GPS units are relatively cheap and they are found on many boats. They measure boat speed over the ground to an accuracy of several metres and can serve as a proxy for trawl speed through the water.

7.6 TOWING DIRECTION

Providing that fishing activity is located on commercial fishing grounds, towing direction may be determined by water depth, sea conditions, prevailing wind, tide and current.

Large variations in water depth should be avoided during and between individual tows as this can alter the geometry and catching efficiency of the trawl. While some depth variation is inevitable, it should be minimized as much as practicable; as a guide, a variation greater than 20 percent of mean water depth should be considered excessive in depths up to 30 m, and this variation should be reduced in deeper water.

A review of the literature suggests that, while a randomized block design may be used to predetermine the location and timing of consecutive tows, the direction of each tow is often not prescribed. Sea state, wind, tide, and current may influence boat handling and performance and, as a result, trawl geometry and BRD performance. Some researchers do not consider these variables important, however, and ignore them unless they affect boat seaworthiness or the ability to operate the fishing gear. As these variables influence boat and trawl speed through the water, they also influence the ability of fish to swim in the codend, reach the BRD, and escape. To accommodate for these variables, a reciprocal towing procedure can be employed, with the boat towing into the weather and/or tide or current for one tow and then towing in the opposite direction in the subsequent tow. The data from these tows can then be combined and compared with other pairs of reciprocal tows. While this technique should reduce the influence of these variables, it effectively halves the number of treatments that can be tested during the fieldwork period, unless additional time is available to increase the number of replicates and account for between-tow variability.

7.7 HAULING THE TRAWL

Hauling the trawl at the completion of each tow should be completed as per normal operating practice. On some small boats, hauling the trawl is a slow process, particularly if the boat is underpowered or the trawl is hauled manually. According to Broadhurst, Kennelly and O'Doherty (1996), there may be a delay on some small boats of up to 15 seconds between slowing the boat and engaging the winch to haul up the trawl. During this time, the speed of the trawl slows before leaving the sea bed, and this presents an opportunity for the catch to swim forward and through the escape openings of a BRD. An additional opportunity to escape occurs during slow hauling from the sea bed to the surface, and then as the trawl is hauled slowly towards the boat. With the trawl at the surface both live and dead animals may filter through the escape openings of a BRD, especially if the catch surges forward through the codend in a sea swell (Plate 36).

PLATE 36 – Hauling the trawl by hand is a time-consuming process that may allow fish bycatch to escape from the codend

CREDIT: W. THIELE

7.8 GEAR CHANGES DURING FIELDWORK

Once fieldwork has commenced, it is important there are no changes to the rigging or operation of the fishing gear apart from replacing gear that is extensively damaged or in need of replacement (although gear replacement may suggest inadequate inspection prior to fieldwork). This includes adjustments to otter board rigging, ground chain settings, fishing depth, warp-to-depth ratio, and towing speed. Failure to adopt this protocol may alter the catching performance of the trawl (or trawls) and introduce catch bias. Any differences in catches between codends and tows could then be caused by the gear changes and not the performance of the BRD. The BRD testing protocol used by the National Marine Fisheries Service (NMFS) in the United States of America requires fieldwork to be re-started if a BRD is altered, although changes to the otter boards, trawls, and rigging are permissible providing the trawls are re-tuned prior to recommencing the fieldwork (NMFS, 2008). It is essential that all gear replacements, repairs and adjustments are recorded in detail, so that data can be analysed accordingly, and data from tows prior to the change removed from the analyses if necessary. Relatively small changes, such as mending small holes in the netting or replacing a broken ground, are not considered a major gear change and require no change to the testing schedule.

It is essential that steps are taken to ensure that the catching performance of repaired or replaced fishing gear is not different to the original gear (Plate 37). A poorly repaired trawl may be distorted underwater and affect trawl geometry, sea-bed contact, catching performance, and behaviour of shrimp and fish. If a trawl is replaced, it is essential that the design, construction and rigging of the replacement trawl are identical to those of the damaged trawl. This includes identical ground gear and attachment to otter boards or sweep lines. Ensuring that all trawls are exact replicas before commencing the fieldwork, and that the ground gear is identically rigged, means that trawls can be replaced quickly and with a high level of confidence. Despite this, efforts must still be made to tune the trawl before installation of a BRD to ensure the new trawl provides consistent performance compared with the old trawl, as well as between sides (if more than one trawl is towed simultaneously).

PLATE 37 – Particular care is required during fieldwork to ensure that any trawl repairs do not adversely affect the performance of the fishing gear

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7.9 EXCHANGING BRDS AND CODENDS

Where two or more trawl trawls are towed simultaneously by a boat, it is normal practice to avoid net bias by testing a BRD attached to each trawl in an alternating sequence. To save time, the BRD should be fitted to a codend prior to the start of fieldwork – if several BRDs are being tested each should be fitted to its own codend – so that the codend can be exchanged or replaced between tows. This avoids the rather laborious and time-consuming process of fitting and removing BRDs from codends between tows.

Many shrimp fishers attach a codend to the lengthener or extension piece of a trawl using a mesh-to-mesh joining rate with a sheetbend joining knot to each individual mesh. This method of attachment is time-consuming and not conducive to rapid exchange of codends between tows, and a variety of options exist to permit codend exchange in a shorter time (Table 8). While these options are all successful to an extent, they must be applied with due consideration of material strength.

7.10 CATCH SAMPLING

When one or more codends are hauled onboard, it is essential that steps are taken to ensure that the entire catch is sampled. Any fish gilled, meshed or entangled in the codend netting should be removed and included in the codend catch. The same process must be repeated for fish in the cover net if one is used in the experiment. Care is also required to ensure that some of the catch is not lost overboard prior to sampling. If a cover net or multiple trawl system is used, then the catch from each net must be kept separate. Each net should be emptied in a different location on deck, and pound boards or other steps taken to ensure the catches do not mix.

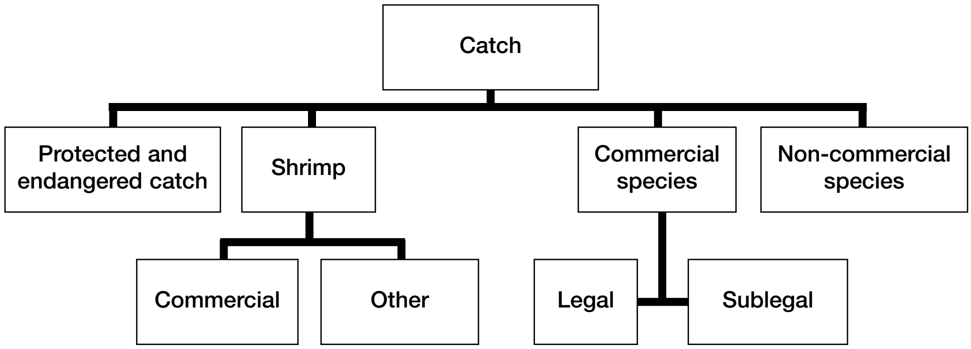
The catch should then be separated into major categories: shrimp, commercial species, non-commercial species, and protected and endangered species (Figure 4). If the protected and endangered catch is alive, data about it should be taken immediately (even before separation of the remaining catch is completed) and then returned overboard into the water. All sea turtles should be retained onboard using correct recovery procedures (Annex 7), and their capture recorded in the fishing log book and reported to the appropriate authorities. Useful measurements

TABLE 8

Options for rapid exchange of codends

Option	Comment
Tying fewer knots	- Twine is threaded through all meshes in the extension piece and codend although only the fifth or tenth mesh in the extension piece (or codend) is tied with a knot - Substantially quicker than tying a knot to each individual mesh - Low cost
Threading a rope through netting	- Rope is alternately threaded through five or ten meshes in the extension piece and the codend - Substantially quicker than tying knots to the extension piece and codend meshes, particularly if using braided rope - Low cost - Ends of rope can be tied using a codend chain knot - Rope length must be sufficient to allow expansion of meshes
Threading a rope through plastic rings	- Rope is threaded through plastic rings attached to meshes in the extension piece and codend, although some overlap of netting is required to prevent catch loss - Very quick option to separate and replace codends - Low - medium cost - Some time required attaching rings to netting prior to fieldwork - Several meshes must be attached to each ring to ensure the weight of the catch does not tear ring from the meshes
Sister clips, spring-loaded quick release clips, or carabiners	- Clips or carabiners are attached to every fifth or tenth mesh in the extension piece and codend and joined together, although some overlap of netting is required to prevent catch loss - Very quick option to separate and replace codends - Medium - high cost - Some time required attaching clips or carabiners to netting prior to fieldwork - Several meshes must be attached to each clip or carabiner to ensure the weight of the catch does not tear clip or carabiner from the meshes
Heavy-duty zipper	- Zippers attached to the leading edge of the extension piece and codend - The quickest option to separate and replace codends - High cost - Availability may be a problem - Considerable time required attaching zippers to each codend prior to fieldwork - Zipper length is fixed and cannot expand or stretch to accommodate the passage of large animals into the codend

FIGURE 4 – Catch sampling



include species identification, weight and measurement. A photograph of these animals is also often useful and required by various agencies as a permanent record.

PLATE 38 – Preparing a catch for sampling. Note the inexpensive tape measure and plastic calipers to measure the catch

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The remaining catch should be separated by species, and weighed to the greatest extent practicable. At a minimum, the catch of shrimp and key commercial (preferably by legal and sublegal categories) and non-commercial species should be identified by species, weighed and measured. The entire catch can be sampled this way if time permits (or where it is a project objective). If scales are unavailable for weighing the catch, an alternative is to count the number of full baskets of fish. Providing each basket is filled to the same level each time, catch comparison can be measured by counting the number of full baskets.

7.10.1 Sub-sampling the catch

Every effort should be made to sample the entire catch (even if a TED is being tested, it is useful to evaluate the effect of this device on the shrimp and fish catch). However, an unexpectedly large catch, limited fishing time, or some other impediment may limit sampling to a smaller portion or subsample of the entire catch. At other times, it may be necessary to prioritize sampling efforts and focus on key species of concern, such as commercially valuable species, juvenile species of commercial importance, and protected and endangered species. In this instance, the entire catch will need to be sorted to identify and collect the high-priority species before discarding the remaining catch overboard.

If a small portion of the catch is to be sampled, it is essential that it accurately reflects the composition of the entire catch and is free from bias. There are several potential sources of bias that can compromise a subsample. During hauling of the catch, stratification (layering) of species groups can occur in the codend before it is emptied on deck. This can be caused by surging of the catch within the codend, especially if hauling is slow and the codend is subject to wave action. Under these conditions, shrimp and other negatively buoyant animals tend to sink to the bottom of the codend while dead fish and other positively buoyant animals rise to the top. Larger or heavier fish may sink below smaller, lighter fish, while episodic encounters with schools of fish ensure an uneven mix of species within the codend. In these circumstances, catch composition will not be uniform when the catch is emptied on deck. If the subsample is only taken from the top of the catch, negatively buoyant animals will be under-represented, while a subsample from other parts of the catch may under- or over-represent schooling species or other animals.

Another potential source of bias occurs when the catch is handled by the crew. In an attempt to clear fish from the deck quickly and efficiently, crew members typically fill baskets with larger fish first before moving on to smaller fish. In this way, there may be a substantial difference in the average length of fish in the first and last baskets. Another common practice is to place animals with spines, sharp teeth, or toxins into their own baskets. This avoids mixing them with baskets containing other animals and potential injury to crew, particularly when further handling of the catch is required; however, it may also mean these animals are not sampled and are under-represented in the catch.

Before taking a subsample, it may first be useful to determine the proportion of the total catch that will comprise the subsample and then apply a sampling method called a "Dutch shuffle" (Anonymous, 1995). If, for example, only one-fifth of the catch is to be sampled, the Dutch shuffle requires that five baskets (or groups of baskets) are filled with the catch and that one of the five baskets is selected randomly as the subsample. Importantly, the catch must be added sequentially to each basket using a shovel or other similar means. The first shovel-load of catch is placed into basket one, the second shovel-load into basket two, and so on. After a shovel-load has been placed into basket five, the process is repeated, starting with basket one, until the entire catch is placed into the five baskets. If more than five baskets are filled, the process is repeated for another five baskets. Then, to group baskets, the sixth basket is placed with basket one, the seventh basket with basket two, and so on until all baskets are grouped into five groups. Another subsampling option is to spread the catch over the deck as evenly as possible, then dividing it into five groups and randomly selecting one group for sampling. This method is relatively simple and quick; however, stratification of the catch could result in a subsample that does not contain key species groups.

7.11 MEASURING THE LENGTH OF FISH, SHRIMP AND OTHER ANIMALS

While the girth of a fish usually determines whether or not it can escape through a codend mesh or opening in a BRD, it is normally easier to measure the length of a fish. Typically, fish length is measured from the forward part of head to the end (total length) or fork (fork length) of the tail (Plate 39). If a fish species is known to have differential growth rates between sexes or they are morphologically different, it may be necessary to separate the sexes before length measurements are made. Normally, the measured length will be that described in fishery regulations or replicate the measurement used in other research with the same species.

PLATE 39 – The total length of this large fish will have to be measured because the caudal fin is not forked

CREDIT: REZA NOURI AND J. MAHDAVI ROSHAN

PLATE 40 – Measuring the carapace length of shrimp

CREDIT: H. NGUYEN

PLATE 41 – Crabs are typically measured across the widest point of the carapace

CREDIT: H. NGUYEN

The measurement of shrimp, lobsters and crayfish is usually based on carapace length (Plate 40), measured from the eye socket to the posterior margin of the carapace. Crabs are typically measured across the width of the carapace (Plate 41), and scallops are measured from the base of the hinge to the furthest margin from the hinge, or by measuring the shell height. The measurement of rays and skates usually extends across the disc or flaps (Plate 42), although total length including tail may also be used, while anal length or total length is sometimes used for long, thin animals such as conger eels.

PLATE 42 – To measure this ray, the width of the discs or flaps can be measured, although beware of the sharp barb in the tail

CREDIT: B. CHOKESANGUAN AND S. CHINDAKHAN

It is essential the researcher is familiar with accepted or previously used measures for each species likely to be encountered during the research; otherwise, interpretation of results may be compromised, particularly if the measurement technique differs to that used to measure minimum legal landing sizes. The comparison of project results may also not be comparable with other similar studies. Whatever measurement is used to record the length of each species, it is essential that it is documented and the same measurement used throughout the entire sampling period.

7.12 RETENTION OF SPECIMENS FOR FURTHER ANALYSIS

Sometimes, it is necessary to retain a subsample for analysis in the laboratory. In such cases, the subsample should be placed into a plastic bag and labelled with the time and date of collection, name of experimental codend, tow number from which the sample was collected, and sampler's name. The plastic bag should be tied securely and placed into a freezer or on cold storage in an ice box or refrigerator. The time required to freeze and thaw the sample should be as short as possible to avoid loss of body fluids and underestimated catch weights. Where possible, the subsample should be weighed before being frozen to avoid this problem.

7.13 CHECKING CATCH VARIATION BETWEEN TRAWLS

The evaluation of BRD performance rests on the assumption that variation in catch volume or composition between experimental and control codends is due to the presence of the BRD and its effect on escape of shrimp and bycatch. If two or more trawls are used in a comparative experiment, every effort should be made to ensure that each trawl is identical in design

PLATE 43 – Care is required to minimize catch bias between trawls, and catch comparison between trawls prior to commencing an experiment is important

CREDIT: M. BROADHURST

PLATE 44 – If a single trawl is used in fieldwork, a large number of tows may need to be completed to overcome between-haul variability in catches

CREDIT: S. EAYRS

and rigging, and that any variation or bias in their catching efficiency is eliminated or minimized prior to commencing an experiment (Plate 43).

Tracking down causes of net bias can be difficult, but includes checking that trawls, otter boards, and warp wires are identical in construction, design and rigging. Operational bias, usually unintended, can also be a contributing factor, such as consistently turning the boat in one direction.

Some researchers take an additional step before commencing an experiment by fishing both trawls in a standard configuration (without BRDs fitted) and comparing catches of shrimp and bycatch. If both trawls are identical and catches are similar, then the assumption of equal catching performance can be accepted, although it is unclear how many tows are required to satisfy this assumption. Eayrs and Prado (1997) completed a single one-hour tow before they were satisfied of equal shrimp catching performance between trawls and commenced their experiment (Plate 44). Warner *et al*. (2004) compared the total catch between trawls following the completion of ten 30-minute tows, and while not explicitly stated, a larger number of replicates was presumably required to systematically reduce (tow-by-tow) catch variation to an acceptable level and satisfy concerns that variation was inconsistent between tows. Broadhurst and Kennelly (1996) tested for differences between trawls but did not indicate the number or duration of tows that were completed before commencing their experiment. Fuls and McEachron (1998) also did not provide the number of tows to assess between-trawl variation, but commenced their experiment after reducing variation in total catch to less than 8 percent between the trawls. Gregor and Wang (2003) completed a total of 15 tows in a calibration experiment, two nights immediately prior to and following a comparative experiment. The authors found no significant difference between the relative difference in shrimp and total bycatch weight between initial and final calibration experiments, indicating the catching efficiency of both trawls was unchanged during the entire testing period.

The catch from each trawl will need to be separated and the total catch volume compared during this period of evaluation. A natural tendency for some fish species to form schools or aggregations could result in substantial catch differences between trawls, so the test will need to be repeated several times to reduce or eliminate the effect of these catches on trawl variation. An alternative option that avoids this problem is to select one or more key species for comparison. Shrimp and benthic finfish species are a good choice because they are dispersed randomly over the sea bed as the trawl approaches, and catch rates are likely to be more consistent between trawls. Species that are sometimes caught in aggregations, including schooling fish, should not be used in this analysis if catch rates are highly erratic, unless they are a specific focus of the research.

An uneven abundance of shrimp and other benthic animals owing to differences between control and experimental trawls can sometimes be remedied through adjustment to the ground chains. For example, increasing the shrimp catch in a trawl may be achieved by shortening the ground chain to increase sea-bed contact, and this process may require several tows before catches are deemed relatively even between trawls. If schooling fish species are included in the analysis, changes to headline height and trawl spread can alter catches of these species. While such changes to the fishing gear are possible, they are unlikely to have a consistent impact on a highly mobile schooling species.

In an experiment where multiple trawls are used, it is likely that checking for catch variation between trawls is limited to ensuring that the dimensions of each trawl are similar. This approach is satisfactory providing the experimental codends and a control codend are randomly interchanged between trawls and/or sides of the boat and there is sufficient replication of treatments. Using such a technique, any variation in catching efficiency between trawls should be overcome or eliminated over the duration of the experiment.

7.14 DATA LOG MANAGEMENT

It is essential that data logs (see Annex 2–4) are completed to their fullest extent, ordered sequentially by tow number, and kept in a secure location throughout the fieldwork period.

Each data log should have two or more entries that link the data sheet to a particular tow or haul. Ideally, this includes the date, gear type, time of deployment and retrieval, and tow number clearly written on each sheet. If several catch logs are used to sample a catch, each log must also indicate the log or page number and the total number of logs completed. Sometimes, it is useful for the people completing the data log to write their name on the sheet. This allows other users of the data to query those persons should an anomaly be found in the data or additional information are sought. No data sheet should be used to record data from more than one tow.

