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Advances and best practices in bycatch reduction in tropical shrimp-trawl fisheries

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Abstract

This technical report describes advances and best practices in bycatch reduction in tropical shrimp-trawl fisheries in over 30 countries around the world. Many of these countries have a long history of research and development in bycatch reduction, and this publication describes these achievements based on four categories: turtle exclusion devices (TEDs), bycatch reduction devices (BRDs), regulation, and outreach and extension. These achievements were then synthesized to identify the best practices in bycatch reduction.

Many countries have made notable achievements in bycatch reduction, although most progress has been made by Australia and the United States of America. Both countries have a long history of developing and testing TEDs and BRDs, both have introduced stringent regulations to ensure bycatch reduction performance is optimized, and both have embarked on extensive outreach programmes to inform fishers and other actors of developments and outcomes. Both countries have also introduced bycatch reduction testing programmes that encourage the active participation of commercial fishers, and many fishers have responded positively by developing their own bycatch reduction devices. In Australia, achievements in bycatch reduction have contributed to Marine Stewardship Council (MSC) certification for a number of shrimp fisheries.

Other countries with recent notable bycatch reduction achievements include India, with the development and introduction of the Central Institute of Fisheries Technology TED, and Mexico, with the development of new trawl designs that simultaneously reduce bycatch, seabed impacts and fuel consumption. In Brazil and Colombia, a significant body of research has investigated the performance of multiple bycatch reduction devices, while efforts in Suriname have contributed to the Marine Stewardship Council certification of the seabob shrimp fishery. Through its collaboration with the Global Environment Facility (GEF) under the REBYC, REBYC-II CTI and REBYC-II LAC projects, and guided by the principles of the *Code of Conduct for Responsible Fisheries* and the *International Guidelines on Bycatch Management and Reduction of Discards*, FAO has contributed significantly to national bycatch reduction efforts across Southeast Asia, the Near East, Latin America and the Caribbean.

The most common and successful bycatch reduction devices are the Super Shooter TED, Fisheye, the square-mesh window, although there are many other, similarly designed, "hybrid" devices in use. Many countries are now using TEDs that are compliant with Section 609 of Public Law 101-162 of the United States of America, which requires fisheries that export wild shrimp to the United States of America to use approved TEDs that reduce sea turtle catches by over 95 percent. By contrast, the performance of the Fisheye and most other BRDs focusing on finfish bycatch is less impressive. While some occasional reports show bycatch reduction rates of greater than 50 percent, they have typically been about 30 percent or lower. The loss of shrimp or other targeted catch is the main factor that limits the performance of many BRDs.

Many countries have now introduced comprehensive TED regulations to protect sea turtles, and the associated monitoring, control and surveillance has reportedly been high. Regulations to reduce fish bycatch – including those related to the design and operation of BRDs – were either less frequently reported, non-existent, or unobtainable. Outreach and extension programmes were typically poorly or weakly described, and in many instances no evidence of such programmes could be found.

Overall, many of the countries covered in this review are striving to achieve best practice in sea turtle and finfish bycatch reduction. However, most efforts focus on limited steps to reduce the former, and all countries included in this review must take additional steps to further reduce finfish bycatch. Most countries require additional technical support and guidance, particularly those that are making modest, slow, or no gains due to a lack of capacity, funding, desire or interest. This technical report aims to identify those countries that are struggling to achieve best practice in bycatch reduction and proposes areas in which to focus future efforts and support in order for it to be achieved.

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Acronyms and abbreviations

AB	All bar taper
BRD	bycatch reduction device
EAF	ecosystem approach to fisheries
EPAA	Environmental Protected Area of Anhatomirim
ETP	endangered, threatened, protected species
FAO	Food and Agriculture Organization of the United Nations
GEF	Global Environment Facility
IUU	illegal, unreported and unregulated fishing
JTED	juvenile and trash excluder device
MCS	monitoring, control and surveillance
MLS	minimum landing size
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NPF	Australia Northern Prawn Fishery
SEAFDEC	Southeast Asian Fisheries Development Center
SMP	square mesh panel
TED	turtle exclusion device
WWF	World Wide Fund for Nature
1N2B	1 normal 2 bar taper
1N4B	1 normal 4 bar taper

Executive summary

Efforts by researchers, fishers and others to reduce bycatch in tropical shrimp-trawl fisheries around the world have escalated significantly in recent decades. Fishers are now consistently using turtle exclusion devices (TEDs) to reduce the capture of sea turtles to comply with the tropical shrimp import regulations of the United States of America. When used correctly, TEDs eliminate the capture of almost all sea turtles, while also substantially reducing the capture of other large animals such as sharks, rays, skates and sponges at the same time. Many of the fishers involved are also using bycatch reduction devices (BRDs) to reduce the capture of small fish and other animals. Collectively, achievements in bycatch reduction have been significant, sometimes resulting in improved market access or, in other instances, certification by bodies such as the Marine Stewardship Council.

While stakeholders should celebrate these achievements, there is still significant room for improvement. Most BRDs do not reduce bycatch by more than 30 percent without significant target species losses. The capture of small fish requires particular attention, since most of these organisms do not survive capture and subsequent release. Tropical shrimp-trawl fisheries must continue to reduce the capture and mortality of large numbers of threatened and endangered species such as sawfish, sea snakes, and syngnathids. Efforts must also continue to reduce shrimp loss from TED or BRD installation, as this impacts the profitability of shrimp trawling and thus impedes the interest and engagement of fishers in bycatch reduction activities. Bycatch reduction research must also be accelerated in countries that have made little progress on bycatch reduction.

This technical report describes efforts to mitigate bycatch through gear modifications and adaptations in the tropical shrimp-trawl fisheries of over 30 countries. It provides a summary of efforts by each country and then synthesizes them to identify and describe best practice. A best practice in bycatch reduction is the application or adoption of appropriate, recognized approaches to modifying fishing gear, with the objective of reducing bycatch to the greatest extent practicable. This information serves as a benchmark to identify countries that are taking appropriate steps to reduce bycatch and those that are not. It also provides context from which the outcomes of research on bycatch reduction can be evaluated and compared, including the identification of effective bycatch reduction devices, and serves to identify future research priorities. In the context of this report, best practice includes the installation and use of TEDs and BRDs that are optimally rigged and operated so as to reduce bycatch. It also includes the application of appropriate regulations to ensure effective performance, as well as the introduction of effective outreach and extension programmes to enhance and sustain best practice to reduce bycatch.

Key findings in this document include:

- Many countries have made substantial progress in bycatch reduction. This includes the use of TEDs that are compliant with Section 609 of Public Law 101–162 of the United States of America, which permits imports of shrimp from countries where the shrimp fishery does not have an adverse impact on sea turtles. A total of 40 countries are certified to export shrimp to the United States of America; several individual shrimp fisheries in Australia and 14 other countries have introduced programmes that provide adequate protection to sea turtles, while the remainder have demonstrated that they pose no threat to sea turtles.