At the completion of each tow, all data logs pertaining to the tow must be collected, checked that all relevant details have been recorded, and then protected against wind, rain, and saltwater spray. Ideally, data sheets should be stored in a waterproof bag or case, then located in the wheelhouse or other protected area of the boat.

At the completion of sea sampling, all data sheets should be photocopied. Both copies should be stored in secure locations, and one preferably stored offsite. This will ensure a copy of the data is available should the other copy be lost as a result of fire or other unforeseen circumstances.

CREDIT: M. BROADHURST

8. Experimental fishing methods to measure BRD performance

There are various experimental fishing methods available to measure the performance of BRDs, and the appropriate method is largely determined by the design and availability of the fishing boat, trawl rigging configuration, project objectives, and research budget.

8.1 COVERED NET METHODS

8.1.1 Covered codend

This method is commonly used to assess the effect of a BRD on codend selectivity, including changes in codend mesh size, and is suitable for artisanal and industrial trawlers that tow a single trawl from the stern. A fine-mesh cover net is placed around the entire codend to retain small shrimp, fish and other animals that escape through the BRD and meshes of the codend. The combined catch from the codend and cover net provides a measure of the total catch that entered the codend, and by comparing catch composition between the codend and cover net, an estimate of BRD performance is achieved. The advantages and disadvantages of using a covered codend are summarized in Table 9.

It is very important that the cover net has minimal influence on the behaviour of shrimp and bycatch in the codend, or the geometry and orientation of the codend. To minimize any such impacts, the cover net should be designed with sufficient clearance so that shrimp and bycatch can escape from the codend without influence (masking) from the cover net. The movement of water in and around the codend should also be affected as little as possible, as this will affect the escape behaviour of shrimp and bycatch, and there should be adequate space behind the codend for these animals to be retained in the cover net without influencing those remaining in the codend (Wileman *et al*., 1996). This will also help reduce the incidence of animals re-entering the codend, particularly during the hauling process when trawl speed through the water is slow.

The cover net is a cylinder of netting that should measure at least 1.5 times the extended width and extended length of the codend (Stewart and Robertson, 1985; Wileman *et al*., 1996; Guijarro

TABLE 9

Covered codend – pros and cons

Advantages	Disadvantages
Data analysis is relatively simple	Handling the codend and cover net is more difficult than a codend alone
Cover net retains animals that have escaped from the codend and BRD	Trawl deployment and retrieval practices may need to be altered
One tow can be sufficient to produce a selectivity curve	Cover may affect trawl or codend geometry and performance
	Cover may affect passage of water over and through the codend and consequently the behavior of fish & shrimp
	Difficulties determining if cover net is adversely influencing fish & shrimp escape behavior
	Variable catch volume (between tows) may affect codend mesh openings and selectivity

PLATE 45 – This fine mesh cover net has substantial clearance so that fish can escape unimpeded from the codend (green netting) and JTED

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PLATE 46 – A fine-mesh cover net and codend ready to be deployed. Note the flotation attached to the cover net and the fine-mesh netting

CREDIT: R. NOURI AND J. MAHDAVI ROSHAN

and Massuti, 2006). The mesh size of the cover net should be sufficiently smaller than the codend mesh to be considered non-selective relative to the codend mesh. As a guide, this mesh size should be approximately no more than one-half the mesh size of the codend (Plates 45 and 46). In Australia's northern prawn fishery, Blaber *et al*. (1993) used a 16-mm diamond mesh cover net to surround 38-mm and 45-mm square-mesh codends, Macbeth *et al* (2001) used 12-mm mesh cover nets to surround 20-mm and 30-mm mesh square-mesh codends in Australia's estuarine prawn fishery, and Chokesanguan *et al*. (2002) surrounded a 45-mm codend with an 18-mm cover net in a shrimp fishery in Indonesia. The diameter of netting twine in a cover net should be as fine as possible while retaining sufficient strength to retain the catch, but no greater than that used in the main body of the trawl. Square-mesh netting can be used but is generally not recommended as small animals may escape through the open meshes of the netting.

To separate the cover net from the codend, at least one polyvinyl chloride (PVC) or wire hoop needs to be attached to the cover net. The hoop should allow at least 500 m clearance between the codend and cover net on all sides; a practical diameter is at least 2.0 m (Box 7). As PVC and wire are negatively buoyant, several floats must be attached to each hoop to provide adequate positive buoyancy and ensure the hoops

BOX 7

Calculating hoop diameter

$$\text{Hoop diameter (m)} = ((C_M \times N_M \times M_O) \div \pi) + (2 \times D)) \div 1\,000$$

Where:

C_M = Codend mesh size (mm)

N_M = Number of meshes in codend circumference

M_O = Estimated mesh opening

D = Desired clearance distance between codend and cover net (mm)

Note: Mesh opening is inconsistent along the length of the codend, and is influenced by codend design and rigging, the orientation of codend meshes, and the catch volume. Therefore, it is usually estimated. As a guide, suitable estimates of codend mesh opening are 0.3 near the extension piece and 0.7 near the posterior of the codend (adjacent the catch).

and cover net do not lie on or near the codend and influence escape behaviour; although if the PVC hoop is airtight, this may not be a problem. The cover net should be attached to the codend as far forward as possible to help reduce the impact of water turbulence induced by the cover net on the escape of shrimp and fish from the codend. This may mean attaching the cover net where the codend is attached to the extension piece. The first hoop should be located about 1–2 m behind this position.

Unless the codend is very small, a second hoop should be located near the end of the codend to ensure adequate clearance between the cover net and accumulated catch in the codend. This hoop should be located no more than 1–2 m ahead of the trailing edge of the codend. As the codend may extend laterally as it fills with fish, it may be necessary to use a larger hoop to ensure adequate clearance (> 500 mm) between codend and cover net. Between each hoop the diameter of the cover net will be reduced (a so-called hour-glass effect) and may affect the escape of small animals from the codend. Additional flotation can be added to the cover net to prevent this, or even an additional hoop.

The hoops are usually attached to the outside of the cover net. Small metal or plastic rings with a diameter large enough for the hoop to pass are first attached to the cover net. For a 2.0-m diameter hoop, about 20 rings are needed, each attached to 3–5 gathered meshes. The hoop is then passed through and tied to each ring; this prevents the rings from bunching up, and is especially important if a flexible wire hoop is used.

An alternative, more user-friendly alternative to wire hoops is to use flexible, hydrodynamic PVC kites attached to the cover net. Developed by He (2007), these kites are trapezoidal in shape and are attached to the cover net at regular intervals. A restraining twine prevents the meshes of the cover net from fully expanding and allows water to flow through the kites and produce hydrodynamic lift, which forces the cover net clear of the codend. Determining the number of kites required to separate the cover net and codend is difficult, and pre-trial tests in a flume tank or underwater video could be used to observe if sufficient number of kites are used.

8.1.2 ESCAPE OPENING COVER NET

This net is designed to retain shrimp, fish and other small animals that pass through the escape opening (or openings) of a BRD, such as a square-mesh panel or JTED. The opening of the cover net is attached to the codend adjacent to the escape openings of the BRD. This ensures that the catch in the cover net consists only of animals that have escaped through escape openings of the device. (A cover net that surrounds the entire codend could be used although the catch may consist of both individuals that have escaped through the device and the codend meshes.) Similar to the covered codend method, the performance of a BRD is determined by comparing the catch composition between the codend and the cover net. This method is also suitable for any artisanal or industrial trawler that tows a single trawl from the stern. The advantages and disadvantages of using a cover net over the escape opening of a BRD are summarized in Table 10.

The design of the cover net is important because it can adversely influence the escape behaviour of some animals. As the cover net fills with catch, it applies additional tension to codend meshes adjacent to the escape openings of the device and this may distort and reduce the performance of the BRD. The catch may also drag the leading edge of the cover net downwards and mask the escape openings of the device. Clearance between the cover net and BRD can be achieved by careful tailoring of the cover net, the use of buoyant netting, and flotation attached to the upper portion of the cover net. The leading edge of the cover net can be attached to the codend about 1 m ahead of the escape openings of the BRD, although this assumes negligible escape through codend meshes encapsulated by the cover net. The sides of the cover net should also be attached a similar distance from the escape openings. Given the complexity of this net, a cover net that surrounds the entire codend may be a simpler option, although this will provide a measure of the selectivity of both the BRD and the codend.

TABLE 10

Escape opening cover net – pros and cons

Advantages	Disadvantages
Only one trawl required to produce a selectivity curve	Complex cover net design
Each tow produces a selectivity curve	Difficulties handling the cover net
Cover net only retains animals that have escaped from BRD	Trawl deployment and retrieval practices may need to be altered
	Cover net may affect codend or BRD geometry and performance
	Cover net may affect fish behaviour

8.2 TROUSER TRAWL

This method involves dividing a trawl into two sections using a vertical panel with a control codend attached to one section of the trawl (leg) and an experimental codend attached to the other section. The performance of the BRD is therefore determined by comparing the catch composition between the standard and experimental codend. The efficacy of a trouser trawl is based on the assumption that similar numbers and sizes of all species pass into each leg of the trawl and enter the codend (Millar and Walsh, 1992; Wileman *et al*., 1996). It is also assumed that differing amounts of catch retained in each codend, which may distort the codends differently, does not bias the number and size of species entering each leg of the trawl. This method is also suitable for any artisanal or industrial trawler towing a single trawl from the stern. The advantages and disadvantages of using a trouser trawl are summarized in Table 11.

Although almost any trawl can be modified into a trouser trawl, its design and construction can be a time-consuming and difficult process. As it is important that the escape location and behaviour of any animal in a trouser trawl is identical to a normal trawl, each codend in the trouser trawl should be identical in design and dimension to a codend in a normal trawl. This may require the tapered extension section of the trawl body to be cut back to obtain a cross-section that can accommodate two codends (Wileman *et al*., 1996).

TABLE 11

Trouser trawl – pros and cons

Advantages	Disadvantages
Between-tow variability problem removed as both codends towed simultaneously	Design and rigging of vertical panel is complex
Only one trawl required to produce a selectivity curve	Billowing vertical panel will divide codends unequally
Each tow produces a selectivity curve	Usually requires model observations in a flume tank or underwater observations to ensure correct design and rigging
Trawl design is generally similar to a commercial trawl	Opening of each leg may differ as different levels of catch accumulate in each codend
Relatively easy to operate and handle	Masking of codend meshes by adjacent codend
Trawl modification costs are low/modest	

The vertical panel must be carefully designed and constructed. If it is too tight, the trawl will become distorted and may lose ground contact; if too loose, the panel will billow to one side and divide the extension unequally. Model experiments in a flume tank and/or underwater observations at sea are the best ways to ensure that the panel is designed correctly. Ideally, the BRD should be alternated between codends in each leg of the trouser trawl to minimize the effects of any bias.

8.3 ALTERNATE HAUL

This method requires the control and experimental trawl to be fished alternately (Plate 47) (Wileman *et al*., 1996). The control codend is assumed to be relatively non-selective and the catch representative of the population of shrimp, fish and other animals that enters the trawl. The performance of the experimental codend is then determined by comparing the catch composition with the control codend. This method is also suitable for any artisanal or industrial trawler towing a single trawl from the stern. The advantages and disadvantages of this method are summarized in Table 12.

A problem with this method is that species composition and abundance may change substantially between successive tows and mask real differences between the control and experimental codend. To minimize the impact of between-tow variability, many more replicate tows are required compared with a paired comparison, for example a covered codend experiment or using a trouser trawl. Attempts are also required to mimic fishing conditions between gear types, including fishing location, direction, towing speed, and trawl operation. Ideally, there should also be minimal delay between successive tows. The shoaling or rhythmic behaviour of various species can result in massive catch variations between subsequent tows, and for these reasons a relatively large number of tows is required to provide sufficient statistical power (Broadhurst, 2000). This method can be utilized by a boat of any size capable of towing a single trawl.

PLATE 47 – A shrimp trawler towing a single trawl may have to use the alternate haul method to compare catching performance of a standard and modified trawl

CREDIT: J. MITCHELL

TABLE 12

Alternate hauls – pros and cons

Advantages	Disadvantages
Trawl is fished as per normal practice	Alternate hauls may not be identical due to changing conditions
No special rigging required	Population estimates between hauls may be different
Avoids possible complications due to cover nets	Relatively more hauls are required to provide accurate comparison
Relatively easy to operate and handle	Requires two or more hauls to calculate selectivity curve
Trawl modification costs are low	Increased sea time and costs

8.4 PARALLEL TRAWLS

This method involves the use of two fishing boats trawling in the same direction along a parallel path as close together as is safely possible. One boat tows a trawl fitted with the control codend, and the other boat tows a trawl fitted with the experimental codend. The boats coordinate their fishing activity so that both trawls are deployed and hauled at the same time. The performance of the BRD is determined by comparing the catch composition between each codend. In order to minimize bias between codends, both boats (design, engine power, propeller, etc.) and trawls (including otter boards) must be as close to identical as possible. Towing speed must also be identical between boats. The control and experimental codends must be exchanged frequently between the two boats or by having duplicate control and experimental codends on each boat and alternating their use so that each boat tests a different codend during a tow. This method is suitable for a pair of artisanal or industrial trawlers towing a single trawl from the stern. The advantages and disadvantages of parallel trawling are summarized in Table 13.

TABLE 13

Parallel tows – pros and cons

Advantages	Disadvantages
Experimental codend is fished as per normal practice, in the same location and time as control codend	Identical boats and trawls must be used
No special rigging required	Coordinating activity between boats
Avoids possible complications due to cover nets	Potential for catch bias between boats, particularly schooling species
Relatively easy to operate and handle	Requires two boats to calculate selectivity curve
Trawl modification costs are low	Requires exchange of control and experimental codend at sea or two sets of codends on each boat
	Increased sea time and costs

8.5 TWIN TRAWL

This method is suitable for use on any sized trawler that tows two trawls simultaneously, one from each outrigger or boom (Plate 48). The experimental and control codends are towed side-by-side at the same nominal speed, in the same location and with minimal distance between them. If both trawls are identical in design and rigging, and tested in good weather conditions, the catching performance of each trawl is considered to be independent of the other trawl. The performance of the BRD is determined by comparing catch composition between each codend. The advantages and disadvantages of twin trawls in comparative fieldwork are summarized in Table 14.

Ideally, towing direction should be straight, and any course alterations limited to a few degrees. During a turning manoeuvre, the outer trawl may experience an increase in speed through the water and perhaps loss of sea-bed contact. The inner trawl will slow, and the otter boards may become unstable and lose wingend spread, and sea-bed contact will be increased.

A variation of the twin trawl arrangement is the dual trawl arrangement. Rarely used in commercial shrimp trawling, this arrangement involves towing two identical trawls side-by-side from a single towing warp extending from the stern of the boat. The inner wingends of each trawl are connected via a sled or sledge, and an otter board is attached to each outer wingend. Testing an experimental codend using this arrangement is similar to the twin trawl arrangement – that is, the control codend is fitted to one trawl and the experimental codend to the other trawl.

TABLE 14

Twin trawl – pros and cons

Advantages	Disadvantages
Single boat tows both codends simultaneously	Potential for catch bias between codends, particularly schooling species, or if turning in one direction
Between-tow variability problem removed as both trawls towed simultaneously	Number and availability of suitably rigged boats may be a problem
Allows direct comparison between control and experimental codend	
No special rigging or gear required to tow both trawls or retain the catch	
Avoids possible complications due to cover nets	
Relatively easy to operate and handle	
Trawl modification costs are low	

8.6 MULTIPLE TRAWLS

In many tropical shrimp fisheries, three (triple rig) or four trawls (quad rig) are towed simultaneously. In a fishery where triple rig is used, only the two outside trawls should be used in comparative fieldwork. The middle or inner trawl is often larger and/or operated at a higher spread ratio than the outer trawls, and will provide a biased comparison with the remaining trawls. The sampling protocol should be identical to that used for twin trawls. The advantages and disadvantages of using multiple trawls in comparative fieldwork are summarized in Table 15.

PLATE 48 – A twin trawl system comprises one trawl towed from each outrigger. A pair of otter boards are used to spread open each trawl. Note the cover net around the codend of the port trawl

CREDIT: B. CHOKESANGUAN AND S. CHINDAKHAN

TABLE 15

Multiple trawl – pros and cons

Advantages	Disadvantages
Single boat tows several codends simultaneously	Potential for catch bias between codends, particularly schooling species, or if turning in one direction
Between-tow variability problem removed as both trawls towed simultaneously	
Allows direct comparison between control and experimental trawl	
No special rigging required	
Avoids possible complications due to cover nets	
Potential for high number of replicates per tow	
Trawl modification costs are low	

In a fishery where quad rig is used, all four trawls are usually identical in size, although in some fisheries the outer trawls may be larger. In United States federal waters in the Gulf of Mexico and Southeast Atlantic Ocean, a testing protocol to evaluate the ability of a BRD to meet bycatch reduction targets and become certified requires that only the outer trawls are used (NMFS, 2008), in part because of concern over the impact of try gear during fieldwork (SAFMC, 1997). In this configuration, the two inner trawls are equipped with certified BRDs to minimize risks to key bycatch species, although catches from these trawls are not used in the study.

In other fisheries where each trawl is identical (and try gear is not used), all four trawls can be used simultaneously. However, this assumes that the catching efficiency of each trawl is independent of the other trawls. In most instances, efforts are made to ensure that each BRD is tested equally on each trawl, and that each trawl is identical in size and rigging. Courtney *et al*. (2008) compared several BRD designs in a scallop trawl fishery using quad rig citing the ability to test four trawls simultaneously at a single site as an advantage of this arrangement. Garcia *et al*. (2008) also used a quad rig because this allowed simultaneous comparison of a control codend plus codends fitted with a TED, a BRD, and both a TED and a BRD.

9. Testing protocols

This section describes basic and detailed protocols for testing one or more BRDs at sea. There is no clear delineation between these two protocols although key differences are summarized in Table 16.

A basic testing protocol is used to conduct a preliminary or basic trial of a small number of BRDs over a short period of time, usually extending no more than one or two days. This protocol is useful for: (i) individuals testing the performance of a BRD for the first time; (ii) demonstrating the operation of several BRDs to researchers or fishers unfamiliar with BRD testing; and (iii) researchers or fishers wanting to conduct a rudimentary evaluation of BRD performance.

TABLE 16

Common or typical differences between a basic and a detailed BRD testing protocol, by fieldwork category

Category	Testing protocol	
(relevant guide sections in brackets)	Basic	Detailed
Fieldwork objective (9.1 & 9.2)	Demonstration or preliminary evaluation of several BRDS	Detailed evaluation of several BRDs
Duration of tests (9.1 & 9.2)	1 or 2 days	2 days or longer
No. of BRDs tested (9.1 & 9.2)	Typically 1 or 2	Several
Location of tests (7.1, 9.1.1, 9.2.1)	Close to port	On commercial fishing grounds
Timing of tests (7.2, 9.1.1, 9.2.1)	Anytime	During fishing season
No. tows per BRD (7.3, 9.1-9.2)	1 or 2	Multiple
Towing duration (7.2, 9.1.1, 9.2.1)	30-mins - 1 hour	1 hour or (ideally) same as commercial trawlers
Towing speed (7.4, 9.1.1, 9.2.1)	Same as commercial trawlers	Same as commercial trawlers
Experimental methods (8.1-8.7, 9.1.1, 9.2.1)	Alternate haul, parallel trawl, twin trawl, multiple trawls	Covered codend, escape opening cover net, alternate haul, parallel trawl, trouser trawl, twin trawl, multiple trawls
Catch sampling (7.9, 9.1.2, 9.2.2)	By major catch category (Box 12)	By species or species group
Data analysis (9.1.3, 9.2.3, 10.1-10.2)	Total number/weight of each catch category between BRDs; Mean number/weight per tow; Kolmorogov-Smirnoff length-frequency comparison	As for basic protocol plus: paired t-test, multi-variate ANOVA or GLM (or non-parametric alternatives if necessary), chi-square comparison of catch proportions, selectivity curves

Using this protocol, the results will provide only a very limited spatial and temporal insight into BRD performance. Catch data will be limited and unlikely to satisfy the assumptions and requirements for many parametric statistical techniques. Data analysis will usually be quite rudimentary, and the final report should reflect these limitations and not overstate the importance of the results. In short, the results of using this protocol will provide little more than a snapshot of BRD performance and its potential to reduce bycatch in the fishery. However, the results of using this protocol may be useful to attract funding for a more extensive research programme in the future and to provide a useful foundation for a future, more-detailed testing programme.

A detailed protocol is suitable where: (i) one or more BRDs are to be tested repeatedly over many days to enable thorough and detailed statistical analysis of BRD performance; (ii) a greater number of BRDs are to be tested simultaneously than can be accommodated using a basic testing protocol; and (iii) there are concerns over the influence of between-tow variability on BRD performance.

Much of the information pertaining to a basic testing protocol also applies to a detailed testing protocol, although the latter provides additional opportunities for analysis and evaluation of BRD performance. The results from this protocol should reveal a more accurate evaluation of BRD performance that more closely resembles BRD performance under normal commercial operating conditions.

9.1 TRIAL DESIGN

9.1.1 Basic protocol

With only a short time available to complete BRD tests using this protocol, it is important to optimize the available fishing time and reduce time spent travelling to and from the fishing grounds, handling fishing gear, and sampling the catch. This might necessitate selecting a fishing ground close to shore with less than optimal shrimp and bycatch abundance and diversity. It might also require the use of short towing times, for example, 30 minutes or 1 hour, in order to complete a sufficient number of replicate tows during the limited time available. It might also require that landed catch is sampled as quickly as possible, or subsampled, so as to not impede the hauling of the subsequent tow.

In these circumstances, a researcher may be tempted to increase the number of replicate tows using a BRD by fishing both night and day and then pooling the catch data. By pooling these data, the researcher assumes that the volume and composition of the catch is independent of changes in the catchability of shrimp and fish between both periods. This is unlikely to be the case as the natural behaviour of shrimp and fish and their response to trawl stimuli is usually not consistent between night and day. Therefore, BRD performance is likely to be substantially different between night and day, and catch data from both periods should not be pooled.

A basic testing protocol is probably not compatible with using a codend cover or trouser trawl, given the time, cost and effort required for their design and construction, unless these are available from previous tests. This protocol is better suited for an alternate haul, parallel trawl, or multiple trawl experimental method. If an alternate haul method is used, an A-B-B-A testing sequence can be applied so that codends are exchanged after each tow. This sequence requires that codend A is tested first followed by codend B, then codend B again, and finally codend A. To determine if the control or experimental codend is designated codend A, a coin can be tossed once – heads is codend A and tails is codend B. If additional tows can be completed within a day then this sequence can be extended, for example, A-B-B-A-A-B or A-B-B-A-A-B-B-A. Alternatively, an A-B-A-B sequence could be applied although this requires a greater number of codend changes and increases the amount of lost fishing time. If a parallel trawl method is being used, the A-B-B-A testing sequence can be applied with each boat using a different codend that is alternated after each tow.

If the fishing boat tows two or three (triple rig) trawls simultaneously, then both the control and experimental codend (Plate 49) can be tested during a single tow (the middle trawl in a triple rig should not be used). One codend can be randomly assigned to the port or starboard trawl for the first tow, and after each tow they should be exchanged to reduce the effect of net bias. Using this method, however, the assignment of a codend to a trawl is no longer random but predetermined and biased. Providing the sampling strategy is unchanged in any way, the effect of this bias can be largely accounted for by testing both codends repeatedly on each trawl. However, care is required to ensure that boat-turning manoeuvres do not consistently favour a particular direction and alter the catching efficiency of each trawl. To eliminate bias entirely, each codend can be randomly assigned to a trawl for each tow. This is the preferred approach if several experimental codends are being tested.

PLATE 49 – Catches from a control and experimental codend will need to be carefully separated to prevent mixing

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If the fishing boat tows four (quad rig) trawls simultaneously as part of normal commercial operations, the control codend and two or more experimental codends can potentially be compared simultaneously. With this rigging configuration, it is wise to assign, initially, the control and experimental codends randomly to each trawl to eliminate any bias between trawls or sides of the boat (Box 8). An interesting option if a quad rig is used is to tow simultaneously two identical control codends and two identical experimental codends. With limited available time, this option doubles the number of replicates per codend-type from a single tow.

BOX 8

Assigning codends to nets used in a quad rigged trawl system

Assign each net a number from 1 to 4. Write each number on a separate piece of paper and place into a container. Assign each codend a letter from A to D. Write each letter on a separate piece of paper and place into a second container. Blindly remove one piece of paper from each container. The selected number and letter indicate the location of the selected codend. Repeat until all numbers and letters are selected. The location of each codend has now been selected for the first tow. Repeat this process for all expected tows.

9.1.2. Detailed protocol

With a greater number of days available for testing BRDs, fishing should occur in regions of high shrimp and bycatch abundance, even if considerable time is required to travel to and from the fishing grounds. Fishing activity should be timed to coincide with the fishing activities of the commercial fishing fleet, including fishing day and night if this is normal commercial practice (although the catch data from both periods should not be pooled). If desired, tow duration can be similar to commercial practice, although 3–4-hour-long tows will substantially affect the total number of tows that can be completed within the testing period. The location of each tow within the fishing ground can now be randomly assigned. However, some researchers allow the captain of the boat to determine the specific location of each tow so that the BRD is tested under conditions that closely mirror commercial fishing practice.

With additional research time using this protocol, a greater number of replicate tows can be completed during fieldwork to reduce between-tow variability. This protocol is therefore well suited to a detailed, paired comparative study using the parallel trawl, alternate haul, covered codend, or multiple trawl experimental methods. The A-B-B-A testing sequence could be used here, but randomly selecting the sequence of codend testing is also an option.

9.2 CATCH SAMPLING

9.2.1 Basic protocol

Using this protocol, there may be insufficient time to sample the entire catch between tows, and so the catch may need to be a subsample. After sampling the catch of endangered or threatened species (Plate 50), the entire shrimp catch can be weighed and a subsample taken to determine species composition. Alternatively, the dominant shrimp species can be weighed, counted and measured, while ignoring any remaining shrimp species. The entire bycatch can then be weighed and subsampled, and key species selected for weighing, counting and measuring. The key species could be selected based on their commercial importance, including legal and sublegal (undersized) fish, or dominance in the non-commercial catch. If time is still a problem and subsampling cannot be completed prior to the next tow, a subsample of the catch can be collected, frozen and analysed at a later date in the laboratory.

PLATE 50 – In this catch, the sea turtle should be sampled first and turtle recovery procedures immediately applied (see Annex 7 for details). If other large bycatch species are alive, they should be sampled next and returned to the sea

CREDIT: S. EAYRS

PLATE 51 – Sorting the bycatch and placing each species into separate baskets

CREDIT: B. CHOKESANGUAN AND S. CHINDAKHAN

9.2.2 Detailed protocol

Unless catches are very large and cannot be fully sampled between tows, efforts should be made to sample the entire catch. All endangered or threatened species must be identified, weighed and measured, and then returned to the sea following the application of correct revival protocols. The entire shrimp catch should be sampled, then separated by species and weighed, counted and measured. The entire bycatch should be similarly sampled (Plate 51), although it may be useful to weigh the catch of legal and sublegal commercially important species separately.

9.3 DATA ENTRY AND ANALYSIS

9.3.1 Basic protocol

All fieldwork data should be entered into a computer database as soon as practicable following completion of the fieldwork. This will increase the possibility that any questions or concerns related to the data can be answered or resolved while the events surrounding the fieldwork are fresh in the minds of fieldwork staff. It is common for data to be entered using commercially available software, such as Microsoft Excel or Access – both are simple to use but the latter is a dedicated database management system that permits simultaneous and varied data queries (by one or more individuals) of the original data set. Using this database, fieldwork data is entered into tables grouped by a common or related characteristic, such as tow, species, weight and length. The database can then be queried to extract only pertinent data and downloaded into a spreadsheet or statistical software for analysis.

At a minimum, the analysis from a basic testing protocol should provide a summary of catch differences between the control and experimental codends. This includes the total weight of shrimp and bycatch between codends, and their average weight per tow (with standard error or standard deviation). Then, the average weight of key shrimp and bycatch species can be provided. If an alternate haul, parallel trawl or covered codend experimental method is used, steps should be taken to standardize catch weights and numbers by towing duration. (If all nets are identical, this method assumes that wingend spread was identical between nets.) If acoustic sensors are available to measure wingend spread, this assumption can be tested and swept area performance (mean wingend spread × distance travelled over the sea bed) standardized between nets. This analysis is extremely useful because it can provide an important comparative summary of BRD performance during the experiment, as well as variation in performance between tows. These data can easily be presented graphically and are easily understood by fishers and others.

A variety of statistical tests are then available to analyse these data in detail (Box 9), although with few tows there is a risk that between-tow variability may mask any real difference between experimental and control codends. As a result, outcomes from these tests may not reflect the true or real performance of the experimental codend. Tests that could be used on paired data include paired t-tests to evaluate BRD performance on catches of shrimp and bycatch (by weight or number) and Kolmogorov–Smirnov tests to compare length-frequency distributions. Analysis of variance (ANOVA) could also be used to compare catches if two or more codends are used. Irrespective of the test used, it is essential to check that all underlying assumptions are not violated, and a statistics manual should be consulted on this matter. If these assumptions are violated and cannot be overcome through data transformation, then non-parametric alternatives should be used.

9.3.2 Detailed protocol

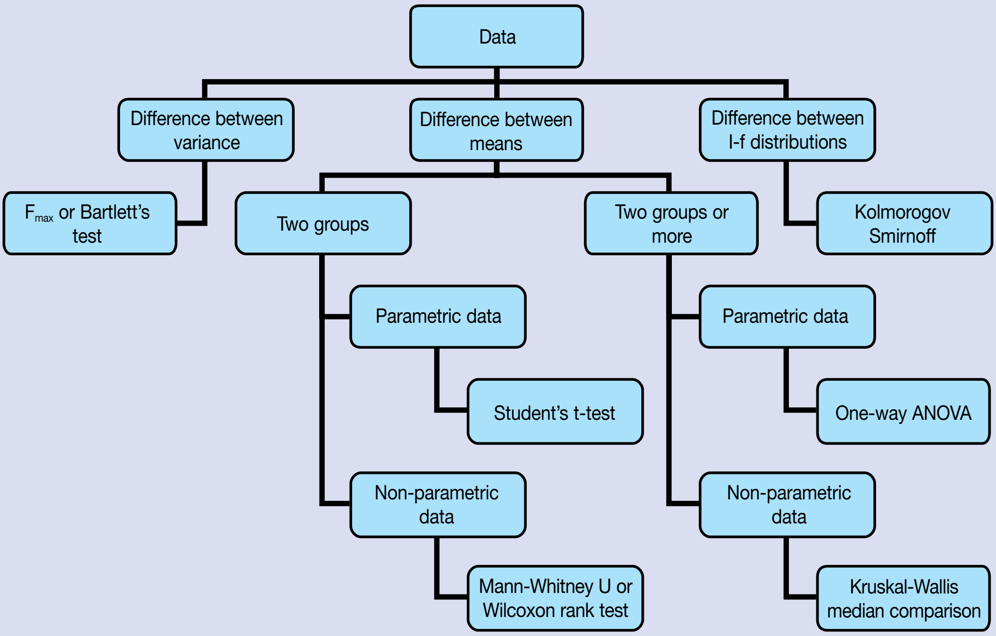
This testing protocol provides an opportunity for a more detailed and thorough analysis of data compared with a basic testing protocol. First, however, it is important to provide a summary of catch differences between the control and experimental codends, and the procedures and tests described for a basic protocol can be applied here.

Using a detailed testing protocol, the extent and detail of catch comparison between codends can be increased, and more sophisticated statistical tests can be applied if necessary. The use of paired t-tests to compare weights and numbers of shrimp and bycatch species between codends remains a common choice (e.g. Broadhurst *et al*., 1999; Broadhurst, Kennelly and Gray, 2002; Watson *et al*., 1999; Ambrose *et al*., 2005). This test is relatively simple to use, and can be applied to catch data using commercially available spreadsheets. If several codends are used, a one-way ANOVA test can be applied. To evaluate the effect of variables such as trawl site, time, BRD type, and trawl, a more sophisticated ANOVA model (e.g. Brewer *et al*., 1998; Broadhurst, Kennelly and Gray, Kennelly and Gray, 2002; Rotherham *et al*., 2000) or a generalized linear modelling (GLM) technique may be used (e.g. Courtney *et al*., 2006, 2008). Basic ANOVA models can be applied using commercially available spreadsheets. However, more detailed evaluation of the data can be achieved if dedicated statistical software is available. This software should also permit post hoc tests of catch data to identify statistically significant variables.

BOX 9

Identifying appropriate statistical tests to compare differences data sets and the assumptions of parametric tests

Statistical tests are often used to test for differences between the control and experimental codends. To test for differences between the means of each codend, it is important to determine first whether the data satisfy the assumptions for parametric testing. These tests are generally regarded to be more powerful than non-parametric tests (Fowler, Cohen and Jarvis, 2005). These assumptions are that the data: (i) were derived from independent, unbiased samples; (ii) are normally distributed; and (iii) have variances that are equal (homogenous).



The collection of independent, unbiased samples is a function of good experimental design and sampling technique. All variables that influence trawl geometry and catching efficiency must be controlled and their variation kept to a minimum. Catches from one tow should not influence catches from another, and, in a paired experiment, catches from one trawl should not influence the catch from another trawl. If catches are subsampled, it is essential that sample collection is unbiased.

As parametric tests usually assume that a sample is normally distributed, it is important to check that this assumption is satisfied. A variety of tests exists to test for normality, although a simple test is to determine if 68 percent of samples fall within the interval outlined by the mean +/- the standard deviation of the sample. If the data fail this test, they are strongly skewed and should be transformed prior to being used in a parametric test. Biological data are commonly transformed using logarithms, square root, or arcsine transformations (Fowler, Cohen and Jarvis, 2005). If these transformations do not improve the distribution, the data will need to be analysed using non-parametric tests.

To check if all sample variances are similar, the F_{max} test can be applied to the sample. This test compares the largest and smallest variances of the samples, and if their variances are not significantly different from each other, then the remaining variances cannot be significantly different either.

While hypotheses regarding BRD performance will be tested with greater precision using this protocol, and the likelihood of accepting an incorrect hypothesis should be reduced, the BRD may perform differently at other times and places within the fishery. This is because testing conditions are never consistent, and changes in the composition, condition, health and behaviour of species may each alter BRD performance. The performance of the fishing gear will also be different, being influenced by environmental variables including sea-bed conditions, water depth, tide, variation in boat towing performance, changes in rigging and the operation of the trawl. Therefore, while the results of a detailed testing protocol describe BRD performance at the time and location testing took place, they only indicate potential BRD performance at other times and locations within the fishery where testing has not been performed.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10. Selectivity curves

To evaluate the selectivity of a BRD or codend, it is useful to evaluate the proportion of shrimp or fish of a given species and length that are retained in the codend. A common option to evaluate this proportion is to produce a selectivity curve. In trawl selectivity studies, this curve is typically S-shaped or sigmoid for shrimp and finfish. Small individuals have a low probability of retention in a codend and many should escape capture. With increasing length, a higher proportion of these individuals are retained, and eventually a length is reached where no individuals escape capture. However, this is not the case when TEDs or other devices are used to exclude the larger individuals from a trawl. In this instance, the probability of retention should decrease with increased length, although the curve may still be sigmoid.

The first step to produce a selectivity curve is to identify the species of interest. Then, length-frequency information about all individuals of that species is collected. If a cover net is used, the selectivity curve is based on the number of individuals of a given length (or length interval) retained in the codend as a proportion of the total catch (codend + cover net) of individuals of that length (or length interval). This process is then repeated for all individuals of all lengths (or length intervals) to produce a selectivity curve of that species. If another experimental method is used, such as alternate haul, trouser trawl, or multiple trawl, the selectivity curve is based on the number of individuals of a given species and length retained in the control codend as a proportion of the sum of individuals of that species and length retained in both control and experimental codends.

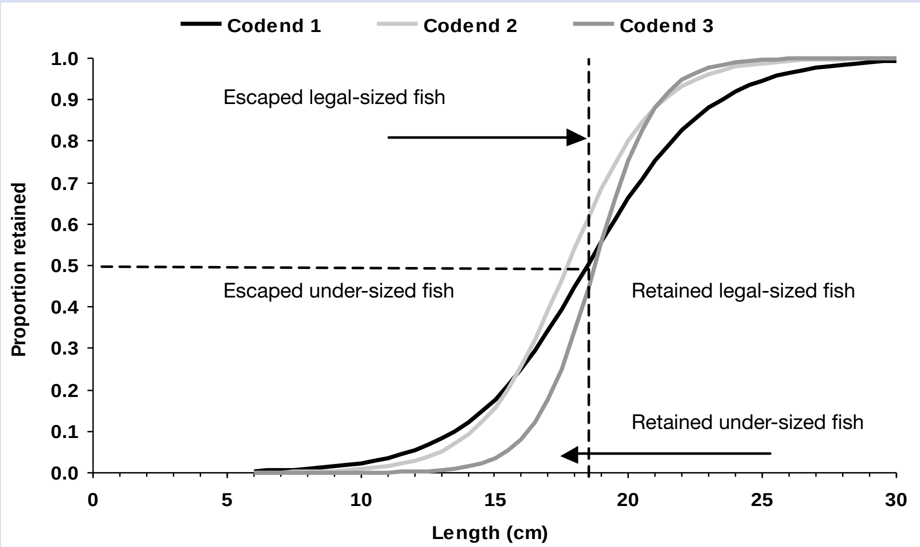
The next step is to produce the selectivity curve (Box 10). For each species, the proportion of individuals retained in the codend for each measured length is plotted either on paper or on a computer (see Annex 8 for details). A line of best fit is then drawn between the data points to produce the selectivity curve. This curve can be drawn by eye, but greater accuracy will result from using an appropriate mathematical expression or function and commercially available software to produce a chart. A fundamental assumption of these curves is that all individuals of a species that are available to the trawl gear are caught, irrespective of their size. In other words, all individuals in the path of the trawl gear are caught in the control codend and either the cover net or experimental codend.