This certification is considered best practice in sea turtle conservation. The Super Shooter appears to be the most widely used TED to reduce sea turtle bycatch, followed by the Nordmore grid.

- Many countries have made substantial efforts to test and implement BRDs to reduce fish bycatch, although the reduction of bycatch using these devices is typically less than 30 percent compared to a standard trawl. The use of BRDs is mandatory in the United States of America, but only BRDs that reduce bycatch by at least 30 percent compared to a standard trawl are certified. In Australia's Northern Prawn Fishery, fishers are voluntarily gravitating toward using new BRDs that have reduced bycatch by up to 40 percent compared to currently approved BRDs. Few other countries have established similar bycatch reduction targets.
- The Fisheye and the square-mesh window are the most widely used BRDs. Many BRD designs have been in existence for many years, sometimes decades, and few new or radically different BRDs have been developed and used in any of these countries.
- Many countries have introduced regulations pertaining to the design, rigging, and operation of TEDs and BRDs, particularly those using TEDs and exporting shrimp to the United States of America. Relatively fewer countries have introduced similar BRD regulations, and some have not introduced any regulations at all, perhaps because reducing fish bycatch is not a priority.
- In many instances, information describing effort and achievement in bycatch reduction was scant or missing critical details. This includes information associated with the design, dimensions and rigging of TEDs and BRDS. Information on associated regulations, and outreach and extension efforts, was similarly missing, as was evidence of bycatch reduction targets. Overall, attention to detail and global reporting standards are not strong and require improvement.
- Significant differences exist between countries in the experimental designs that were applied for evaluating the performance of a TED or BRD. This includes fieldwork and catch sampling methodology, data analysis and reporting. In some instances, experimental design was incompletely reported, important details were missing, and incorrect or inadequate statistical analyses were completed. Moreover, findings were sometimes contradictory within the same report or between reports of the same research or trials. There is a clear need for improvement and consistency in experimental design and reporting.
- Outreach and extension efforts are poorly documented or described, and it appears that only a few countries engage in comprehensive programmes to share information with fishers and others. Many of these efforts appeared piecemeal and lacking in detail and intent, possibly because they were not deemed sufficiently important to report.
- Through the *International Guidelines on Bycatch Management and Reduction of Discards*, and the REBYC, REBYC-II CTI and REBYC-II LAC projects, FAO plays a significant role in improving bycatch reduction performance in many countries. However, bycatch reduction achievement remains modest or limited. Global, regional and local institutions must enhance their efforts on this topic to achieve satisfactory outcomes through the application of best practice. While Australia and the United States of America are leading these efforts, their methodology can be readily adapted and introduced to other countries while allowing for social, economic, political and cultural differences. This includes experimental design, testing protocols, and the delivery of effective outreach and extension programmes.

Overall, while many countries actively engage in bycatch reduction research, they seldom apply best practice standards. Key areas for action include capacity building to ensure that bycatch reduction research is conducted using appropriate experimental design and testing protocols, and that appropriate reporting is completed with close attention to detail. This will also help ensure that research programmes run efficiently, using limited resources or funds productively and effectively to achieve desired programme outcomes. Improved capacity will also strengthen outreach and extension programmes, which are important to communicate research findings and encourage fishers and others to participate in bycatch reduction efforts. Over time, these efforts should facilitate improvements in TED and BRD performance, and ultimately, achieve best practice in bycatch reduction in tropical shrimp-trawl fisheries.

1. Introduction

This technical report describes best practices for bycatch reduction in tropical shrimp-trawl fisheries around the world, with a focus on the modification of trawl gear. It was prepared as part of the GEF/FAO Project on the Sustainable Management of Bycatch the Bottom Trawl Fisheries of Latin America and the Caribbean (REBYC-II LAC), a five-year initiative involving six countries and regional organizations to improve the management of bycatch, support the sustainable development of shrimp-trawl fisheries, and support the coastal fishers and communities that depend on these fisheries. The six participating countries were Brazil, Colombia, Costa Rica, Mexico, Suriname and Trinidad and Tobago. Details of the project can be found at www.fao.org/in-action/rebyc-2.

The term *best practice* usually refers to a technique, method, or process that produces one or more superior outcomes compared to an alternative practice. It is a widely accepted standard of performance that focuses and standardizes efforts to achieve a desired outcome, and it serves as a benchmark with which other practices can be compared and evaluated.

In the context of this report, best practice refers to the application of appropriate, recognized approaches to modifying fishing gear or operational methods, with the aim of reducing bycatch to the greatest extent practicable (Box 1). This includes the installation and operation of turtle exclusion devices (TEDs) and bycatch reduction devices (BRDs that are rigged and operated optimally to reduce bycatch. It also includes the application of appropriate regulations, as well as the introduction of effective outreach and extension programmes to inform and build the capacity of fishers and others to reduce bycatch.

A failure to apply best practice will result in sub-optimal bycatch reduction, usually characterized by poor coordination and application of resources, uncertainty between individuals, and limited progress towards achieving bycatch reduction goals and targets. It will also hamper the ability to evaluate the performance of TEDs or BRDs, prevent replication of fieldwork at a later date or in a different location, whether by the same or a different researcher, and undermine and erode confidence in the ability of the researcher and their research. Ultimately this delays or prevents adoption of these gears in management. Finally, it will risk missing the important details and opportunities that

BOX 1

Best practice in bycatch reduction

In the context of this technical report, best practice refers to the application of techniques, methods, or processes that produce superior outcomes in bycatch reduction. These includes:

- modification to traditional trawl gear and operational practice;
- application of appropriate experimental design, including testing protocols, evaluation, and reporting procedures;
- achievement of recognized standards in bycatch reduction;
- application of appropriate and effective monitoring, control, and surveillance strategies that support and encourage best practice, and their compliance;
- appropriate outreach and extension strategies for fishers, including low-risk opportunities for fishers to test the devices on their boat voluntarily.

are vital to an effective outreach and extension programme. This includes publishing information for fishers and others to understand the outcomes of TED and BRD testing, which is important to stimulate interest and encourage widespread adoption of these devices. Poor outreach and extension also hampers efforts to overturn deep-rooted beliefs and practices and cement a new culture in the fishing industry that actively seeks opportunities to reduce bycatch.

The section entitled "Modification to traditional trawl gear and operational practice" summarizes the state of bycatch reduction efforts, identifies current best practice, and flags areas that require improvement. This synthesis draws information from the section "Summary of bycatch reduction efforts, by country", which reviews literature on efforts to reduce bycatch in tropical shrimp-trawl fisheries in 19 countries around the world. These efforts are described using four key categories: TEDs; BRDs; Regulation;[1] and Outreach and Extension. These categories were selected because applying best practice in each, some or all can result in a fishing industry that is informed and engaged, and takes proactive steps to reduce bycatch.