If the number of retained individuals of a given species per tow is low, a selectivity curve may have to be produced that represents all individuals of that species from all tows (pooled analysis). Such a curve is adequate providing that all individuals were caught in the same vicinity over a period of several days. However, a problem with this method is that the curve could be influenced by large catches from a handful of tows, particularly if the length-range of these individuals is substantially smaller or larger compared with the length-range of individuals caught during the remaining tows. One option to help overcome this problem is to ensure that the catch sample used in the analysis is a constant proportion of the total catch. However, as this option may be difficult to achieve in practice, another option for each species is to produce selectivity curves for each tow as well as a combined curve. In this way, variation in curve shape can be observed, and the effect of large catches easily identified.

BOX 10

Selectivity Curves

Selectivity curves are useful for evaluating the performance of a BRD fitted into a codend or comparing the retention probability of shrimp or fish using a control and experimental codend. In the following hypothetical example, the performance of three codends is evaluated in a shrimp-trawl fishery where the minimum landing size (MLS) for a fish species is 18.5 cm. Codend 1 is the standard codend currently used by fishers, and codends 2 and 3 were fitted with different BRDs. A small-mesh cover net was used to surround each codend and retain all fish that passed through the codend.



Interpretation of selectivity curves is relatively straightforward. The position on the curve where 50 percent (0.5) of individuals are retained is known as the L_{50} value. Here, the L_{50} value of the standard codend coincidentally corresponds exactly to the MLS for this species. This means that 50 percent of fish measuring 18.5 cm were retained in codend 1 and 50 percent escaped capture. On the other hand, codend 2 retained about 63 percent of fish measuring 18.5 cm, but only about 43 percent of these fish were retained using codend 3.

Two other values that help interpret a selectivity curve are the L_{25} and L_{75} values. These values respectively indicate fish length where there is a 25 percent and 75 percent probability of retention in the codend. The difference between these two values ($L_{75} – L_{25}$) is known as the selection range (SR), and this provides information about the steepness of the curve. A steep curve infers a small selection range (more selective). In this example, the selection range of the standard codend is 5 cm, while the selection ranges for codends 2 and 3 are 3.5 cm and 2.5 cm, respectively. When comparing curves from two or more codends, the most desirable codend is often the one with the smallest selection range and L_{50} value closest to the MLS.

Several other important results can be identified from this example. The highest proportion of undersized fish measuring 15.5–18.5 cm was retained by codend 2, but the highest proportion of fish shorter than 15.5 cm was retained by the standard codend. The lowest proportion of undersized fish was retained by codend 3.

BOX 10 (Continued)

The highest proportion of legal-sized fish between 18.5 cm and 21 cm was retained by codend 2, while the highest proportion of larger fish was retained by codend 3. The lowest proportion of fish larger than 19 cm was retained by the standard codend.

Based on these curves, it is likely that fishers will prefer to use codends 2 and 3, because they retained a higher proportion of large fish compared with the standard codend. However, from an ecological perspective, codend 3 is superior because it retained substantially fewer undersized fish and has the smallest selection range. Therefore, it would seem that replacing the standard codend with codend 3 provides the best outcome for the fishery; fishers will increase their catches of larger fish while simultaneously reducing catches of undersized fish.

Finally, it is important to appreciate the limitations of the data and curve output. The analysis of selectivity data assumes that individuals of all lengths are available for capture by the trawl gear and that all of these individuals are retained in the codend or cover net. This is probably not the case because the catchability of these individuals varies with variation in environmental conditions (e.g. water temperature and ambient light levels) and trawl performance. As these parameters vary by time and place, catchability will never be consistent. Moreover, while steps can be taken to evaluate how well the curve represents the data, to improve the fit of the curve, and to evaluate the variation of multiple curves, there are no consistently applied guidelines indicating when a curve is considered a poor fit and should be modified or discarded. Selectivity curves should therefore be considered only an indicator or "snapshot" of the true selectivity of the trawl gear at the time and location that sampling took place.

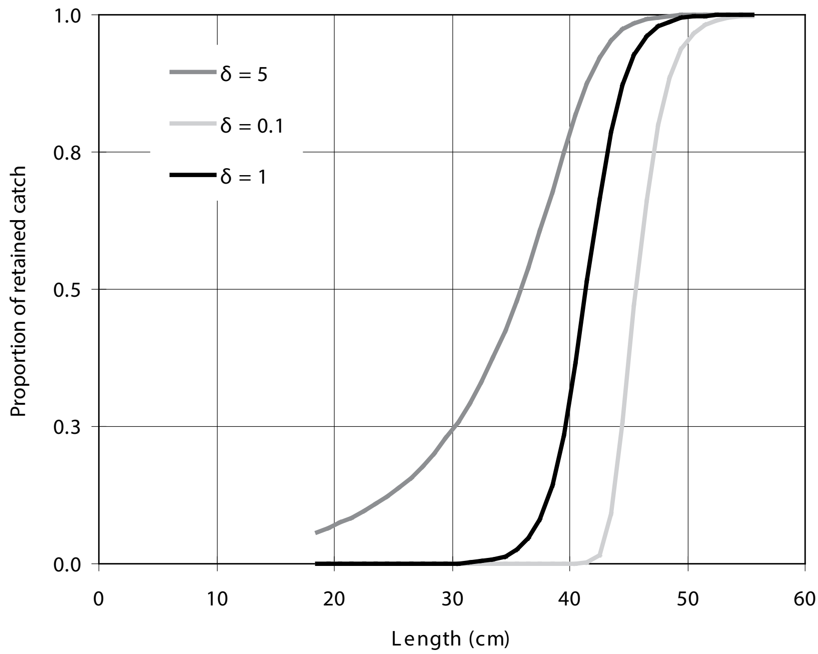
10.1 LOGISTIC AND RICHARD'S CURVES

To produce a selectivity curve that accurately represents the performance of a BRD or codend, mathematical expressions using either the logistic (or logit) or Richard's functions (Annex 8) can be used. The logistic function produces a curve that is symmetrical about the L_{50} value, and the shape of the curve either side of this length is identical (Anonymous, 1995). This was the expression used to produce the curves in Figure 5. The shape and steepness of this curve is determined by two parameters, 'a' and 'b', which can be estimated from the observed length frequencies (see Annex 9 for details).

The Richard's function produces a curve that is similar to the logistic curve but slightly more complex to produce, because it is typically asymmetric about the L_{50} value with one side of the curve steeper or flatter than the other side. The parameter 'δ' represents the asymmetry of a curve produced using the Richard's function (Box 8). If $0 < \delta < 1$, the curve has a longer lower tail, a steeper (sharper) slope between L_{25} and L_{75}, and a shorter upper tail. If $\delta > 1$, the curve has a shorter, flatter lower tail, shallower slope between L_{25} and L_{75}, and a longer upper tail. If $\delta = 1$, the curve is identical to a logistic curve.

Determining which function to use in order to represent selectivity data graphically is not always obvious. If the observed data points form a symmetric curve, then the logistic function may be most appropriate. If the curve is asymmetric, then the Richard's function may provide a better fit. In both instances, the function should improve the estimate of L_{50} and the selection range (Anonymous, 1996). If it is unclear which function should be used, both should be attempted. Visually, it may then be obvious which curve best represents the data. Two other methods exist to

FIGURE 5 – Richard's curves indicating the effect of the asymmetric parameter (δ)



Note: When δ = 1, the curve is identical to a logistic curve.

identify the most appropriate (best-fitting) curve, the Akaike Information Criterion (AIC) or analysis of the residuals of the curves. In the worked examples provided in the DVD accompanying this guide, the AIC is used to indicate the goodness of fit of the data to a probability curve. This parameter is dimensionless, and the curve with the lowest AIC value is generally considered a better fit to the data. Discussion of residuals is beyond the scope of this guide, but details can be found in Wileman *et al*. (1996). Worked examples of selectivity curves using the logistic and Richard's functions are described step-by-step in Annex 9.

10.2 PREPARING SELECTIVITY DATA

Prior to presenting catch data using the logistic or Richard's curve, the data are prepared using one of the following statistical methods.

10.2.1 Maximum likelihood method

This method is commonly applied to covered codend experiments, and replaces the traditionally applied method of fitting-by-eye or least-square regression analysis. It uses the observed catch data and produces a line of best fit that maximizes the likelihood (probability) of obtaining the observed catch of each length group in the experiment (Anonymous, 1995).

10.2.2 Contact probability method

A simple modification can be applied to the maximum likelihood method that considers the probability that a fish will encounter the BRD. When a BRD is inserted into to a codend, such as a square-mesh window, fisheye or JTED, it is unreasonable to expect that all individual fish encounter or contact the device. Many will swim below or around the device, and do not have an opportunity to escape. The contact probability model takes this into account by modifying the logistic function with a contact probability parameter (see Case study 3). This model assumes that all sizes of a species of interest have the same contact probability. The theory behind this model is described in Tokai *et al*. (1996) and Zuur *et al*. (2001).

10.2.3 SELECT method

The SELECT (Share Each LEngth's Catch Total) method is widely used to analyse catch data from paired comparative experimental methods using a trouser trawl, alternate haul, or parallel haul (Wileman *et al*.,1996). This method assumes the both gear are sampling the same population of fish or shrimp, and the selectivity of the experimental gear is measured relative to the control gear, which should have a mesh size small enough to be considered non-selective (Anonymous, 1995).

Using the SELECT method, the probability of capture of a particular length group in the experimental gear depends not only on the total number of fish caught in both the experimental and control gear but also the fishing efficiency of each gear. Unequal fishing efficiencies between the experimental and control gear are accommodated for and do not adversely affect the analysis of catch data.


COURTESY OF BUNDIT CHOKESANGUAN AND SONGPHON CHINDAKHAN

11. Report writing

A report describing the accomplished work and results is essential. Not only does this document the methodology, results and outcomes of the research, but it is testament to the research capability of the author (or authors). It may also serve as a useful tool to demonstrate the need for additional or future research, and to attract further research funding. Sometimes, several reports must be prepared during the life of a research project, including periodic or milestone reports, a draft final report, and a final report.

11.1 PERIODIC OR MILESTONE REPORTS

A periodic report is written after a predetermined time to describe research progress to date for stakeholders. It is generally a relatively short report that describes the status of the experiment or project, preliminary results, problems that have been encountered, deviations from the original research methodology, and future plans. This report is typically only several pages in length and only a summary of results is provided.

A milestone report is similar to a periodic report, except the timing of the report is linked to the completion of a particular activity (or milestone). Typical milestones include the purchase and construction of fishing gear, identification of a suitable fishing boat, completion of fieldwork, or completion of data analyses.

PLATE 52 – A mixed catch of shrimp and bycatch

CREDIT: S. EAYRS

11.2 FINAL REPORT

The final report will provide a full and detailed account of all research activity. Key sections of a final report include a title page, an abstract, introduction, materials and methods, results, discussion, conclusion, appendixes, and relevant figures, tables or photographs (e.g. Plates 52 and 53). Often a draft final report is prepared for review by project staff and others, and any comments can be considered for inclusion in the final report. This helps ensure the final report provides a clear and thorough description of the fieldwork, including data analysis and interpretation, and importance of the research findings to the bycatch problem and fishery.

This report is suitable for fishery managers, policy-makers, researchers and others with an interest in the research, while a summary of this report (1–2 pages) may need to be produced for fishers and others that do not wish to read the entire report. Raw data may be included in the final report, or supplied on a computer disk or stored on a database, to allow further analysis of the data if desired by others.

PLATE 53 – A good catch of shrimp with relatively little bycatch

CREDIT: S. EAYRS

Sometimes, the final report can also serve as a paper for scientific publication, although in many instances the final report will have to be altered to comply with the publishing requirements of the particular target journal. In this instance, the final report may need to be written concisely in order to meet strict word limits. To gain an insight into the content and format of a final report, it is useful to read similar reports by other authors. These reports also provide options and ideas for graphically presenting data including fishing gear details, fishing location, and catch information. Care is required in preparing the title page because the project title, author details, and selected keywords, provide other researchers access to this report via computer search engines and databases.

11.2.1 Abstract

An abstract is a brief, stand-alone summary of the purpose and content of the report, including objectives, methods, results and conclusions drawn from the research. An abstract is typically several hundred words in length. However, because many readers use an abstract to determine whether the report warrants further reading, it is important to be comprehensive and non-repetitive. It is usually the last section of a report to be written so that all essential information can be summarized and included.

11.2.2 Introduction

This section arouses the reader's interest by introducing the rationale and history of the bycatch issue to be addressed. That is, it will cover the extent and magnitude of the particular bycatch problem, and potential implications for failing to address the problem. These details are usually supported with relevant facts and references, including details of efforts by researchers, fishers, and others to reduce bycatch in the same fishery, as well as other local and international shrimp-trawl fisheries. The introduction should also contain a clearly written statement describing the hypotheses to be tested.

11.2.3 Materials and methods

This section includes a description of the fishing boat, experimental method, trawl (including rigging details) and BRD (or BRDs) used in the research. A detailed diagram of the codend and BRD must be included (see Annexes 5 and 6 for examples), and preferably a diagram of the trawl. Also included is a description and map of the fishing area with justification for using this location.

The methods used to sample the catch, including catch measurements, should also be included, as well as technical and operational information pertaining to the fieldwork, such as tow duration, direction and timing. Analytical techniques used to evaluate the results and test the hypotheses should be described, including reasons for using each particular statistical technique.

In short, sufficient information should be provided in this section to allow the reader to understand fully how the hypotheses were tested and confidently repeat the study if desired.

11.2.4 Results

The results section must contain all catch details, including species composition, catch rates, and statistical results. Key information about the fishing and environmental conditions encountered during the study, including the number of valid tows, must be provided so the reader can fully understand the conditions and variables that influenced the collection of data. The results should be presented in a way that clearly relates to the problems that were described in the introduction, and they should flow logically from the information provided in the materials and methods section. Care is required to ensure that this section is not used to interpret the results or discuss their importance.

11.2.5 Discussion

Here, an interpretation of the results is provided for the reader. The implications of the results are evaluated, particularly with respect to the problems and hypotheses outlined in the introduction, and inferences and conclusions are drawn. Comparison with other similar studies should be made in this section, problems or limitations with the methodology or fieldwork should be discussed, and any need and description of further work should also be provided.

11.2.6 Conclusion

This section is an opportunity to summarize briefly the results and interpretation of the research, and to state any inferences and conclusions as they relate to the bycatch problem. This section is usually no longer than a short paragraph.

11.2.7 Appendixes

Appendixes contain information that is too large or inappropriate for the main body of the report but which is nevertheless important for the report to include. Examples include trawl plans, raw data, computer programs, case studies and worked examples.

11.2.8 Figures and tables

Appropriate figures and concise tables should be included in the report to present and support research findings. In the final report a plan of the trawl and BRD (or BRDs) used in the fieldwork should be provided, with sufficient detail to allow construction of identical fishing gear by others interested in repeating the research. A map of the area of operations should be provided, with coastline, latitude and longitude, and points of interest indicated, and appropriately marked to indicate the precise location of fishing operations. Also important are graphs depicting differences in catch between experimental codends and cover nets, or between control and experimental codends, histograms indicating the length-frequency of retained shrimp or other species in each trawl, and pie charts representing catch proportions by species. Presenting selectivity curves is important to illustrate the relationship between the retained proportion of shrimp or other species in the codend at each length class.

Tables should also be used to provide important information, such as the codend testing sequence used in the fieldwork and summaries of results, including summaries of statistical analyses.

Both figures and tables can be located either within the main body of the report, such as the methods and results sections, or at the end of the report following the reference section. Locating figures and tables within the main body of the report allows the data to be presented adjacent to the relevant text, while their location at the end of the report requires the reader to flip pages between the relevant text and the figure or table. This latter option is less convenient and can be a disruption and a distraction for the reader; however, the editors of journals and other publications often require figures and tables to be located at the end of a submitted manuscript. This is convenient for the publishers because it simplifies type-setting the article and allows them to control the location of figures and tables within the article.

11.3 INFORMATION SHARING WITH INDUSTRY

If there is an expectation that fishers will adopt and use BRDs, they need to be informed of the results and outcomes of the research. Most fishers will not be interested in reading a long, wordy document filled with extensive tables and statistical results. Alternative options to transfer or extend the results and outcomes of the research must therefore be sought (Plate 54).

One option is to present a summary of the results in a short document, perhaps one or two pages in length. An effort should be made to keep the text to a minimum and allow photographs,

PLATE 54 – This simple brochure was produced to provide local fishers with details of bycatch reduction devices approved for the fishery

CREDIT: S. EAYRS

tables and figures to present key information. A one-page brochure or a poster is another way to deliver the results and outcomes. Information should be succinct, perhaps using dot or bullet points to present important highlights and key facts or outcomes. There will be little opportunity to present a detailed interpretation of the results of the research. Including quotes from fishers involved in the research is useful to add credibility to the research from the perspective of the fishing industry.

One of the most successful ways to exchange information with fishers, interest them in BRD research and encourage them to consider using a BRD is to present underwater video footage of the trawl and BRD in action, with fish and other animals passing through the trawl and escaping through the BRD. Many fishers will not have seen fishing gear in operation underwater, or shrimp, fish and other animals responding to the gear, and are usually curious to do so. Discussing the observations with fishers is an excellent way to encourage participation and gain their input into ways to improve further BRD performance (Plate 55). Conducting meetings or workshops at the fishing port, accompanied by underwater video footage where possible, is an excellent way to attract fishers to meetings, extend research results, stimulate discussion, and perhaps attract further investment or involvement in BRD research (Plate 56).

PLATE 55 – Information exchange between researchers, fishers, and others is an essential component of BRD research

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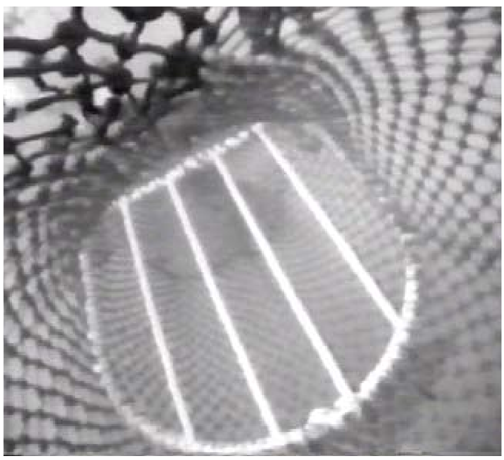
PLATE 56 – Underwater video of fishing gear in action is an excellent way to interest fishers in TED and BRD research



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12. Conclusion

With the information provided in this guide, researchers should be in a position to undertake at-sea research to test a BRD with a degree of confidence and competence. The researchers will no doubt experience numerous problems and issues that will challenge their ability to complete the research in a timely and effective manner. While the information provided in this guide is based on many years of experience and literature, arguably the greatest challenge for researchers will be to adapt the information in this guide to respond to particular operating conditions and circumstances. An ability to be flexible when conducting research and, more importantly, to know when to be flexible, is perhaps one of the greatest challenges facing any researcher.

BUNDIT CHOKESANGUAN AND SONGPHON CHINDAKHAN

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COURTESY OF HAI NGUYEN

14. Glossary of BRD research terms

Bycatch

Part of the catch affected incidentally by the fishing gear, in addition to the target species. It includes all non-target animals and non-living material that a fisher did not intend to catch, did not want to catch, and did not chose to use for whatever reason, including those that interact with the fishing gear but are not landed onboard. In some fisheries, bycatch refers to a portion of the total catch that is not consistent with a fishery management plan. Some or all of the bycatch may be returned to the sea as discards, usually dead or dying. Bycatch is sometimes referred to as accidental catch, incidental catch, or non-target catch. For a more detailed explanation, see FAO Fisheries and Aquaculture Report No. 934.

Bycatch reduction device (BRD)

Any modification to fishing gear designed to reduce the capture of bycatch, including any device inserted into the codend or extension piece of the trawl for the purpose of reducing bycatch. Other modifications that may reduce bycatch include larger meshes in the codend or body of the trawl, ground gear modification, or adjustment to headline height.

Catchability

In a broad sense, catchability is the extent to which a shrimp or fish is susceptible to capture by fishing gear. In stock assessment, it is the proportion of the stock removed by one unit of fishing effort, e.g. one tow.

Comparative fieldwork

Fieldwork with the main objective to compare the catching performance of a trawl fitted with a BRD against a trawl without a BRD fitted.

Control codend

A codend that is not equipped or fitted with a BRD during comparative fieldwork. It may be a fine-mesh codend or identical to the standard codend used by commercial fishers.

Discards

Discards are the portion of the total catch that is thrown away or slipped overboard during processing of the catch. Discards may be comprised of single or multiple species and may be alive or dead as they are discarded. The survival rate of live discards is not well understood.

Experimental codend

A codend that is modified to reduce bycatch or equipped with a BRD during comparative fieldwork.

Incidental catch

Has the same meaning as bycatch or non-target catch.

Industrial fishery

A fishery involving commercial fishing companies using relatively large amounts of capital and energy, relatively large fishing boats and fishing gear, making long fishing trips, usually offshore, and with the catch usually destined for export.

Low-value fish

Also sometimes called trash fish. The part of a catch typically with little or no commercial value, although in some shrimp-trawl fisheries, low-value fish is retained for use in fish or shrimp culture, fishmeal production, or human consumption. A term mainly used in Asian fisheries.

Net bias

An ability of a net to fish differently and retain a different catch composition compared with an identical net fished from the same boat during a paired fishing experiment

Non-target species

Has the same meaning as bycatch or incidental catch.

Paired tests
A simultaneous test of two codends, usually a control codend and an experimental codend, where catches from each codend are compared.

Replicates
Repeats of a controlled experiment or test to allow statistical analyses of data. If both a control and experimental trawl are towed more than once during fieldwork, they produce replicate data sets. Replicates allow statistical tests to be conducted which can then be used to determine whether any differences in catches are real, e.g. due to fish escaping from a BRD, or due to chance, e.g. a chance encounter with a large aggregation of fish by either the control or experimental trawl.

Responsible Fishing
Fishing activity that is sustainable, with minimal impact on the environment, and provides consumers with high-quality, nutritious seafood that meets appropriate food safety standards.

Sample size
A statistical term that can refer to the number of observations or objects that constitute a sample. For example, the number of successful tows for each treatment that are completed as part of a sampling programme, or the number (or weight) of a catch of a particular species or species group from one or more tows.

Selective fishing
Fishing activity using selective fishing gear.

Selective gear
A fishing gear that captures specific species and sizes of fish or other animals.

Selectivity
An ability of a fishing gear or method to target and capture animals by size and species during the fishing operation allowing non-targets to be avoided or released unharmed.

Shrimp trawler
A commercial fishing boat used to target shrimp, although fish and other animals may comprise a portion of the overall commercial catch.

Small-scale fishery
A traditional fishery involving fishing households (as opposed to commercial companies), using relatively small amounts of capital and energy, relatively small fishing boats (if any) making short fishing trips, close to shore, and with the catch destined mainly for local consumption.

Stakeholder
An individual, company or organization with an interest in a fishery. In the broadest sense, everyone is a stakeholder because fishery resources are a community asset.

Subsistence fishery
A fishery where the catch is shared and consumed directly by the family and relatives of fishers rather than being bought by an intermediary and sold at the next larger market.

Sustainable Fishing
Fishing activities that do not cause or lead to undesirable changes in biological and economic productivity, biological diversity, or ecosystem structure and functioning, from one human generation to the next. Fishing is sustainable when it can be conducted over the long term at an acceptable level of biological and economic productivity without leading to ecological changes that foreclose options for future generations.

Target species
The subject of directed fishing effort in a fishery. Usually, those species of a desirable size (length) that are primarily sought by fishers in a particular fishery.

TED
An inclined grid or netting panel that prevents the passage of large animals such as sea turtles, sharks, stingrays, skates, jellyfish, sponges and large fish into the codend and guides them through an escape opening located in the codend. Sometimes smaller animals such as fish, squid, and other animals that can pass through the grid avoid capture by voluntarily swimming through the escape opening. TED is an acronym for turtle exclusion device, but sometimes means a trawl efficiency device. A TED is a type of BRD.

Trawl
Referred to in this guide as the actual net and its component parts, including the otter boards, ground gear, codend, and towing wires.

Treatment
A statistical term that refers to sampling units in an experiment or study. For example, if the selectivity of several different codends (including a control codend) is repeatedly tested using a single trawl, each codend is called a treatment. The trawl is the experimental unit and the sampling units or treatments that are administered to the trawl are the codends.

Tuning a trawl
Systematically adjusting a trawl to minimize or eliminate any bias in catching efficiency between two trawls used in a comparative study.

Undersized fish
Fish caught that are smaller than the minimum landing size (MLS) established by regulation. The MLS is often set so fish can reproduce at least once before they can legally be captured and retained onboard.

Variables
This statistical term refers to the categories of interest that are analysed in a study, for example, shrimp weight, bycatch weight, and number of species.

CREDIT: S. EAYRS

Annex 1 – Shrimp trawl components and terminology

Terms adapted from Day (2000)

Aspect ratio:

The ratio of otter board height and length. Most otter boards in shrimp-trawl fisheries have a low aspect ratio, typically about 0.5. In contrast, the aspect ratio of otter boards used in fish-trawl fisheries may be about 2.0.

Booms (outriggers)

Steel or aluminium framework that may measure 10 m or more and extend perpendicularly to the fore/aft direction of the boat (Figure A1.1). The warp wire passes through a towing block located near the end of each boom.

Bosom

Central part of a trawl where the headline and footrope are normal to the towing direction (Figure A1.2).

Bridles

Wire rope connecting the otter boards (and sleds) to the warp wire, and usually constructed from identical material to the warp (Figure A1.1). As a guide, bridle length should be at least four times longer than headline length.

Chaffing mat or net

A panel of netting attached to the underside of the codend, usually constructed from heavy netting material, sometimes with lengths of frayed rope attached. An alternative is a length of canvas extending underneath the codend, attached along its leading edge to the codend netting. A chaffing mat is used to protect the codend from abrasion.

FIGURE A1.1 – Key components of a shrimp trawl system

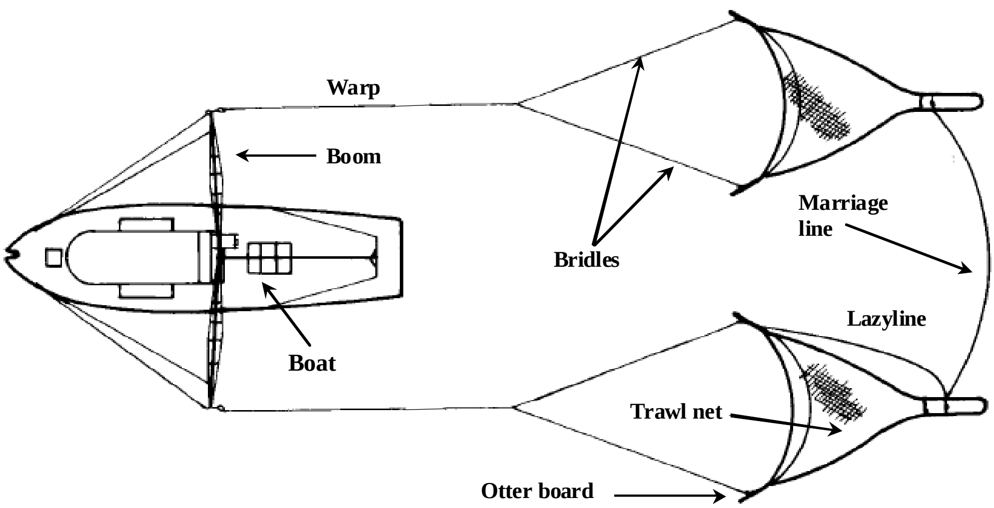
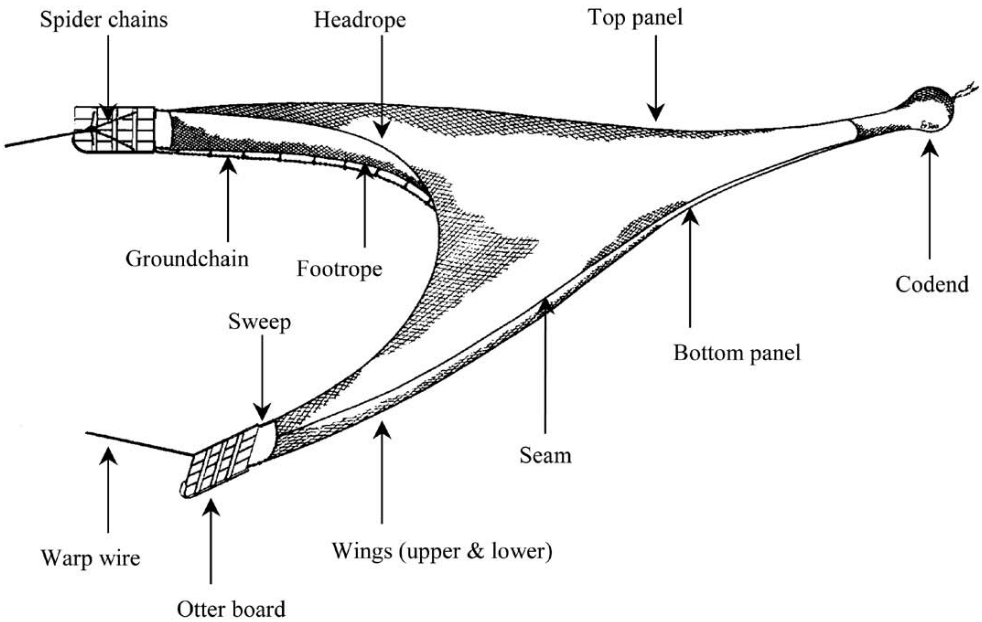


FIGURE A1.2 – Key components of a shrimp trawl



Codend
A netting bag connected to the aft end of the trawl to collect and retain the catch during the tow (Figure A1.2). Usually constructed from smaller mesh-netting than other sections of the trawl, with heavier diameter twine to increase abrasion resistance and withstand stresses caused by the catch.

Drop Chain
A length of chain, sometimes referred to as “drops” or “droppers”, usually measuring 150–200 mm long. Several drop chains are used to connect the footrope to the ground chain at approximately 1 m intervals. The resulting space between footrope and ground chain allows less-mobile benthic animals and debris to pass beneath the trawl and escape capture.

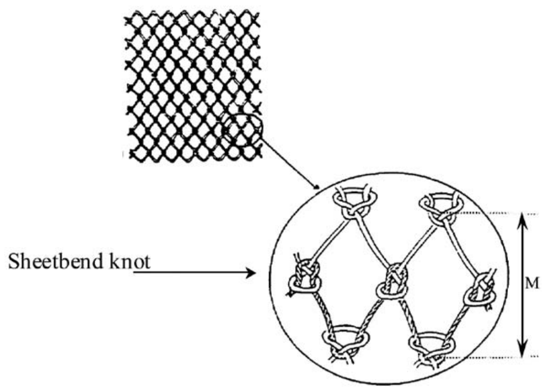
Fly wire
A wire connecting the headline of a trawl to the bridle approximately 10–20 m ahead of the otter board. With the headline no longer attached to the otter board, the vertical opening of the trawl is increased. Sometimes used to catch semi-pelagic shrimp.

Footrope
Lower frame line to which netting is connected (Figure A1.2). Also referred to as the fishing line, footline or groundrope

Ground Chain
A length of chain that travels across the sea bed and keeps the trawl close to the sea bed (Figure A1.2). If a Texas drop ground chain arrangement is used, the ground chain is measured carefully to ensure it is several chain links shorter than the footrope. In this way, the chain travels ahead of the shrimp stimulating them to rise from the sea bed and enter the trawl over the footrope. If scalloped ground chain rigging is used, the chain drags behind the footrope.

Ground Gear
That part of the trawl designed to contact the sea bed. The ground gear includes the ground chain, drop chains, and if used, the tickler chain and mudrope.

FIGURE A1.3 – Measuring the mesh size



Hanging
Method for attaching the upper and lower panels of netting to their respective headline or footrope. Typically, several meshes are "hung" between individual hangings.

Hanging ratio
The ratio between the length of a hanging on a headline or footrope and the stretched mesh distance of the 'hung' netting.

Headline/Headrope
Upper frame line to which netting is connected in a trawl. Also referred to as the headrope (Figure A1.2). Headline length is often used as a measure of trawl size, and is the measured distance between the first hanging on one wingend to the last hanging on the other wingend.

Lazy line
A rope used to haul the codend on board (Figure A1.1). It is normally connected permanently to the codend. When the trawl is deployed, the free end of the lazy line is attached to the otter board. When the trawl is retrieved, this line is connected to a lazy line winch or manually hauled onboard

Leadahead
Where the headline is forward of the footrope to form an overhanging sheet of netting. The leadahead is designed to prevent shrimp from escaping over the headline, and may extend 300 mm or more ahead of the footrope at the bosom. Near the wingends, the leadahead is almost nonexistent. In some trawl fisheries, the leadahead is known as verandah or cover.

Logrope
A length of small diameter rope threaded through the meshes of the wingend between the headline and footrope to provide support and strengthen the wingend.

Marriage line
A small diameter rope extending between lazy lines (Figure A1.1). This rope, being near the stern of the boat when the gear is hauled, is easily recovered by grapnel to provide access to all lazy lines. The use of this rope is optional

Mesh Size
The distance between the centres of opposing sheetbend knots when the mesh is pulled taut (Figure A1.3)..

Mud Rope
Ground chain or stainless steel wire that is wrapped in rope. This increases the diameter of the ground gear to prevent the trawl dredging in soft sediments as it passes across the sea bed.

Net
The net, or trawl, consists of several panels of fine-mesh netting tapered to guide the catch towards the codend (Figure A1.1). The simplest shrimp nets are constructed with an upper and lower panel (two-seam trawl) while a more complex net is constructed with the addition of side panels (four-seam trawl). The leading edge of the upper panel is hung on an upper frame line (headline) and the leading edge of the lower panel is hung on a lower frameline (footrope). The ground gear is attached to the lower frame line.

Otter board
An otter board is towed over the sea bed to provide a lateral spreading force and open the trawl horizontally (Figures A1.1 and A1.2). Usually, the headline of the trawl is attached to the top of the otter board to provide vertical opening. The otter board also helps keep the trawl in contact with the sea bed.

Seam
The product of joining two panels of trawl together along the length of the trawl from wingend to codend (Figure A1.2). Sometimes called a selvedge

Side Panel
Longitudinal panel of netting built into the side of the trawl to increase headline height.

Skirt
A cylindrical netting cover over the codend of similar material and circumference to reduce wear on the codend and protect the catch against attack by sharks, dolphins or other animals. In some fisheries, the skirt may be sealed over the codend using a drawstring as additional security against catch loss.

Spread
The lateral distance that the headline spans while the gear is travelling over the sea bed.

Spread ratio
Ratio of wingend spread to headrope length.

Sweep
A length of wire extending from the otter boards to the headline or footrope (Figure A1.2). In some fisheries, the sweep is more than 15 m in length and serves to herd fish into the trawl and increase headline height

Swept Area
Refers to the area of sea bed covered by a trawl (Figure A1.4) and is defined by the equation:

$$As = HL \times Sr \times D$$

Where;

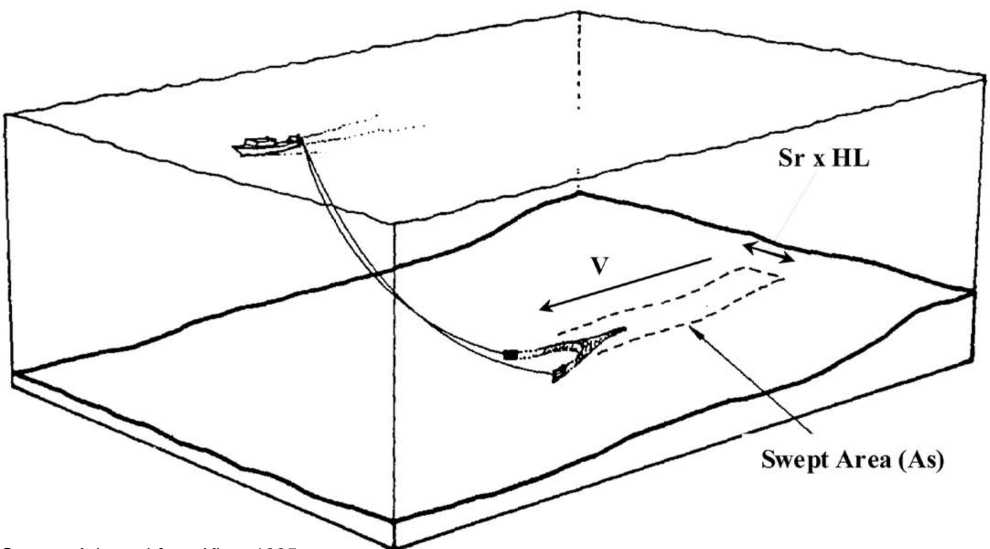
As = the swept area of the trawl (m^2)

HL = headrope length (m)

Sr = ratio of wingend spread to headrope length, and

D = towed distance (m) = towing speed (m/s) x towing time (s).

FIGURE A1.4 – The area swept by a trawl



Source: Adapted from King, 1995.

Taper
A combination of mesh cuts at various angles in the netting to shape a panel of netting.

Tickler Chain
Chain of shorter length than the ground chain designed to increase the shrimp catch. This chain travels across the sea floor ahead of the ground chain to evoke an early reaction by shrimp and reduce their escape below the footrope. It is either attached to the trailing edge of the otter boards or to the ground chain. Usually, no drop chains are used.

Trawl body
Section of the trawl between the bosom and the codend.

Trawl
See definition for net.

Try Gear
A scaled-down shrimp trawl that may be used periodically from the stern or outrigger of a shrimp trawler to provide a sample of the shrimp catch and indicate relative shrimp density without having to deploy the main gear. The try gear can also be used when the main gear is in operation to determine shrimp density without having to haul the main gear. Fishers use the catch from the try gear to identify fishable quantities of shrimp and to remain in regions of high shrimp density.

Warp wire
Main towing wire connected to the otter boards, typically measuring between 8 mm and 16 mm in diameter depending on size of boat and trawl (Figures A1.1 and A1.2). On small boats, rope may be used instead. To ensure the trawl is in sea-bed contact when fishing, typical warp to depth ratios range from 4 to 1 in deep water to 10 to 1 in shallow water.