BOX 2

Are TEDs a type of BRD?

Many countries have fishery regulations that specify the size, design and rigging of bycatch reduction devices in a shrimp trawl. The regulations associated with TEDs are designed to reduce the capture of sea turtles in a trawl, while BRD regulations are designed to reduce the capture of other bycatch, usually fish and other small animals. However, TEDs can also reduce the capture of other bycatch species, such as sharks, rays, skates and large sponges. They can also be modified to reduce the capture of small fish bycatch, usually by reducing bar spacing in the grid, while remaining fully compliant with regulations to protect sea turtles. It is therefore reasonable to assume that a TED is a type of BRD, despite the literature often describing BRD performance only in terms of fish and other small animal bycatch. One explanation for specific regulations associated with TEDs is a desire to separate concerns over threatened sea turtle populations from other bycatch concerns, focus attention on the development of effective TED designs, and to meet strict requirements governing shrimp exports into the United States of America. Nevertheless, unless otherwise described in this report, the term BRD refers specifically to devices that reduce fish and other small animal bycatch, but are unable to reduce the capture of sea turtles and other large animals.

Many of the documents referenced in this report are publicly available and accessible online, although some were received directly from individuals with a history of bycatch reduction research. This includes peer-reviewed scientific literature as well as conference proceedings and technical reports. Occasionally, information was sourced directly from a brochure or a page on a website, particularly with regard to the reporting of TED and BRD regulations, or descriptions of outreach and extension efforts. In all instances, efforts were made to verify these details from other documents, including scientific literature, although this was not always possible. Significant variations in document objectives and reporting styles (between scientific literature and

[1] Best practice ideally includes the application of effective monitoring, control and surveillance (MCS) programmes. However, not much information describing monitoring and surveillance programmes is available in published literature. As a result, this document uses regulation as a category and proxy for control, and assumes that best practice achievements in the remaining three categories partially reflected the presence of an effective MCS programme, particularly in fisheries using approved TEDs.

summary documents, for example) also challenge global review documents like this report. Language differences can lead to a poor command of detailed, sector-specific language when a report is either written by a non-native speaker, or is only available in a language not spoken or written by the authors, and where translation issues may lead to the loss of important information. Every attempt has been made to verify details contained in these documents whether by searching for supporting references or contacting the author directly.

This report complements several other key FAO technical reports and documents that provide important additional information and context. The technical report by Perez-Roda *et al.* (2019), *A third assessment of global marine fisheries discards*, contains the most recent FAO update and estimate of discards from fisheries around the world. It also evaluates the bycatch and discard of endangered, threatened and protected (ETP) species, reviews current methods for managing bycatch and reducing discards, and discusses other sources of fishing mortality such as discard mortality and ghost fishing mortality. Another important technical report is *Discards in the world's marine fisheries* (Kelleher, 2005) and while some information has now been superseded by Perez Roda *et al.* (2019), it provides a thorough description of the quantity of discards globally, fishery by fishery. Kelleher (2005) also discusses the environmental and technical implications associated with discarding, a "no-discards" policy, and provides suggestions for future directions in bycatch reduction. These reports are complemented by *Defining and estimating global marine fisheries bycatch* (Davis *et al.*, 2009) which quantifies global bycatch and provides bycatch summary information for a wide range of countries.

The *Global study of shrimp fisheries* (Gillett, 2008) provides an excellent review of shrimp fisheries around the world. It highlights the direct and indirect social, economic and environmental impacts of shrimp trawling activity, including bycatch, seabed impact and fuel consumption. In addition, the publication describes the impacts of shrimp farming on shrimp fishing, options to regulate these fisheries, the efficacy of shrimp trawling, and trade and economic issues. Finally, it examines shrimp fishing activity in ten countries that are representative of geographic regions around the world: Australia, Cambodia, Indonesia, Kuwait, Madagascar, Mexico, Nigeria, Norway, Trinidad and Tobago and the United States of America.

A guide to bycatch reduction in tropical shrimp-trawl fisheries (Eayrs, 2007) provides a detailed description of bycatch reduction devices used in tropical shrimp-trawl fisheries around the world, including their design, rigging, operation, and troubleshooting considerations. This report also describes how to select a TED or BRD, the factors that influence the performance of these devices, and provides technical data sheets for a number of devices to guide their construction and rigging in a trawl. Finally, *Comparative testing of bycatch reduction devices in tropical shrimp-trawl fisheries: A practical guide* (Eayrs, 2012) is designed to guide researchers and others through the process of testing a TED or BRD by using best practice in experimental design; this includes the preparation, testing, analysis and reporting of efforts to reduce bycatch. The publication also includes instruction and guidance to produce basic selectivity curves to evaluate the impact of a TED or BRD on size classes of shrimp and bycatch. All of these FAO technical reports are available at www.fao.org/fishery/publications/en.

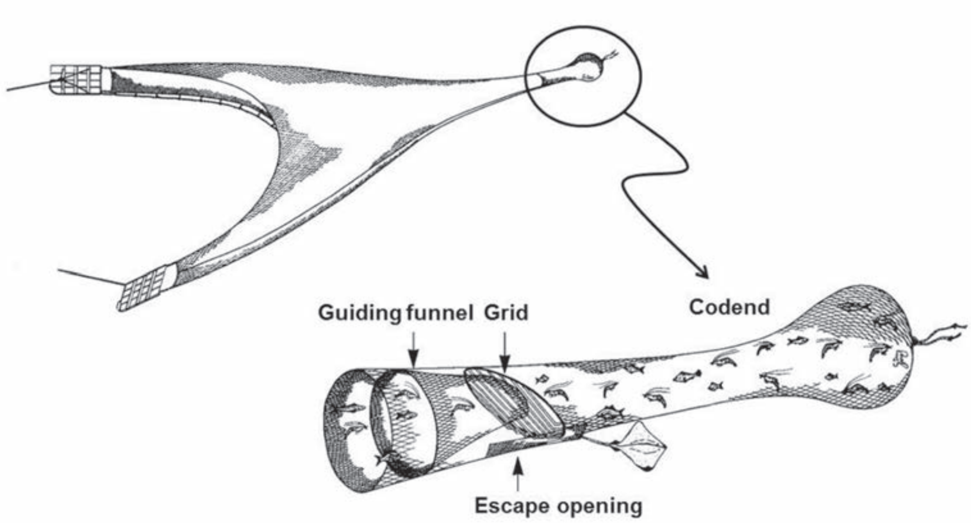
2. Bycatch reduction devices: designs, performances and best practice

2.1 BYCATCH REDUCTION DEVICES: RESEARCH AND DEVELOPMENT

There is a substantial body of literature describing efforts to reduce bycatch in tropical shrimp-trawl fisheries around the world. Much of this literature stems from Australia and the United States of America as they have been most active in this field since the 1980s, when efforts to reduce bycatch in their respective shrimp fisheries commenced in earnest. These countries have achieved notable success in reducing bycatch, supported by effective regulations, and outreach and extension programmes. Other countries with a relatively long and documented history of bycatch reduction research include Brazil, Mexico, Philippines (the), Suriname and Thailand. Over the past two decades, a large body of literature has also been produced relating specifically to bycatch reduction efforts by FAO through multiple projects around the world (Box 3).