Wing
A panel of netting forward of the trawl bosom extending to the otter boards (Figure A1.2). All shrimp trawls are designed with an upper and lower wing.

Wingend
The forward or leading edge of the wing between the upper and lower frame lines. The wingend is usually strengthened by the addition of a logrope.

Wingend spread
The lateral distance between the wings of the net when the trawl is fishing, measured between the first hanging on each wingend. This distance can be measured using acoustic distance sensors or estimated geometrically providing the warp length and angle between the warps is known (this method assumes the warps are straight).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Annex 2 – A boat and trip information log

VESSEL AND TRIP INFORMATION LOG

PROJECT NAME	
PROJECT NUMBER	
TRIP ID	

VESSEL NAME	VESSEL NUMBER	DATE SAIL mm/dd/yy / /	TIME SAIL 24 h :
PORT LANDED (CITY, STATE)	DEALER'S NAME	DATE LAND mm/dd/yy / /	TIME LAND 24 h :

GEAR TYPE CODE	TARGET SPECIES	FISHING LOCATION	# DAYS	# HAULS

COMMENTS

Annex 3 – A haul or tow log

TRAWL HAUL LOG

HAUL #	GEAR #	WEATHER CODE	WIND		WAVE HEIGHT	DEPTH HAUL	GEAR DAMAGE? NO / YES (comment if yes)
			SPEED	DIRECTION			
			kt		m	fm/m	

HAUL INFO	DATE mm/dd/yy	TIME 24 h	**LATITUDE/LONGITUDE (DD.MM.M)**				WIRE OUT
			STATION 1	**LATITUDE**/Bearing	STATION 2	**LONGITUDE**/Bearing	fm/m
BEGIN	/ /	:					TARGET SPECIES
END	/ /	:					

SPECIES (K – kept; D – discarded)

NAME	K/D	WEIGHT (kg)	NAME	K/D	WEIGHT (kg)	NAME	K/D	WEIGHT (lkg)

COMMENTS

Annex 4 – A catch log

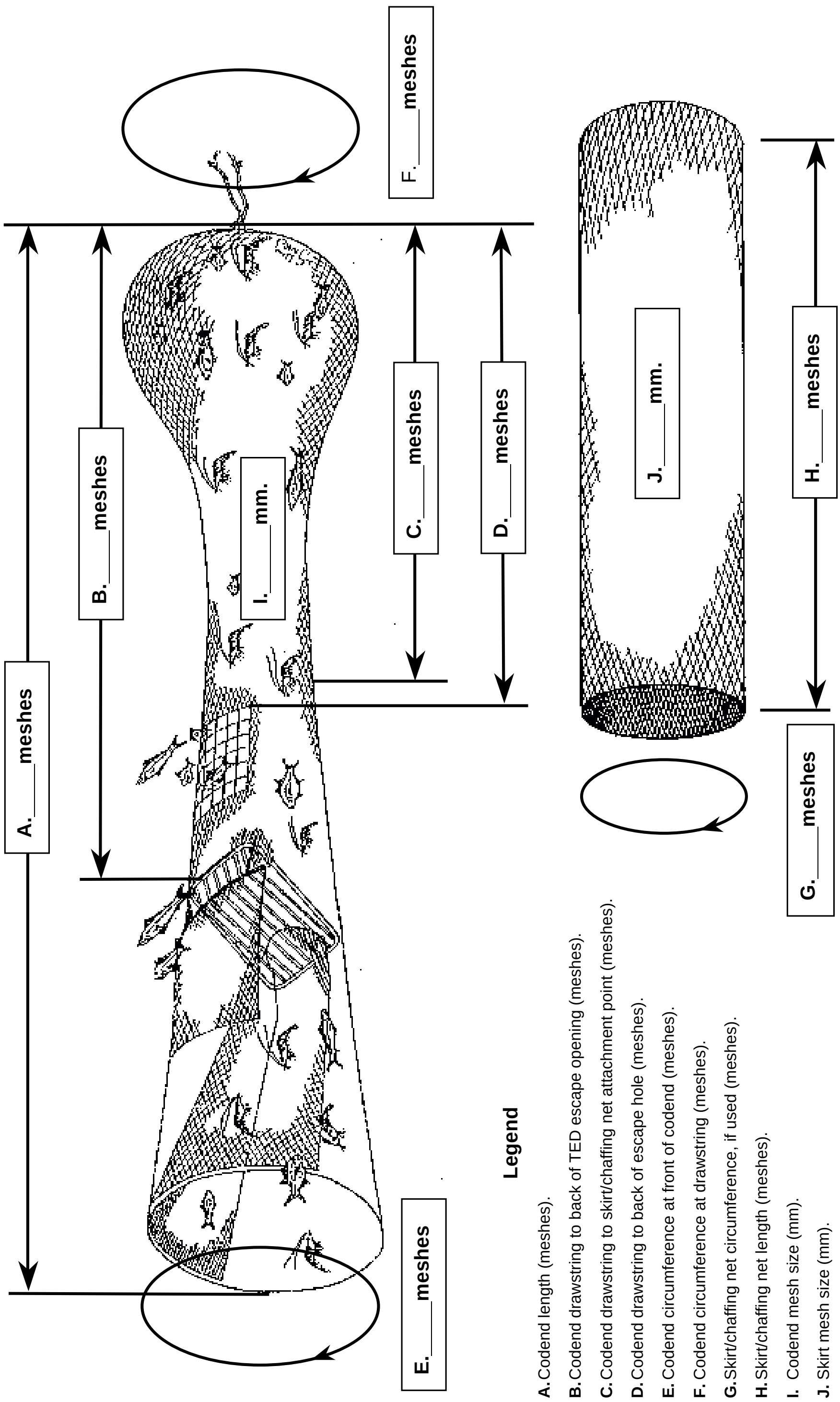
TRIP ID	
PAGE #	OF
HAUL #	
GEAR #	

LENGTH FREQUENCY DATA LOG

SPECIES NAME																								
SPECIES CODE																								
KEPT/DISCARDED																								
SAMPLE WEIGHT																								
MEASUREMENTS	0		0		0		0		0		0		0		0		0		0		0		0	
Finfish, Squid - cm	1		1		1		1		1		1		1		1		1		1		1		1	
Shellfish - mm	2		2		2		2		2		2		2		2		2		2		2		2	
COMMENTS	3		3		3		3		3		3		3		3		3		3		3		3	
	4		4		4		4		4		4		4		4		4		4		4		4	
	5		5		5		5		5		5		5		5		5		5		5		5	
	6		6		6		6		6		6		6		6		6		6		6		6	
	7		7		7		7		7		7		7		7		7		7		7		7	
	8		8		8		8		8		8		8		8		8		8		8		8	
	9		9		9		9		9		9		9		9		9		9		9		9	
	0		0		0		0		0		0		0		0		0		0		0		0	
	1		1		1		1		1		1		1		1		1		1		1		1	
	2		2		2		2		2		2		2		2		2		2		2		2	
	3		3		3		3		3		3		3		3		3		3		3		3	
	4		4		4		4		4		4		4		4		4		4		4		4	
	5		5		5		5		5		5		5		5		5		5		5		5	
	6		6		6		6		6		6		6		6		6		6		6		6	
	7		7		7		7		7		7		7		7		7		7		7		7	
	8		8		8		8		8		8		8		8		8		8		8		8	
	9		9		9		9		9		9		9		9		9		9		9		9	

Annex 5 – A gear log to record important codend and BRD details

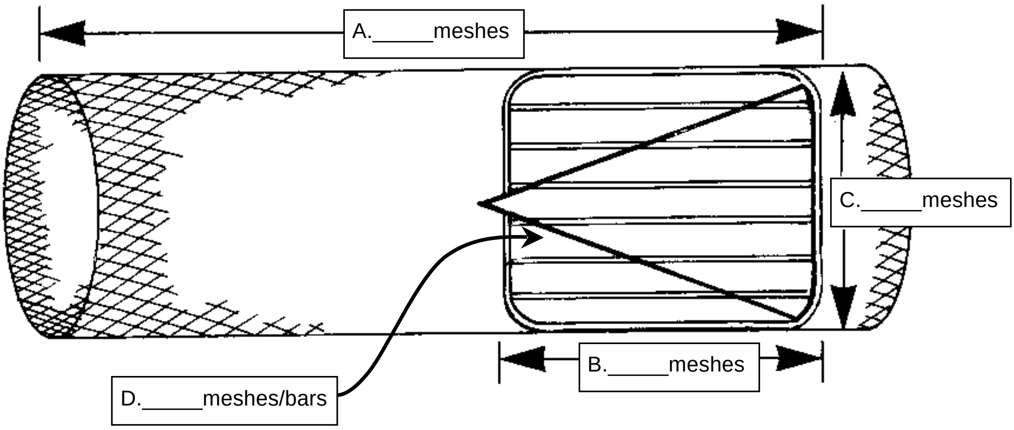
Codend name/BRD type: ____________



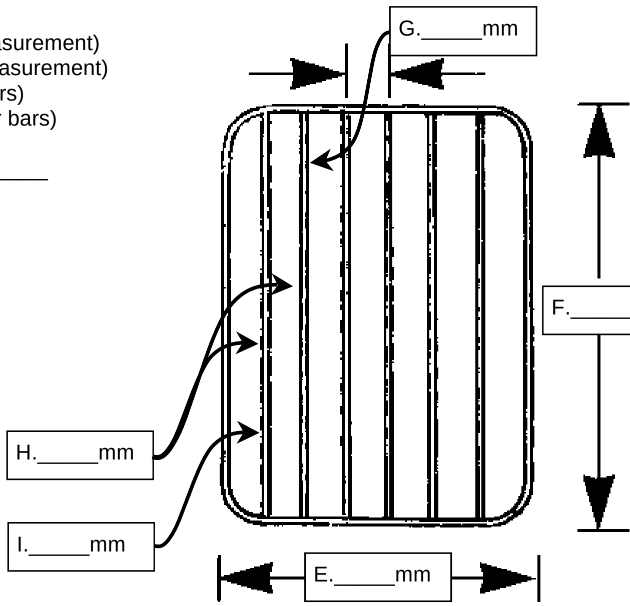
Legend

A. Codend length (meshes).
B. Codend drawstring to back of TED escape opening (meshes).
C. Codend drawstring to skirt/chaffing net attachment point (meshes).
D. Codend drawstring to back of escape hole (meshes).
E. Codend circumference at front of codend (meshes).
F. Codend circumference at drawstring (meshes).
G. Skirt/chaffing net circumference, if used (meshes).
H. Skirt/chaffing net length (meshes).
I. Codend mesh size (mm).
J. Skirt mesh size (mm).

Annex 6 – A gear log to record TED details



A. No. meshes from back of escape hole to front of codend.
B. No. meshes from back of grate to front of grate.
C. No. meshes wide
D. Taper details
E. Grate width (outside measurement)
F. Grate height (outside measurement)
G. Bar spacing (between bars)
H. No. bars (excluding outer bars)
I. Bar diameter
J. Grate material ______________

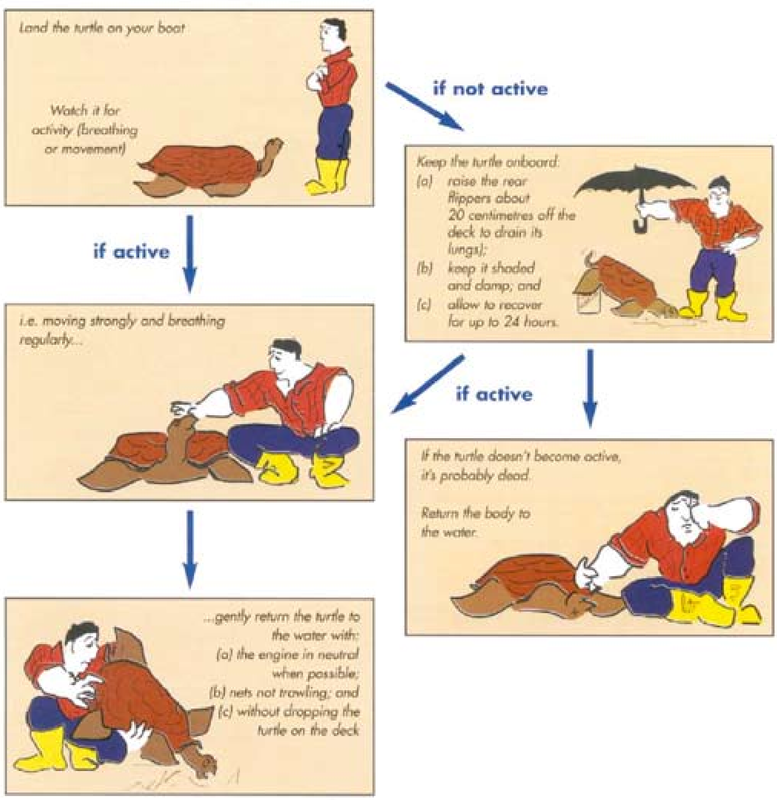


Annex 7 – Sea turtle recovery procedures

The following sea turtle recovery procedures illustrate how to handle a sea turtle after it has been landed on the deck of a trawler. These procedures are used by Australian shrimp fishers. Researchers testing BRDs in shrimp-trawl fisheries in other countries must familiarize themselves with local regulations and procedures pertaining to sea turtle capture prior to commencing fieldwork.

Turtle Recovery Procedures

Sea turtles caught in trawl nets may be stressed. Most are conscious and able to swim away after removal from the net, but some may be tired or appear lifeless. Turtles that appear lifeless are not necessarily dead. They may be comatose. Turtles returned to the water before they recover from a coma will drown. A turtle may recover on board your boat once its lungs have drained of water. This could take up to 24 hours. By following these steps you can help to prevent unnecessary turtle deaths:



Additional information

All records of turtle catches and deaths are important. If you catch a sea turtle record when, where, what species and what condition it was in when released. Record any tag numbers that may be on the front flippers of the turtle. This information should be recorded on your compulsory fishing log book or passed on to the Southern Fisheries Centre, telephone: (07) 3817 9500.

Source: J. Robins of the Queensland Department of Primary Industries and Fisheries, Australia.

Annex 8 – Mathematical expressions for the logistic and Richard's curve

Expressions for logistic and Richard's curves and related parameters. *r*(*l*) = the probability that fish of length *l* is retained in the codend and 'a' and 'b' are parameters that describe the shape and steepness of the curve. The parameter 'δ' represents the asymmetry of the Richard's curve.

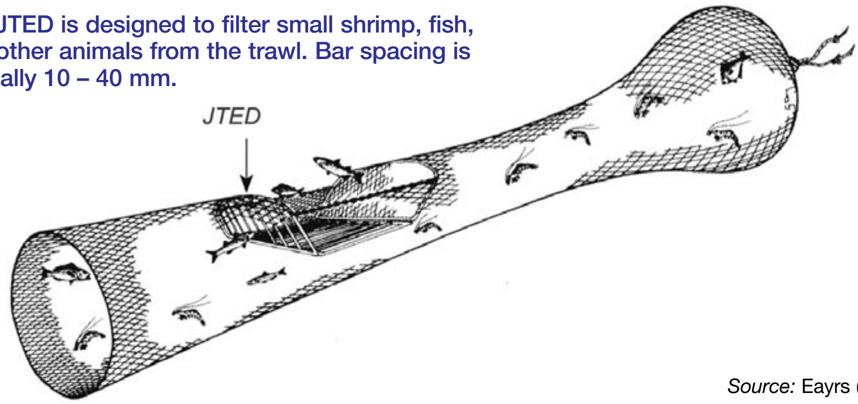
Parameter	Selectivity curve	
	Logisitic	Richard's
r(*l*)	$\frac{\exp(a+bl)}{1+\exp(a+bl)}$	$\left(\frac{\exp(a+bl)}{1+\exp(a+bl)}\right)^{3/\delta}$
a	$-L_{50}$ x (2 x ln(3) ÷ SR)	$-L_{50}$ x (2 x ln(3) ÷ SR)
b	2 x ln(3) ÷ SR	2 x ln(3) ÷ SR
L_{50}	-a ÷ b	$\left(\ln\left(\frac{0.5^{\delta}}{1-0.5^{\delta}}\right)-a\right)\div b$
L_{25}	(-ln(3) – a) ÷ b	$\left(\ln\left(\frac{0.25^{\delta}}{1-0.25^{\delta}}\right)-a\right)\div b$
L_{75}	(ln(3) – a) ÷ b	$\left(\ln\left(\frac{0.75^{\delta}}{1-0.75^{\delta}}\right)-a\right)\div b$
SR	(2 x ln(3) ÷ b) or (L_{75} – L_{25})	L_{75} – L_{25}

Annex 9 – Case studies

The following case studies describe the construction of selectivity curves using the logistic and Richard's functions and either the maximum likelihood method, contract probability method, or the SELECT method.

Case Studies 1–3 are based on data from a covered codend experiment by Nguyen (2006) in a Vietnamese shrimp-trawl fishery. The objective of this experiment was to test the ability of a juvenile and trash (low-value) fish excluder device (JTED) to exclude small fish and retain shrimp and large fish. A cover net was attached to codend meshes adjacent to the escape opening of the device to retain all individuals that escaped through the bars of the JTED. The experiment assumed that the codend and cover net retained all individuals that entered the trawl net. The output from each case study is provided in spreadsheets in the accompanying DVD.

The JTED is designed to filter small shrimp, fish, and other animals from the trawl. Bar spacing is typically 10 – 40 mm.



Source: Eayrs (2007).

In Case Study 1, the logistic function and maximum likelihood method are used to construct a selectivity curve. In Case Study 2, the logistic function is replaced with the Richard's function, while in Case Study 3, the logistic function is modified by a parameter representing the contact probability. This parameter accounts for individuals in a trawl net that may not encounter the BRD and pass directly into the codend. By applying catch data to each of the three methods, the selectivity curve that best fits the data can be identified and the selectivity parameters determined from this curve.

Case Studies 4 and 5 describe the construction of a selectivity curve using the SELECT method and the logistic function. This method can be used to evaluate the selectivity of any BRD using a paired experimental method, including trouser trawl and twin trawl arrangements. The data used in these case studies were collected by Pope *et al*. (1975) from an alternate haul experiment comparing an experimental codend constructed from 87-mm mesh with a control codend constructed from 35-mm mesh. In Case Study 4, the SELECT method is applied to the data assuming an equal split between the paired codends, i.e. an equal probability that fish will enter either gear. In Case Study 5, an unequal split is assumed, and the SELECT method accommodates for catch bias between codends.

While the SELECT method described in the case studies uses only the logistic function, this method can be applied to the Richard's function if desired. Attempts should be made to apply catch data to both functions because this will allow the researcher to identify the function that best fits the data.

Case Study 1 – Constructing a selectivity curve using a logistic function and the maximum likelihood method

The data and relevant worksheets in the following Case Study are located in the file titled, 'JTED experiment'. The data are based on catches of tiger shrimp in an experiment testing a JTED. Apply the following steps and a selectivity curve using the logistic function and maximum likelihood method will be produced. Tabular and graphic output from these steps is provided at the end of this case study.

- Copy the catch data from the 'Tiger shrimp data' worksheet and paste into the length-frequency table (Table 1) in the 'Tiger shrimp – Logistic curve' worksheet. The total catch for each length group should automatically be calculated. Note some cells in Table 2 now have numerical entries and some do not. Cells without entries have been conditionally formatted so that the cell remains blank until satisfying a specified criterion (see the format tab in the toolbar for details).
- The observed proportion of the total catch (O) for each length group is now indicated in Chart 1. Chart 2 is a length-frequency histogram indicating the catch from both codend and cover net.
- Estimate the L_{50}, L_{75} and L_{25} values from the observed values in Chart 1, and insert these estimated values into Table 3. Note the initial values of selection range (SR), 'a' and 'b' are generated automatically. These values are derived from the logistic function presented in Annex 8.
- Copy the initial values for 'a' and 'b' and paste these values into the adjacent calculated value cells for 'a' and 'b'. Note that if the initial values are rounded to one or two decimal places and typed into each cell, the final AIC value will not correspond precisely to the value shown in Table 4 below. If the program responds with an error message related to a circular reference, ignore the message and click the cancel tab.
- In the tools tab of the file, locate the solver function. If unavailable, locate add-ins in the tools tab, tick the solver add-in box and click ok.
- Open solver. The solver parameter dialogue box should now be open. The target cell is the cell indicating the sum of all log-likelihood (ln(l)) values. This cell needs to be maximized, so click the maximize (Max) option. Next, specify the changing cells by selecting the two cells representing the calculated value of 'a' and 'b'. Now click the solve box, and keep the solver solution. If the solver dialogue box indicates an error value in a target or constraint cell, select restore original values and click ok. Next, manually adjust these 'calculated' values and repeat using solver. If all restraints are not satisfied, adjust these values until they are all satisfied.
- Note that the calculated values of all curve parameters in Table 3 now differ to the initial values, and the sum of the log-likelihood is a relatively low value. The expected values (E) in Table 2 have also changed from their original values.
- Add the expected values to the observed values on Chart 1. This can be done by selecting the expected values and dragging them onto the chart. (Alternatively, click on Chart 1, then click the chart tab in the toolbar and select add data. Highlight the data range and click ok.) The expected values should closely but not exactly follow the observed values. The curve parameters can now also be read from Table 3.
- By transforming the maximum likelihood estimates using natural logarithms a value for the Akaike's Information Criterion (AIC) is also determined. AIC is defined as:

$$AIC = -2L_m + 2m$$

where L_m is the maximized sum of the log-likelihood values and m is the number of parameters in the model. The AIC is in effect an index or metric that can be used to indicate the statistical goodness of fit of an expected probability curve. A relatively low AIC value is preferred as it indicates the expected probability curve is a good fit to the observed probability data. This criterion can be applied when both logistic and Richard's curves are being utilized; in the former there are two parameters, 'a' and 'b', however in the latter, there are three, including the asymmetry parameter, 'δ'. The AIC value for the tiger shrimp logistic curve is 193.3647.

For simplicity, the above steps avoided describing how to calculate the maximum likelihood estimate (MLE) for each length class. While it is not essential to understand how these values are calculated to produce a selectivity curve, for the researcher interested in this process the following provides an explanation.

For each length group, a maximum likelihood estimate (MLE) is required to be calculated. Mathematically, the expression to calculate MLE for a given fish length is:

$$MLE = \binom{\text{total catch}}{\text{codend catch}} \times \left(\text{Expected probability}^{\text{Codend catch}}\right) \times \left(1\text{-Expected probability}^{\text{Cover catch}}\right)$$

For example, based on Table 1 data, the maximum likelihood estimate of the 6 cm length group is:

$$MLE = \binom{145}{32} \times \left(0.2169^{32}\right) \times \left(1 - 0.2169^{113}\right)$$

$$= \left(1.3708 \times 10^{32}\right) \times \left(5.7194 \times 10^{-22}\right) \times \left(1.0098 \times 10^{-12}\right)$$

$$= 0.0792$$

Note that $\binom{145}{32}$ represents a combination of 32 fish in a sample of 145 fish, and 1.3708 x 10^{32} represents the number of 32-fish samples that can be randomly selected without replication from the 145 fish. (Many calculators have probability keys that allow this figure to be calculated.) Check a calculator manual for instruction on using these keys. Note that in the completed worked example the expected value (E) is 0.2169 and the maximum likelihood estimate (MLE) is 0.0792. The MLE for each length class are then transformed using natural logarithms and summed.

Table 1

Length	Catch		
(cm)	Codend	Cover	Total
0	0	0	0
1	0	0	0
2	0	0	0
3	0	0	0
4	0	0	0
5	0	0	0
6	32	113	145
7	45	110	155
8	52	126	178
9	77	124	201
10	95	98	193
11	132	91	223
12	197	82	279
13	256	35	291
14	264	20	284
15	296	25	321
16	325	32	357
17	309	26	335
18	344	17	361
19	315	15	330
20	247	10	257
21	193	12	205
22	164	3	167
23	112	2	114
24	118	0	118
25	126	1	127
26	125	0	125
27	92	2	94
28	69	0	69
29	65	1	66
30	0	0	0

Table 2

Proportion of total catch retained in the codend		Likelihood of each length class	
Observed (O)	Expected (E)	(l)	ln (l)
	0.0306	1.0000	0.0000
	0.0434	1.0000	0.0000
	0.0611	1.0000	0.0000
	0.0855	1.0000	0.0000
	0.1184	1.0000	0.0000
	0.1617	1.0000	0.0000
0.2207	0.2169	0.0792	-2.5362
0.2903	0.2845	0.0696	-2.6657
0.2921	0.3635	0.0087	-4.7472
0.3831	0.4506	0.0089	-4.7222
0.4922	0.5408	0.0230	-3.7713
0.5919	0.6284	0.0290	-3.5414
0.7061	0.7083	0.0522	-2.9528
0.8797	0.7772	0.0000	-12.7844
0.9296	0.8336	0.0000	-13.9623
0.9221	0.8779	0.0031	-5.7905
0.9104	0.9117	0.0734	-2.6116
0.9224	0.9368	0.0467	-3.0644
0.9529	0.9552	0.0966	-2.3374
0.9545	0.9683	0.0424	-3.1612
0.9611	0.9777	0.0333	-3.4015
0.9415	0.9844	0.0001	-9.3972
0.9820	0.9891	0.1639	-1.8083
0.9825	0.9924	0.1590	-1.8391
1.0000	0.9947	0.5326	-0.6299
0.9921	0.9963	0.2951	-1.2204
1.0000	0.9974	0.7232	-0.3240
0.9787	0.9982	0.0120	-4.4188
1.0000	0.9987	0.9169	-0.0868
0.9848	0.9991	0.0546	-2.9079
	0.9994	1.0000	0.0000
		Sum (∑) =	**-94.68**

Table 3

Curve parameters	Initial value	Calculated value
L50 =	10	9.5
L75 =	12	12.6
L25 =	8	6.5
SR =	4	6.1
a =	-5.4931	-3.4555
b =	0.5493	0.3619

Table 4

Akaike's Information Criterion	
Value =	**193.3647**

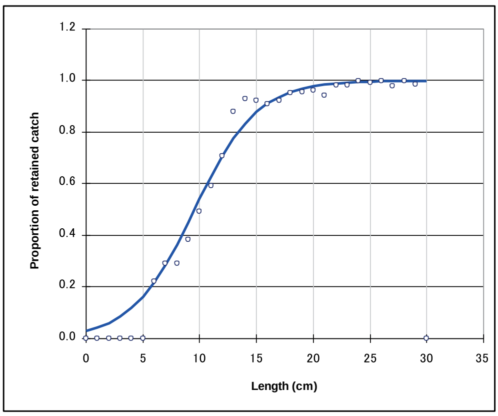


Chart 1

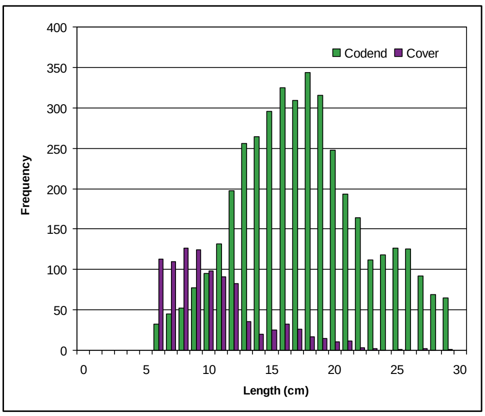


Chart 2

Case Study 2 – Constructing a selectivity curve using a Richard's function and the maximum likelihood method

The data and worksheets in the following case study are located in the file titled, 'JTED experiment'. The data are based on catches of tiger shrimp in an experiment testing a JTED. Apply the following steps and a selectivity curve using the logistic function and maximum likelihood method will be produced. Tabular and graphic output from these steps is provided at the end of this case study.

- Copy the catch data from the 'Tiger shrimp data' worksheet and paste into the length frequency table (Table 1) in the 'Tiger shrimp – Richard's curve' worksheet. The total catch for each length group should automatically be calculated. Note some cells in Table 2 now have numerical entries and some do not. Cells without entries have been conditionally formatted so that the cell remains blank until satisfying a specified criterion (see the format tab in the toolbar for details).
- The observed proportion of the total catch (O) for each length group is now indicated in Chart 1. Chart 2 is a length-frequency histogram indicating the catch from both codend and cover net.
- Estimate the L_{50}, L_{75} and L_{25} values from Chart 1 or the observed proportion column (O) and insert these initial values into Table 3. Note the initial values of selection range (SR), 'a' and 'b'. These values are derived from the Richard's function in Annex 8. The cell below represents curve asymmetry, 'δ'. If this value is equal to 1, the curve is symmetrical and equivalent to the logistic curve. If the value is greater than 1, the lower tail of the curve is skewed and flatter, while for values less than 1 the lower tail of the curve has a sharper slope. Check chart 1 and predict an initial value for curve asymmetry, or simply insert 1 as an estimate.
- Copy the initial values for 'a', 'b', and 'δ' into the adjacent calculated value cells for 'a', 'b', and 'δ'. Note that if the initial values are rounded to one or two decimal places and typed into each cell, the final AIC value will not correspond precisely to the value shown in Table 4. If the program responds with an error message related to a circular reference, ignore and click the cancel tab.
- In the tools tab on the file, locate the solver function. If unavailable, locate add-ins in the tools tab, tick the solver add-in box and click ok.
- Open solver. The solver parameter dialogue box should now be open. The target cell is the cell indicating the sum of all log-likelihood (ln(l)) values. This cell needs to be maximized, so click the maximize (Max) option. Next, specify the changing cells by indicating the three cells representing the calculated value of 'a' and 'b' and 'δ'. Now click the solve box, and keep the solver solution. If the solver dialogue box indicates an error value in a target or constraint cell, select restore original values and click ok. Next, manually adjust these 'calculated' values and repeat using solver. If all restraints are not satisfied, adjust these values until they are all satisfied.
- Note that the calculated values of all curve parameters in Table 3 now differ to the initial values, and the sum of the weighted least squares is a relatively low value. The expected values (E) in Table 2 have also changed from their original values. (See Case Study 1 for details describing how the expected values are calculated.)
- Add the expected values to the observed values on Chart 1. This can be done by selecting the expected values and dragging them onto the chart. (Alternatively, click on Chart 1, then

click the chart tab in the toolbar and select add data. Highlight the data range and click ok.) The expected values should closely but not exactly follow the observed values. The curve parameters can now also be read from Table 3.

– By transforming the maximum likelihood estimates using natural logarithms a value for the Akaike's Information Criterion (AIC) can be determined (see Case Study 1 for details). AIC is defined as:

$$AIC = -2L_m + 2m$$

where L_m is the maximized log-likelihood and m is the number of parameters in the model. Note that the AIC effectively penalizes the Richard's curve because of the third parameter, 'δ'. The AIC value for the Richard's curve is 186.6009.

– By applying the maximum likelihood method to catch data and using both logistic and Richard's functions to produce selectivity curves, the AIC provides a simple option to evaluate which function produces the best fit to the catch data. Despite the apparent penalty applied to the Richard's curve due to the additional parameter, it produced an AIC value that is less than the logistic curve AIC value of 193.3647; hence, the Richard's curve is a superior fit to the observed data (although in this example there appears to be little difference between the curves).

Case Study 2 continues in the next page

Table 1

Length (cm)	Catch Codend	Catch Cover	Catch Total
0	0	0	0
1	0	0	0
2	0	0	0
3	0	0	0
4	0	0	0
5	0	0	0
6	32	113	145
7	45	110	155
8	52	126	178
9	77	124	201
10	95	98	193
11	132	91	223
12	197	82	279
13	256	35	291
14	264	20	284
15	296	25	321
16	325	32	357
17	309	26	335
18	344	17	361
19	315	15	330
20	247	10	257
21	193	12	205
22	164	3	167
23	112	2	114
24	118	0	118
25	126	1	127
26	125	0	125
27	92	2	94
28	69	0	69
29	65	1	66
30	0	0	0

Table 2

Proportion of total catch retained in the codend: Observed (O)	Expected (E)	Likelihood of each length class: (l)	ln (l)
	0.0062	1.0000	0.0000
	0.0120	1.0000	0.0000
	0.0226	1.0000	0.0000
	0.0409	1.0000	0.0000
	0.0706	1.0000	0.0000
	0.1155	1.0000	0.0000
0.2207	0.1778	0.0337	-3.3898
0.2903	0.2573	0.0458	-3.0833
0.2921	0.3500	0.0170	-4.0734
0.3831	0.4494	0.0095	-4.6568
0.4922	0.5478	0.0174	-4.0533
0.5919	0.6388	0.0192	-3.9553
0.7061	0.7182	0.0474	-3.0499
0.8797	0.7844	0.0000	-11.5629
0.9296	0.8376	0.0000	-13.1784
0.9221	0.8791	0.0036	-5.6368
0.9104	0.9108	0.0737	-2.6079
0.9224	0.9346	0.0550	-2.9011
0.9529	0.9524	0.0985	-2.3176
0.9545	0.9654	0.0617	-2.7848
0.9611	0.9749	0.0538	-2.9217
0.9415	0.9819	0.0003	-8.0905
0.9820	0.9869	0.1971	-1.6242
0.9825	0.9906	0.1985	-1.6169
1.0000	0.9932	0.4466	-0.8062
0.9921	0.9951	0.3353	-1.0928
1.0000	0.9965	0.6425	-0.4424
0.9787	0.9975	0.0224	-3.8001
1.0000	0.9982	0.8812	-0.1264
0.9848	0.9987	0.0798	-2.5280
	0.9991	1.0000	0.0000
		Sum (?) =	**-90.30**

Table 3

Curve parameters	Initial value	Calculated value
L50 =	10	9.5
L75 =	12	12.5
L25 =	8	6.9
SR =	4	5.5
a =	-5.4931	-2.0781
b =	0.5493	0.3293
δ =	1.0	0.4

Table 4

Akaike's Information Criterion	
Value =	**186.6009**

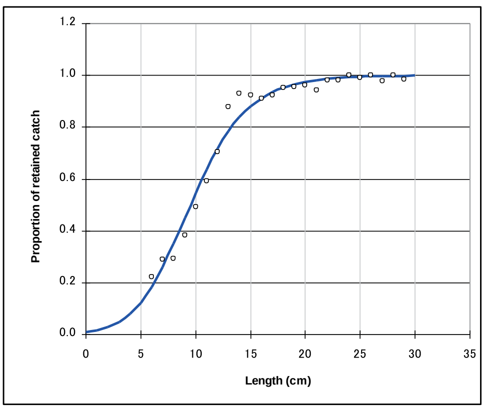


Chart 1

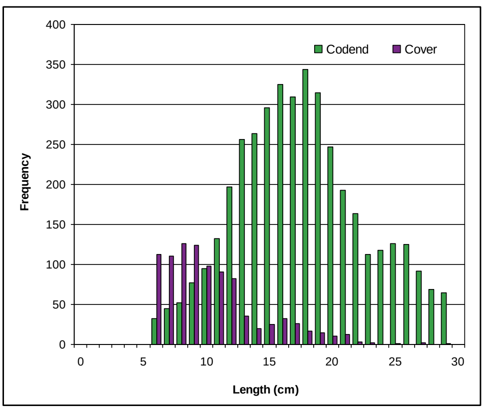


Chart 2

Case Study 3 – Constructing a selectivity curve based on contact probability and the logistic function

The data and worksheets in the following Case Study are located in the file titled, 'JTED experiment'. The data are based on catches of a local fish called bream in an experiment testing a JTED.

Based on the JTED's design and location in the codend, some shrimp and fish may not encounter the device and simply pass below it and enter the codend. In this case, it is appropriate to evaluate the selectivity of the JTED using a modified logistic function that accounts for the probability of contact with the JTED for each length group. The output from this evaluation can then be compared with output from the normal logistic function and the Richard's function using the same data, and the selectivity curve that best fits the data can then be selected and analysed. This case study applies data located in the 'Bream data' worksheet in the file titled, 'JTED experiment' to the 'Bream – Contact prob. & Log.' worksheet. Noteworthy is that this process is only slightly different to using the logistic function and maximum likelihood method to produce a selectivity curve. Additional worksheets are also provided using flathead and snakefish data to compare selectivity curves between the contact probability model with logistic function and the Richard's curve. Note how the contact probability model for bream and flathead produces a selectivity curve that is a superior fit to the data, while there is little difference between curves using the snakefish data.

Apply the following steps and a selectivity curve based on contact probability and the logistic function will be produced. Tabular and graphic output from these steps is provided at the end of this case study.

- Copy the catch data from the 'Bream data' worksheet and paste into the length-frequency table (Table 1) in the 'Bream – Contact prob. & Log' worksheet. The total catch for each length group should automatically be calculated. Note some cells in Table 2 now have numerical entries and some do not. Cells without entries have been conditionally formatted so that the cell remains blank until satisfying a specified criterion (see the format tab in the toolbar for details).
- The observed proportion of the total catch (O) for each length group is now indicated in Chart 1. Chart 2 is a length-frequency histogram indicating the catch from both codend and cover net.
- Estimate the L_{50}, L_{75} and L_{25} values from Chart 1 or the observed proportion column (O) in Table 2, and insert these initial values into Table 3. Note the initial values of selection range (SR), 'a' and 'b'. These values are derived from the logistic function presented in Annex 8. Insert 0.8 (80 percent) to represent the 'p' value. This indicates an assumed probability of each length group encountering the JTED. (This assumption is a reasonable starting point given that individuals passing through the lower 20 percent of the codend would not encounter the JTED.)
- Copy the initial values for 'a', 'b', and 'p' into the adjacent calculated value cells for 'a', 'b', and 'p'. These values will be changed shortly following subsequent steps.
- In the tools tab on the file, locate the solver function. If unavailable, locate add-ins in the tools tab, tick the solver add-in box and click ok

- Open solver. The solver parameter dialogue box should now be open. The target cell is the cell indicating the sum of all log-likelihood (ln(l)) values. This cell needs to be maximized, so click the maximize (Max) option. Next, specify the changing cells by indicating the cells representing the calculated value of 'a', 'b', and 'p'. Now click the solve box, and keep the solver solution. If the solver dialogue box indicates an error value in a target or constraint cell, select restore original values and click ok. Next, manually adjust these 'calculated' values and repeat using solver. If all restraints are not satisfied, adjust these values until they are all satisfied.
- Note that the calculated values of all curve parameters in Table 3 now differ to the initial values, and the sum of the log-likelihood is a relatively low value.
- The calculated 'p' value is 0.86. This means that bream had an 86 percent chance of encountered the grid.
- The expected values (E) have also changed from their original values. Add the expected values to the observed values on Chart 1. This can be done by selecting the expected values and dragging them onto the chart. (Alternatively, click on Chart 1, then click the chart tab in the toolbar and select add data. Highlight the data range and click ok.) The expected values should closely but not exactly follow the observed values. The curve parameters can now also be read from Table 3.
- The AIC value for this study is 104.2602.
- This value can then be compared with the AIC values for the bream data using the logistic curve (without contact probability) and the Richard's curve. The AIC value from the Bream – Logistic curve worksheet is 170.3144 and the AIC value from the Bream – Richard's curve worksheet is 142.6806. As the AIC value is smallest when contact probability is included in the logistic model, the curve representing this model is a better fit to the data.