According to this literature, most efforts to reduce bycatch have focused on codend modification, usually by inserting a TED or BRD into the codend – or the extension just before the codend – or by modifying the mesh size or orientation of the codend (Figure 1). By contrast, relatively few efforts to reduce bycatch focus on the trawl net or ground gear, perhaps due to a perception that it is easier to concentrate the entire catch in the codend before attempting to reduce bycatch. This is an understandable and obvious early step to reduce bycatch, although it increases the risk of injury and mortality to organisms as they pass through the trawl due to contact with netting, other animals, or the TED or BRD. It may also negatively affect the quality of the shrimp catch or other commercially valuable species.

FIGURE 1
Most efforts to reduce bycatch in shrimp-trawl fisheries have historically focused on adding a TED or BRD into the codend



Source: S. Eayrs (Smart Fishing Consulting).

BOX 3

FAO projects to reduce bycatch in shrimp-trawl fisheries

1. **Reduction of environmental impact from tropical shrimp trawling through the introduction of bycatch reduction technologies and change of management (REBYC).** This project was funded by the Global Environment Facility (GEF), coordinated by the United Nations Environment Programme (UNEP), and executed by FAO over a six-year period commencing in 2002 (Hermes, 2009). The aims of the project were to:
   i. introduce appropriate fishing technologies to reduce bycatch from shrimp trawling, in particular the capture of juveniles of commercially important species; and
   ii. provide a better understanding of the impact of shrimp trawling on marine habitats (FAO, 2017a).

   A number of countries participated in this project, primarily: Cameroon, Colombia, Costa Rica, Cuba, Indonesia, Iran (Islamic Republic of), Mexico, Nigeria, Philippines (the), Trinidad and Tobago, and Venezuela (Bolivarian Republic of). It also included the participation of the Southeast Asian Fisheries Development Center (SEAFDEC), an autonomous intergovernmental organization representing countries in the Association of Southeast Asian Nations (ASEAN). A description of this project is available online at www.fao.org/fishery/gefshrimp/en. A mid-term review of this project was included in Westlund (2006) and a final performance review provided in Hermes (2009).

2. **Strategies for trawl fisheries bycatch management (REBYC-II CTI).** This project was designed as a follow up to REBYC-I (FAO, 2017a). It was funded by the Global Environment Facility (GEF) as well as FAO, SEAFDEC, and participating countries Indonesia, Papua New Guinea, Philippines (the), Thailand, and Viet Nam in 2011–16. This project was structured around four interrelated components:
   i. The introduction of policy, legal and institutional frameworks to facilitate the establishment of national or area-specific bycatch management plans, and the building of institutional capacity for their implementation.
   ii. The introduction of resource management programmes to reduce bycatch, including adoption of more selective fishing gear and practices, steps toward the implementation of fishing zones and spatial-temporal area closures, improved counts of fishing vessels, and recommendations for the improved management of fishing effort.
   iii. The introduction of improved data management and communications, including bycatch data collection, mapping of fishing grounds, socio-economic monitoring, communication sharing, and standardized bycatch data collection methods.
   iv. The introduction of improved methods to raise awareness and knowledge, including the need to reduce bycatch and available bycatch reduction methods.

   A description and review of this project is available at GEF (2011) and FAO (2017b).

3. **Sustainable management of bycatch in Latin America and Caribbean trawl fisheries (REBYC-II LAC).** This project is funded by GEF, FAO, and participating countries Brazil, Colombia, Costa Rica, Mexico, Suriname, and Trinidad and Tobago, with an expected completion date of 2021 (FAO, 2019a) . It is similarly structured around four components:
   i. improving institutional and regulatory frameworks for shrimp/bottom trawl fisheries and co-management;
   ii. strengthening bycatch management and responsible trawling practices through application of an EAF framework;
   iii. promoting sustainable and equitable livelihoods through enhancement and diversification; and
   iv. monitoring project progress, its evaluation and the dissemination and communication of information.

   A description of this project is available in FAO (2019a). Further information is available at www.fao.org/in-action/rebyc-2/en/.

A preferred approach to bycatch reduction is to avoid the risk of injury or mortality and to minimize impact on the shrimp catch. This can conceivably be achieved by preventing their entry into the trawl in the first instance; examples include the use of barriers across the trawl mouth to prevent the ingress of sea turtles (see NOAA, 2017), reducing trawl headline height to reduce the capture of small fish bycatch (see Eayrs, 2003; Broadhurst and Sterling, 2016), headline illumination to deter sea turtles and other bycatch from entering the trawl (see Maynard and Gaston, 2010), and the modification of the ground gear to reduce the capture of benthic species and the damage to benthic habitat (see Broadhurst and Sterling, 2016). While these examples have produced positive and encouraging outcomes, none have yet been widely adopted by fishers. Further development and refinement of these options by researchers also appears limited, despite their potential. The reasons for this lack of progress are unclear, but it may be due to their perceived complexity and cost, as well as lingering concerns over the loss of shrimp or other landable species.

The literature review also suggests few novel developments in TED and BRD design since the 1980s, despite global efforts by fishers and researchers to reduce bycatch. Many TED and BRD designs in use today have been available for decades, sometimes modified slightly to suit regional needs and improve performance, but fundamentally remaining the same. For example, in shrimp fisheries where TEDs are a mandatory requirement, one of most commonly used is the Super Shooter TED (Eayrs, 2007). This is a bent-bar, oval-shaped rigid grid, with a bar spacing that typically measures 100 mm (Figure 1). It is usually orientated as a bottom-excluding device and is sometimes fitted with a funnel of netting to guide the catch to the centre of the codend and away from the escape opening. Testing and use of this device is widespread (Table 1), and when the literature refers to "TED" testing, it is often clear from the description of the device that the authors are describing a Super Shooter TED. The other commonly used TED is the Nordmore grid. This is a flat-bar rectangular grid often used as an upward-excluding device. The bar spacing of this TED is often much less than 100 mm in an effort to exclude fish and other small animals from the trawl, and sometimes it is used without a guiding panel or funnel. Other TED designs include grids with a rectangular lower section and curved upper section, oval grids with flat bars rather than bent bars, and designs with an improved escape opening on the cover net. In many instances, fishers concerned over grid clogging and shrimp loss drive the development of new or adapted designs. They have also been driven by the United States of America to reduce the capture of leatherback turtles (*Dermochelys coriacea*), which particularly influenced the design of the escape opening and cover net.

TABLE 1
Commonly used TEDs (by country), including those tested but not adopted by fishers or subject to regulation

Country	TED															
	SS	NG	TTFD	TTED	GJ	STED	AW	NTED	NMFS	HTED	WTED	ATED	CTED	TKU	FTED	TED*
Australia	√	√				√		√			√	√				√
Bangladesh																√
Bahrain																√
Brazil		√														√
Cambodia																
Cameroon																√
Colombia	√															√
Costa Rica																√
Cuba				√												
French Guyana	√	√		√												
Guyana																√
India	√												√			√
Indonesia	√															
Iran (Islamic Republic of)								√								
Kuwait																√
Madagascar																√
Malaysia			√													
Mexico							√								√	√
Myanmar																
Nigeria	√	√														
Pakistan																√
Papua New Guinea																√
Philippines	√		√							√						
Senegal		√														
Suriname	√			√												
Thailand	√		√		√									√		
Trinidad and Tobago																√
United States of America	√	√			√	√	√		√							
Venezuela (Bolivarian Republic of)	√															
Viet Nam																
Count	**11**	**6**	**3**	**3**	**2**	**2**	**2**	**2**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**15**

SS - Super Shooter, NG - Nordmore grid, TTFD - Thai Turtle Free Device, GJ - Georgia jumper, STED - soft TED, AW - Anthony Weedless, NTED - NAFTED, NMFS - NMFS Box TED, HTED - Hooped TED, WTED - Wick's TED, ATED - AusTED, CTED - CIFT TED, TKU - Thai Kasetsart University TED, FTED, FEDINP, TED, TED*, TEDs unspecified design.
See country reports for details, as well as Broadhurst (2000) and Eayrs (2012).

The absence of any radical or newly approved TED designs in recent years may reflect the ability of existing TEDs to meet the legislative requirements associated with the protection of sea turtles, as well as a level of satisfaction with TEDs by fishers, particularly with respect to shrimp loss. Broadhurst (2000), Eayrs (2007) and Pravan *et al.* (2011) all describe available TED designs, while Roa (2011) provides a global review of TED performance. Nevertheless, while TED design have remained largely unchanged for many years, improvements are still required to overcome the poor exclusion of large, endangered or vulnerable organisms such as sawfish and sponges, and to reduce shrimp loss.

TABLE 2
Commonly used BRDs (by country), including those tested but not adopted by fishers, or subject to regulation

Country	BRD															
	FE	SMW	JTED	RES	SMC	BED	EMF	BE	FB	FRD	SN	T90	CP	CSMP	JD	JFE
Australia	√	√		√	√			√	√					√		
Bangladesh																
Bahrain		√														
Brazil	√	√		√												
Cambodia			√													
Cameroon		√										√				
Colombia	√									√						
Costa Rica	√	√														
Cuba	√															
French Guyana																
Guyana		√														
India	√							√			√					√
Indonesia			√			√										
Iran (Islamic Republic of)	√	√	√	√												
Kuwait			√	√	√											
Madagascar																
Malaysia			√			√										
Mexico	√		√	√			√									
Myanmar			√													
Nigeria	√															
Pakistan																
Papua New Guinea																
Philippines			√													
Senegal																
Suriname		√														
Thailand																
Trinidad and Tobago	√	√														
United States of America	√	√		√			√		√				√		√	
Venezuela (Bolivarian Republic of)		√														
Viet Nam			√													
Count	**11**	**11**	**9**	**6**	**2**	**2**	**2**	**2**	**2**	**1**	**1**	**1**	**1**	**1**	**1**	**1**

FE - Fisheye, SMW - Square-mesh window (or panel), JTED - Juvenile and Trash Exclude Device, RED - Radial Escape Section, SMC - Square-mesh codend, BED - Bycatch Excluder Device, EMF - Extended Mesh Funnel, BE - Bigeye, FB - Fishbox, FRD - Fish Reduction Device, SN - Sieve Net, T90 - T90 codend, CP - Composite Panel, CSMP - Composite Square-Mesh Panel, JD - Jones-Davis BRD (including modified Jones-Davis BRD), JFE - JFE-SSD.
See country reports for details, as well as Broadhurst (2000) and Eayrs (2012).

For BRDs, the Fisheye (FE) and the square-mesh window (SMW) are the most widely used to reduce fish bycatch (Table 2). They are simple, easy-to-use and low-cost devices, which probably explains their popularity. They can also be installed well ahead of the accumulated catch to minimize shrimp loss (Eayrs, 2007), an obviously attractive outcome for fishers. The literature describing the performance of these devices indicates that bycatch reduction performance may range from 30–50 percent (Broadhurst, 2000; Laird *et al*., 2020), to only 10–30 percent (see Eayrs and Prado, 1998; Boopendranath *et al.*, 2008; Sabu, Gibinkumar and Boopendranath, 2011; Eayrs, 2012; Scott-Denton *et al.*, 2012; Al-Baz and Chen, 2014); this means that most bycatch entering the net ends up hauled onboard. Clearly, there is substantial room for improvement. One option is to relocate the device so that it is closer to the accumulated catch; however, as this can increase shrimp loss, fishers typically prefer to attach them as far forward in the codend as is legally allowed.

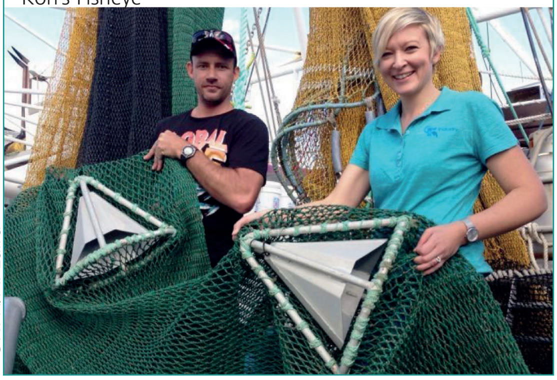
Recent efforts to improve bycatch reduction performance include the Popeye fish box, Kon's Fisheye, the nested cylinder device, and the Witches hat enhancer (Plate 1), as well as modifications to the anterior section of the trawl such as headline height reduction and headline illumination. The FishEX 70 and Tom's Fisheye are very recent Fisheye innovations in Australia and testing has reported bycatch reduction of around 40 percent (Laird *et al*., 2020). The performance of these two devices is linked to their position only 60 meshes from the codend drawstrings, and they are now used by almost the entire trawl fleet in the Northern Prawn Fishery. Significantly, all of these modifications rely on exploiting differences in fish and shrimp behaviour to facilitate a reduction in bycatch, with the exception of headline illumination – they are also all variations of concepts or designs described in the literature at least 20 years ago.