Table 1

Length (cm)	Catch Codend	Catch Cover	Catch Total
0	0	0	0
1	0	0	0
2	0	0	0
3	0	0	0
4	0	0	0
5	52	284	336
6	147	672	819
7	121	590	711
8	197	851	1048
9	266	1068	1334
10	344	1250	1594
11	370	1174	1544
12	469	1347	1816
13	853	985	1838
14	887	372	1259
15	751	205	956
16	349	85	434
17	69	13	82
18	47	6	53
19	54	2	56
20	47	5	52
21	33	0	33
22	29	1	30
23	31	2	33
24	17	0	17
25	28	0	28
26	25	0	25
27	27	0	27
28	0	0	0
29	0	0	0
30	0	0	0

Table 2

Proportion of total catch retained in the codend: Observed (O)	Expected (E)	Likelihood of each length class: (l)	ln (l)
	0.1398	1.0000	0.0000
	0.1404	1.0000	0.0000
	0.1414	1.0000	0.0000
	0.1430	1.0000	0.0000
	0.1457	1.0000	0.0000
0.1548	0.1502	0.0585	-2.8392
0.1795	0.1577	0.0089	-4.7269
0.1702	0.1700	0.0398	-3.2243
0.1880	0.1900	0.0311	-3.4713
0.1994	0.2216	0.0039	-5.5538
0.2158	0.2696	#NUM!	
0.2396	0.3382	#NUM!	
0.2583	0.4287	#NUM!	
0.4641	0.5357	#NUM!	
0.7045	0.6470	#NUM!	
0.7856	0.7485	0.0009	-7.0682
0.8041	0.8306	0.0171	-4.0706
0.8415	0.8907	0.0482	-3.0325
0.8868	0.9316	0.0842	-2.4745
0.9643	0.9580	0.2678	-1.3174
0.9038	0.9746	0.0082	-4.8006
1.0000	0.9847	0.6017	-0.5079
0.9667	0.9909	0.2100	-1.5607
0.9394	0.9946	0.0132	-4.3260
1.0000	0.9968	0.9463	-0.0552
1.0000	0.9981	0.9474	-0.0540
1.0000	0.9989	0.9718	-0.0286
1.0000	0.9993	0.9818	-0.0184
	0.9996	1.0000	0.0000
	0.9998	1.0000	0.0000
	0.9999	1.0000	0.0000
		Sum (∑) =	-49.13

Table 3

Curve parameters	Initial value	Calculated value
L50 =	14	13.3
L75 =	15	15.4
L25 =	8	11.2
SR =	7	4.2
a =	-4.3944	-6.9364
b =	0.3139	0.5214
p =	0.8	0.86

Table 4

Akaike's Information Criterion

Value = 104.2602

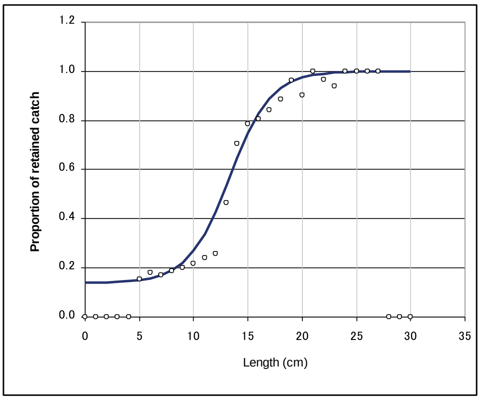


Chart 1

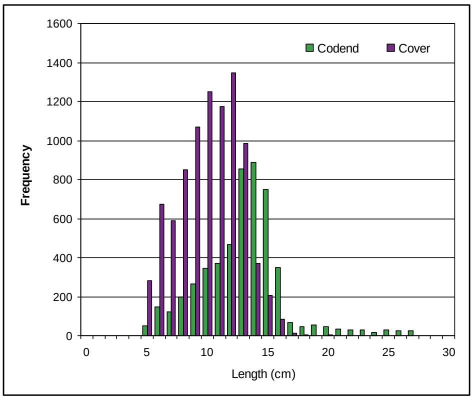


Chart 2

Case Study 4 – Constructing a selectivity curve using the SELECT method and the logistic function (assuming an equal split)

In this example, a selectivity curve is constructed using data from an alternate haul experiment by Pope *et al*. (1975) comparing catches of a species of fish retained in a small-mesh codend (control codend) and a large-mesh codend (experimental codend). The assumption is that each length group has an equal opportunity to be retained in either codend.

This case study uses applies data located in the 'Fish data' worksheet in the file titled, 'SELECT method'. Apply the following steps and a selectivity curve based on the SELECT and the logistic function will be produced. Tabular and graphic output from these steps is provided at the end of this case study.

- Copy the catch data from the 'Fish data' worksheet and paste into the length frequency table (Table 1) in the 'Equal split' worksheet. The total catch for each length group should automatically be calculated. Note some cells in Table 2 now have numerical entries and some do not. Cells without entries have been conditionally formatted so that the cell remains blank until satisfying a specified criterion (see the format tab in the toolbar for details).
- The observed proportion of the total catch (O) for each length group is now indicated in Chart 1. Chart 2 is a length-frequency histogram indicating the catch from both codend and cover net.
- Estimate the initial L_{50}, L_{75} and L_{25} values from the observed proportions (O) column in Table 2 or from Chart 2, and insert these values into Table 3. Note the initial values of selection range (SR), 'a' and 'b'. These values are derived from the logistic function presented in Annex 8. Insert 0.5 to represent the 'p' value. This indicates an assumed 50 percent chance (equal likelihood) that each length group entered the experimental codend.
- Copy the initial values for 'a', 'b', and 'p' into the adjacent calculated value cells for 'a', 'b', and 'p'. The values for 'a' and 'b' will be changed shortly following subsequent steps. (The 'p' remains unchanged because the assumed split is 50:50.)
- In the tools tab on the file, locate the solver function. If unavailable, locate add-ins in the tools tab, tick the solver add-in box and click ok.
- Open solver. The solver parameter dialogue box should now be open. The target cell is the cell indicating the sum of log-likelihood (ln(l)) values. This cell needs to be maximized, so click the maximize (Max) option. Next, specify the changing cells, by indicating the cells representing the calculated value of 'a', 'b' and 'p'. Now click the solve box, and keep the solver solution. If the solver dialogue box indicates an error value in a target or constraint cell, select restore original values and click ok. Next, manually adjust these 'calculated' values and repeat using solver. If all restraints are not satisfied, adjust these values until they are all satisfied.
- Note that the calculated values of all curve parameters in Table 3 now differ to the initial values, and the sum of the log-likelihood is a relatively low value. The expected values (E1) have also changed from their original values.
- Copy the expected values to Chart 2. This can be done by selecting the values and dragging them onto the chart. (Alternatively, click on Chart 1, then click the chart tab in the toolbar and select add data. Highlight the data range and click ok.) The expected values should closely but not exactly follow the observed values. The curve parameters can now also be read from this chart.

– By transforming the maximum likelihood estimates using natural logarithms a value for the Akaike's Information Criterion (AIC) can be determined. AIC is defined as:

$$AIC = -2L_m + 2m$$

where L_m is the maximized log-likelihood and m is the number of parameters in the model. The AIC is in effect an index or metric that can be used to indicate the statistical goodness of fit of an expected probability curve. A relatively low AIC value is preferred as it indicates the expected probability curve is a good fit to the observed probability data. This criterion can be applied when both logistic and Richard's curves are being utilized. In the former, there are two parameters, 'a' and 'b'; however, in the latter, there are three, including the asymmetry parameter, 'δ'. Note that the AIC effectively penalizes the Richard's curve because of this additional parameter. The AIC value for this study is 119.941.

– Notice how the line, expected (p = 0.5), poorly fits the observed data for larger fish (> 31 cm).

Case Study 4 continues in the next page

Table 1

Length (cm)	Number of individual fish		
	Exp. codend	Control codend	Total catch
24	0	1	1
25	0	1	1
26	0	3	3
27	1	14	15
28	5	30	35
29	19	49	68
30	29	60	89
31	51	50	101
32	91	70	161
33	120	108	228
34	118	88	206
35	107	84	191
36	78	68	146
37	52	37	89
38	40	33	73
39	17	12	29
40	17	5	22
41	14	6	20
42	10	10	20
43	4	1	5
44	6	6	12
45	2	2	4
46	5	1	6
47	1	0	1

Table 2

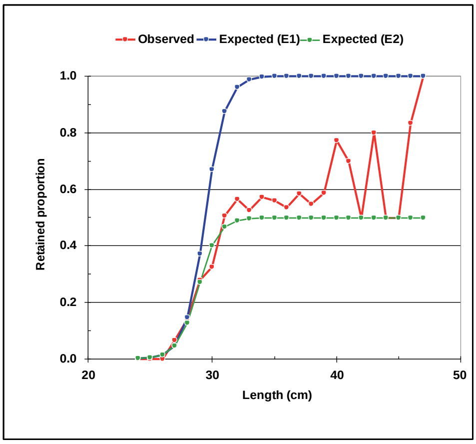
Probability that each length group is retained in the experimental codend		Probability that each length group enters the exp. codend	Likelihood of each length group	
Observed (O)	Expected (E1)	Expected (E2)	(l)	ln(l)
0.0000	0.0012	0.00123	0.99877	-0.00123
0.0000	0.0042	0.00420	0.99580	-0.00421
0.0000	0.0143	0.01414	0.95819	-0.04271
0.0667	0.0476	0.04543	0.35541	-1.03447
0.1429	0.1465	0.12777	0.18301	-1.69822
0.2794	0.3709	0.27055	0.10586	-2.24562
0.3258	0.6694	0.40099	0.03075	-3.48184
0.5050	0.8743	0.46647	0.05869	-2.83550
0.5652	0.9598	0.48975	0.01008	-4.59730
0.5263	0.9880	0.49697	0.03569	-3.33296
0.5728	0.9965	0.49911	0.00594	-5.12595
0.5602	0.9990	0.49974	0.01432	-4.24604
0.5342	0.9997	0.49992	0.04683	-3.06121
0.5843	0.9999	0.49998	0.02401	-3.72937
0.5479	1.0000	0.49999	0.06680	-2.70609
0.5862	1.0000	0.50000	0.09666	-2.33654
0.7727	1.0000	0.50000	0.00628	-5.07063
0.7000	1.0000	0.50000	0.03696	-3.29780
0.5000	1.0000	0.50000	0.17620	-1.73615
0.8000	1.0000	0.50000	0.15625	-1.85630
0.5000	1.0000	0.50000	0.22559	-1.48905
0.5000	1.0000	0.50000	0.37500	-0.98083
0.8333	1.0000	0.50000	0.09375	-2.36712
1.0000	1.0000	0.50000	0.50000	-0.69315
			Sum (∑) =	-57.97

Table 3

Curve parameters	Initial value	Calculated value
L50 =	31	29.4282
L75 =	40	30.3185
L25 =	29	28.5379
SR =	11	1.7806
a =	-6.1922	-36.3145
b =	0.1997	1.2340
p =	0.50	0.50

Table 4

Akaike's Information Criterion	
Value =	119.941



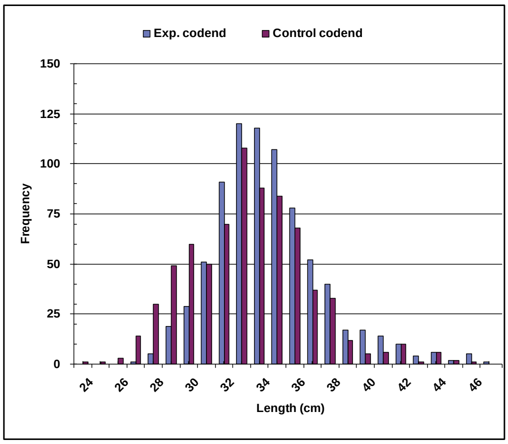


Chart 1: The expected (E1) line is a selectivity curve representing the retained proportion of each length group in the experimental (large-mesh) codend. The expected (E2) line represents the probability that each length group enters and is retained the experimental codend. This line fits the observed catch of small fish very well, but does not well represent the observed catch of large fish (> 31 cm). Chart 2: Length frequency chart of fish catch in the experimental and control codends.

Case Study 5 – Constructing a selectivity curve using the SELECT method and the logistic function (assuming an unequal split)

When using an alternate haul or other 'paired' experimental method, the catch is often biased in favour of one codend or net, despite the application of an experimental design to reduce or minimize such bias.

This case study uses applies data located in the 'Fish data' worksheet in the file titled 'SELECT method'. Apply the following steps and a selectivity curve based on the SELECT and the logistic function will be produced. Tabular and graphic output from these steps is provided at the end of this case study.

- The unequal split model is very simple. All steps towards producing a selectivity curve assuming an unequal split are identical to that for the equal split model with one minor difference.
- When solver is used to maximize the target cell (sum of the log-likelihood ln(l) values), instead of selecting only cells represented by 'a' and 'b' to change, select cells 'a', 'b', and 'p'. Then click the solve box, and keep the solver solution. Note that if the solver dialogue box indicates an error value in a target or constraint cell, select restore original values, click ok, and then manually adjust these values and repeat using solver.
- The Akaike's Information Criterion (AIC) and the unequal split parameter can now be determined.
- The AIC value for this study is 98.749, and the p value is 0.57. When an equal split was assumed the AIC value was 119.941; hence the selectivity curve produced by the unequal split model is a better fit to the data. Notice how the line, expected (p = 0.57), is a better fit to the observed data compared with when an equal split was assumed.

Case Study 5 continues in the next page

Table 1

Length (cm)	Number of individual fish: Exp. codend	Control codend	Total catch
24	0	1	1
25	0	1	1
26	0	3	3
27	1	14	15
28	5	30	35
29	19	49	68
30	29	60	89
31	51	50	101
32	91	70	161
33	120	108	228
34	118	88	206
35	107	84	191
36	78	68	146
37	52	37	89
38	40	33	73
39	17	12	29
40	17	5	22
41	14	6	20
42	10	10	20
43	4	1	5
44	6	6	12
45	2	2	4
46	5	1	6
47	1	0	1

Table 2

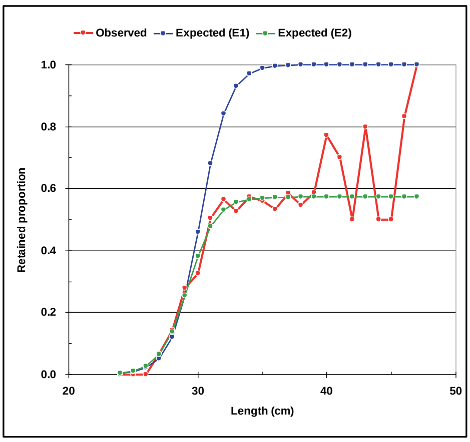
Probability that each length group is retained in the experimental codend: Observed (O)	Expected (E1)	Probability that each length group enters the exp. codend: Expected (E2)	Likelihood of each length group (l)	ln(l)
0.0000	0.0035	0.00463	0.99537	-0.00465
0.0000	0.0086	0.01145	0.98855	-0.01152
0.0000	0.0213	0.02780	0.91891	-0.08457
0.0667	0.0517	0.06479	0.38048	-0.96633
0.1429	0.1199	0.13849	0.18893	-1.66640
0.2794	0.2540	0.25411	0.09588	-2.34468
0.3258	0.4599	0.38147	0.04954	-3.00498
0.5050	0.6804	0.47712	0.06772	-2.69241
0.5652	0.8419	0.53029	0.04263	-3.15518
0.5263	0.9301	0.55503	0.03618	-3.31938
0.5728	0.9708	0.56558	0.05490	-2.90222
0.5602	0.9881	0.56992	0.05599	-2.88261
0.5342	0.9952	0.57167	0.04364	-3.13184
0.5843	0.9981	0.57237	0.08337	-2.48442
0.5479	0.9992	0.57265	0.08539	-2.46053
0.5862	0.9997	0.57277	0.14748	-1.91405
0.7727	0.9999	0.57281	0.02883	-3.54640
0.7000	1.0000	0.57283	0.09646	-2.33862
0.5000	1.0000	0.57284	0.14218	-1.95065
0.8000	1.0000	0.57284	0.22998	-1.46975
0.5000	1.0000	0.57284	0.19834	-1.61777
0.5000	1.0000	0.57284	0.35925	-1.02373
0.8333	1.0000	0.57284	0.15809	-1.84457
1.0000	1.0000	0.57284	0.57284	-0.55715
			Sum (∑) =	-47.37

Table 3

Curve parameters	Initial value	Calculated value
L50 =	31	30.1754
L75 =	40	31.3742
L25 =	29	28.9767
SR =	11	2.3975
a =	-6.1922	-27.6542
b =	0.1997	0.9164
p =	0.50	0.57

Table 4

Akaike's Information Criterion	
Value =	98.749



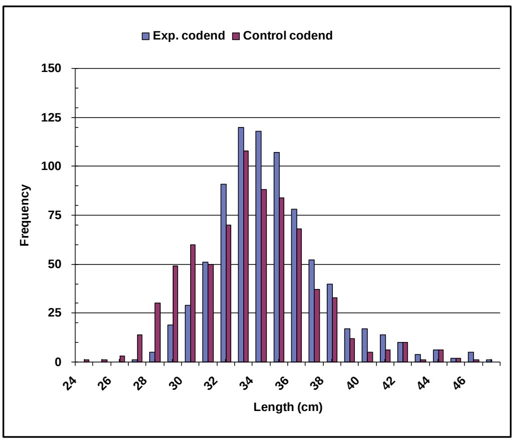


Chart 1: The expected (E1) line is a selectivity curve representing the retained proportion of each length group in the experimental (large-mesh) codend. The expected (E2) line represents the probability that each length group enters and is retained the experimental codend. This line is a better fit to the observed catch data than the line represented by the equal split model. Chart 2: Length-frequency chart of fish catch in the experimental and control codends.

Annex 10 – Useful contacts for information on bycatch reduction fieldwork

Food and Agriculture Organization of the United Nations (FAO)
Fishing Technology Service
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Tel.: +39 06 57055836, Fax: +39 06 57055188
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Philippine Coconut Authority (PCA) Building
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Iranian Fisheries Organization (Shilat)
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NOAA Fisheries Service, Pascagoula Laboratory
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