PLATE 1
Examples of experimental BRD designs

Popeye fishbox

©Ch. McKillop

Kon's Fisheye



©NPFI/A. Laird

Nested cylinder

©NOAA/D. Foster

Witches hat enhancer with square-mesh panel

©J. Wakefield

2.2 BEST PRACTICE IN TED/BRD EVALUATION: PERFORMANCE STANDARDS

Ideally, bycatch reduction measures must exist against a recognized or approved performance standard. The most notable example is a requirement by the United States of America for TEDs to exclude at least 97 percent of sea turtles that enter a shrimp trawl (Federal Register, 1990a; NOAA, 2019a). This standard applies to local fishers as well as to those from countries that export wild-caught shrimp into the United States of America. Jenkins (2012) provides a description of TED testing protocols to achieve this standard.

The United States of America has a testing protocol for recognizing BRD performance against a 30 percent bycatch reduction target (Helies and Jamison, 2009; NOAA, 2016). This means that all approved BRDs must reduce fish bycatch by at least 30 percent compared to a standard (unmodified) trawl.[2] This protocol also describes strict testing requirements (NOAA, 2016), including the need to complete at least 30 valid paired hauls. To receive certification for use, new BRD designs must achieve a 30 percent bycatch reduction in at least half of the hauls, and in no more than 10 percent of hauls can it achieve a bycatch reduction of less than 25 percent (Helies and Jamison, 2009; NOAA, 2016). The first condition establishes a minimum acceptable standard of performance, while the second establishes a maximum acceptable level of variation in bycatch reduction performance (Graham and Reisinger, 2014).

In Australia's Northern Prawn Fishery (NPF), the fishing industry is voluntarily gravitating toward using new BRD designs that reduce fish bycatch by 30 percent compared to a currently approved square-mesh panel BRD (Laird, Cahill and Liddell, 2016). Historically, BRDs in this fishery were approved if they reduced bycatch by at least 10 percent compared to a standard (unmodified) codend. While this new standard is not enshrined in fishery regulation, it was designed to encourage improvement in bycatch reduction by July 2018, as part of a suite of improvements to maintain the fishery's MSC certification. To achieve this outcome, a simple BRD testing protocol was used (Figure 3) and a reward of AUD 20 000 was available to fishers who most successfully demonstrated achievement of this performance target.[3]

Based on the literature, it appears that most other countries that target tropical shrimp with bottom trawls have no formal bycatch reduction targets.

2.3 TURTLE EXCLUSION DEVICES (TEDS) – REGULATIONS

In 1987, the United States of America introduced regulations requiring shrimp fishers to install approved TEDs in their trawls and reduce sea turtle mortality (Federal Register, 1990a). Initially, five TED designs were approved: the NOAA Fisheries' TED, the Cameron TED, the Matagorda TED, the Georgia TED, and the Morrison soft TED (NOAA, 2019b). Nowadays, a number of other TEDs are approved, providing they

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2 The standard trawl includes the mandated TED.

3 About 15 000 USD at 2018 exchange rate.

BOX 4

Core features of TED regulations from the United States of America

The TED regulations from the United States of America represent best practice in TED design, rigging and operation to minimize the capture and drowning of sea turtles in a shrimp trawl. Core features of these regulations include:

Construction material:

- hard TEDs must be constructed from steel, aluminium, or another rigid material;
- soft TEDs must be constructed from polyethylene or polypropylene material.

Grid shape:

- hard TEDS can be oval, round or tombstone-shaped.

Grid angle:

- between 30 and 55 degrees from the horizontal when the trawl is in operation.

Bar spacing:

- no more than 102 mm between adjacent bars.

Grid size:

- at least 813 mm horizontally and vertically.

Grid flotation:

- no less than 6.4 kg flotation;
- attached to top half of the grid, if the grid is used as a downward excluder;
- must not impede the passage of turtles.

Location and size of escape opening:

- escape opening must be immediately ahead of the grid frame;
- located at the top of the codend if the TED is an upward excluder;
- located at the bottom of the codend if the TED is a downward excluder;
- must measure at least 1 420 mm wide and 510 mm long when stretched*.

Escape cover:

- constructed from netting material with a stretched mesh size of less than 41 mm;
- attached along the entire forward edge to the codend;
- must measure 3 378 mm wide by 1 321 mm long in offshore waters*;
- can be constructed from two, partially overlapping panels of netting*.

*Dimensions for the double-cover offshore TED escape cover.

Source: Federal Register (2016), Wildlife and Fisheries (2019).

meet existing regulations. Box 4 summarizes current regulations associated with the design, construction and size of TEDs.

In 1989, Section 609 of the United States of America Public Law 101–162 regulated shrimp imports, allowing only those from countries where the shrimp fishery did not have an adverse impact on sea turtles (Eayrs, 2007; NOAA, 2019b). Initially this applied only to countries in South America and the Caribbean, but in 1996 it was extended globally: all countries exporting shrimp to the United States of America were now required to have a sea turtle protection programme of comparable effectiveness. Each country has the flexibility to develop their own national TED regulations, although the regulations from the United States of America were often viewed as a foundation upon which to achieve this outcome. Most countries therefore have TED regulations that are similar to those in the United States of America (see country reports for details). These are described in Eayrs (2007), which includes technical data sheets for the construction of approved TEDs, as well as in Davis (2016) and NOAA (2019b).

As of publication, 40 countries are certified to export shrimp to the United States of America. Of these, 14 countries (Colombia, Costa Rica, Ecuador, El Salvador, Gabon, Guatemala, Guyana, Honduras, Mexico, Nicaragua, Nigeria, Pakistan, Panama and Suriname) have introduced programmes that provide a comparable level of sea turtle protection. The remainder have demonstrated that their fisheries pose no threat to the incidental capture of sea turtles (Davis, 2016; Federal Register, 2016a), usually because the risk of encountering a sea turtle is minimal. Several shrimp fisheries in Australia may also export to the United States of America either because of their effective TED programme or because their fisheries do not pose a danger to sea turtles. Other countries, such as Madagascar and Thailand, have recently had their approval revoked as United States of America inspectors determined that their sea turtle protection programmes were inadequate. Similar efforts to protect sea turtles are under active consideration in the European Union (Davis, 2016).

2.4 BYCATCH REDUCTION DEVICES (BRDS) – REGULATIONS

As most BRDs designed to reduce fish bycatch in tropical shrimp-trawl fisheries originated in the United States of America, it follows that their introduction to other countries has been accompanied by similar regulations. These regulations have in some cases been modified at a later stage to refine bycatch reduction performance.

The BRDs currently regulated and approved for use in the United States of America include: the Jones-Davis and modified Jones-Davis BRDs, the Cone Fish Deflector Composite Panel, the Square-Mesh Panel Composite Panel, and the Fisheye (NOAA, 2019c). A description of construction details is provided in Eayrs (2007), Federal Register (2016), and NOAA (2019c).[4]

In Australia's Northern Prawn Fishery, BRDs approved for use include: the Square-mesh codend, Square-mesh panel, Fisheye, Yarrow Fishery, Tom's Fisheye, Kon's Fisheye, FishEX70, the Radial Escape Section, Modified TED, and the Popeye Fishbox (design and construction details are provided in AFMA, 2019a). In the Queensland East Coast Fishery, the Square-mesh codend, Square-mesh panel and Fisheye are also approved for use, as well as the Bigeye and a V-cut (details are provided in Queensland Government, 2017).

A description of BRD regulations for other countries is provided in the section, "Progress and accomplishments in bycatch reduction in tropical shrimp-trawl fisheries in selected countries", although many countries are yet to introduce such regulations.

[4] A graphic representation of bycatch reduction devices is also available at www.fisheries.noaa.gov/southeast/bycatch-reduction-device-pictures

BOX 5

Improving the participation of fishers in bycatch reduction research

Eayrs (2012) and Davis (2016) demonstrate that fishers should actively participate in bycatch reduction research, and recommend the following actions.

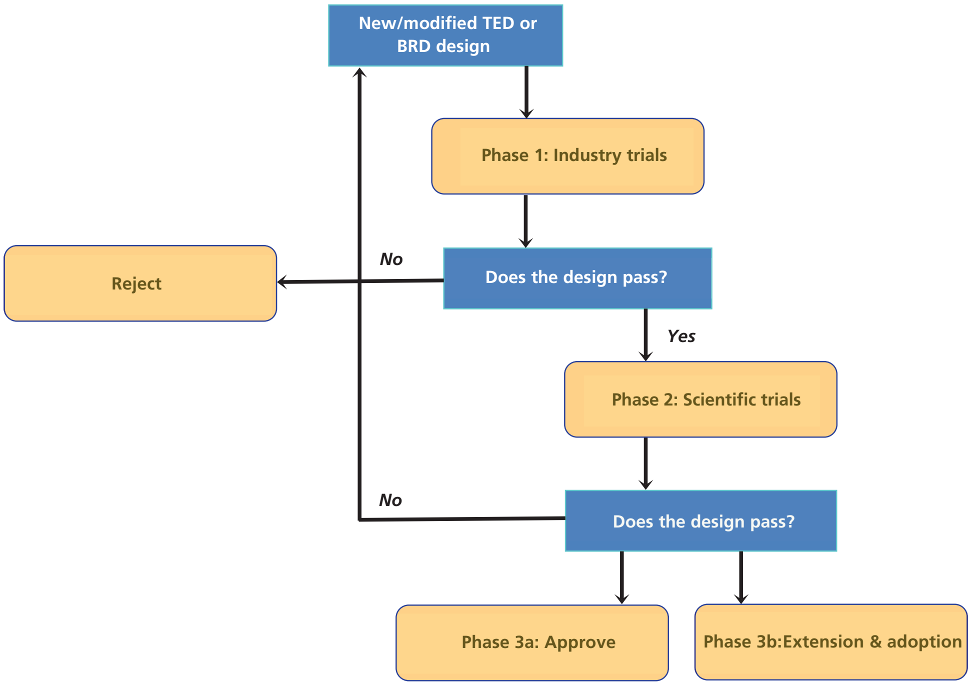
- Identify fishers, or a group of fishers, willing to work with researchers.
- Provide opportunities for fishers to contribute and co-own the research process, including by:
  - inviting them to contribute and test ideas to reduce bycatch independently;
  - inviting them to contribute to research planning, including gear design and construction, fieldwork, outreach and extension;
  - conducting research on their trawlers and giving them an opportunity to improve BRD performance, when not in conflict with research and/or conservation objectives;
  - seeking their advice regarding outreach and extension opportunities, report preparation, co-authorship of papers, and presentation of results to fishers and others.
- Make an effort to reduce bycatch that fishers would like to catch less frequently.
- Introduce a comprehensive outreach and extension programme that:
  - provides fishers with a rationale for reducing bycatch, including potential threats bycatch may pose to their livelihood through trade embargos, loss of markets, or other economic impacts;
  - discusses the potential economic benefits of using a BRD openly, including improved trawl performance and catch quality, reduced trawl damage, and potential to access preferential markets;
  - discusses the concerns and fears of fishers associated with using a BRD, and indicates how these fears will be addressed;
  - provides fishers with timely feedback on research progress and results, BRD design, rigging and operation;
  - provides fishers with opportunities to build capacity and become engaged in efforts to reduce bycatch.
- Recognize and promote their research involvement and contributions to other fishers, researchers, regulators, environmentalists and the public.

2.5 CURRENT ISSUES AND BEST PRACTICE IN BRD TESTING AND EVALUATION

Testing and evaluating a BRD is a challenging and complex activity: it requires significant planning and preparation, and best practice usually demands the significant involvement of fishers from the outset (see Box 5). This may be difficult if fishers are not interested in reducing bycatch due to a fear of losing shrimp or other commercial catch, concerns about BRDs increasing fishing costs, concerns over crew safety, a lack of awareness regarding the need to reduce bycatch, or a distrust or lack of familiarity with working with researchers or government (Eayrs, 2012). Therefore, the challenge for researchers is to identify and act on opportunities to address their concerns associated with reducing bycatch, as well as opportunities for them to benefit from reduced bycatch.

In some circumstances it is useful to give fishers an opportunity to develop their own BRDs and conduct basic or preliminary tests without the presence of researchers. There are multiple benefits to this approach, including the empowerment of fishers to be part of the bycatch reduction programme. It is also a relatively low-cost way to assess the potential of a BRD, prior to deciding whether detailed and costly testing is necessary. Fishers are ideally placed to develop new and innovative devices, improve the performance of existing devices, and/or design solutions to any rigging and handling

FIGURE 2
TED and BRD testing protocol



Adapted from Eayrs (2004) and AFMA (2014a).

issues. The National Marine Fisheries Service (NMFS) of the United States of America has a long history of allowing fishers to develop their own TEDs and then testing them under controlled conditions at sea in the presence of NMFS gear technologists (Jenkins, 2012). This includes an opportunity to film the device in the clear waters of the Gulf of Mexico and make any necessary changes deemed necessary to improve performance. In Australia's Northern Prawn Fishery, fishers also have opportunities to develop their own BRDs, and a testing protocol has been developed to facilitate review of their performance (Figure 2). This is a simple three-phase assessment procedure, which provides a flexible, cost-effective way for interested fishers to develop their own devices and potentially have them approved for use in the fishery.

Appropriate experimental design, including testing methodology, data analysis and reporting also constitutes best practice in bycatch reduction. However, it is common to find critical details omitted when interpreting BRD trial results in the research literature; these can include the number of hauls, haul duration per treatment, and fishing location. The same applies to other important BRD details such as overall dimensions, orientation, dimensions of the escape opening or openings, the number of escape openings, and the location in the codend. It is unclear why such fundamental information is sometimes omitted, but it significantly hampers evaluation of BRD performance and undermines confidence in the researcher.

In scientific journals, efforts to standardize net performance and minimize catch bias between nets or hauls are sometimes not described, and descriptions of statistical analysis are sometimes lacking adequate detail, or they are applied incorrectly. One example is an over-reliance upon shrimp-to-bycatch ratios (by weight) to evaluate bycatch reduction performance, particularly in order to compare ratios at different times or fishing locations. This approach fails to consider that different shrimp-to-bycatch ratios can be independent of BRD performance, showing differences in the abundance of shrimp or bycatch at the time of the study, for example. As it is not always possible

to determine which of these variables has changed, the use of this statistic serves little purpose, particularly when used to compare catch ratios that are months or years apart, or in different locations. Another example is to present selectivity curves based on a small number of hauls, or a few kilograms of catch, thereby giving these curves greater credibility than they deserve. In these instances the curves present no important findings because the sample size is too small and not indicative of the true population of the sampled species. Finally, examples can also be found where written descriptions and details of a BRD in a figure or table are different or contradict those provided in the text, and sometimes they are even missing units of measurement.

These issues suggest there is a strong need to improve capacity in experimental design and implementation, including fieldwork design, and introduce minimum acceptable standards of analysis and reporting. This will improve the understanding of best practice in bycatch reduction research and increase the likelihood that these efforts are productive, achieve desired outcomes, do not waste resources, and contribute to sound decision-making. The FAO publication, *Comparative testing of bycatch reduction devices in tropical shrimp fisheries: A practical guide* by Eayrs (2012), available online at no cost, explores these issues and describes best practice in BRD testing, evaluation and reporting. It also describes how good planning and preparation can accommodate effective decision-making when sudden or unpredicted changes are necessary, particularly during fieldwork, and it stresses the importance of close attention to detail. A review of related research in prominent scientific journals is also a useful option, including the *ICES Journal of Marine Science* and *Fisheries Research*. These journals have high standards and publish relevant papers that closely reflect best practice in bycatch reduction, including acceptable standards of experimental design, data analysis, and reporting, which can then be incorporated into plans for future research activity.

2.6 CURRENT STATUS AND BEST PRACTICE IN OUTREACH AND EXTENSION

Many countries that have embarked on a TED or BRD research programme have also, to a greater or lesser extent, included outreach and extension programmes (see country reports for details). For example, at least 2 900 CIFT-TEDs were given to shrimp fishers free of charge in India, in order to accelerate their uptake of TEDs and thus protect sea turtles (Boopendranath, 2007). Fishers were also given detailed explanations on TED construction, maintenance and handling details, and at least 40 demonstration and training programmes were conducted in multiple fishing ports around the country, focusing primarily on the design and operation of the TED. At least 1 800 boat owners, operators and others were trained in TED operation in both English and local languages.

It is essential that researchers inform fishers of the results and outcomes of BRD/TED research, and receive important technical information about their design, rigging and orientation (Eayrs, 2012). This helps fishers' confidence and improves their capacity to adopt a TED or BRD, reduce bycatch, and comply with (any) associated regulations. Such programmes should not only describe bycatch reduction performance, but also focus on ways to optimize this performance, notably by minimizing any impact on catch value such as shrimp loss or reduction in shrimp quality. Important design and operational details should also be provided. In this way, fishers may better appreciate the efforts of researchers, feel more valued as individuals, and be more willing to participate in bycatch reduction programmes both now and in the future.

Australia and the United States of America both have a long history of bycatch reduction outreach and extension programmes in shrimp fisheries. The United States of America programme began in association with TED and BRD research and development in the 1970s, and included activities such as dockside workshops for fishers to view these devices on display and talk to experts, as well as brochures, videos and reports describing these devices, and any results of recent at-sea testing (Jenkins, 2012).

The outreach and extension programme included notifying both local and foreign country fleets of requirements to ensure they comply with TED regulations, as well as regulations for approved types of BRDs. Their outreach and extension efforts also include the involvement of a team from NOAA Fisheries and the Department of State to review sea turtle conservation programmes in shrimp fisheries around the world (NOAA, 2019b). The role of these officials is to determine whether each country has a sea turtle conservation plan equally effective to that in the United States of America, to help develop their own TED regulations and enforcement programmes, and to provide vital technical assistance to local fishers and others actors.

In the late 1990s, fishers in Australia's Northern Prawn Fishery were the recipients of a multi-year outreach and extension programme to prepare them for the mandatory introduction of both TEDs and BRDs in 2000 (Burke, Barwick and Jarrett, 2012). This programme continued a few years afterwards, in order to provide technical training and support to fishers to improve bycatch reduction performance. It also included the production of regular newsletters and posters describing TED and BRD designs, rigging and performance (Brewer *et al*., 2004). The programme produced several videos demonstrating the operation of these devices underwater, multiple port-side and at-sea workshops where fishers had an opportunity to inspect the devices and talk with researchers, in addition to an opportunity for fishers to test a suite of TED and BRD designs on their own vessel at no cost for a limited period of time, under the tutelage of an expert. It also established appropriate TED and BRD design and rigging regulations, associated presentation of these regulations in workshops, a brochure, and other sources of industry literature, as well as the related training of enforcement officers. By the time these devices became mandatory, many had taken the opportunity to learn and gain experience in their use. This programme was widely considered to be very successful; it significantly reduced the mortality of sea turtles captured in trawl gear (Barwick, 2011) and ultimately resulted in the fishery being approved to export shrimp to the United States of America and, more recently, certification by the Marine Stewardship Council. Similar programmes were also introduced in other Australian shrimp fisheries – in Queensland, New South Wales, South Australia and Western Australia – and have similarly been rewarded with certification by the Marine Stewardship Council.

The Southeast Asian Fisheries Development Center (SEAFDEC) Training Department, based in Thailand, also has a long history of providing outreach and extension materials to fishers and other actors. Their involvement in the project on "Reduction of environmental impact from tropical shrimp trawling through the introduction of by-catch reduction technologies and change of management (REBYC)" in 2002–2008, and the subsequent project, "Strategies for trawl fisheries bycatch management (REBYC-II CTI)", involved an extensive effort to share information with fishers and others in multiple countries in Southeast Asia. This information included pamphlets, brochures, videos, t-shirts, stickers, meetings and workshops with fishers, local fishery authorities and others. Officials complemented these efforts with static gear displays for fishers to inspect a TED or BRD, and brief at-sea demonstrations on a commercial vessel (details are provided in Chokesanguan *et al*., 2010).

In contrast to the aforementioned initiatives, based on published descriptions it is clear that many countries have not embarked on significant outreach and extension programmes or have not taken steps to publicly describe such programmes. In the latter instance, this is an unfortunate outcome because it deprives similar initiatives from learning about previous experiences and findings. For example, despite a significant and ambitious programme, very few fishers ultimately continued to use the CIFT-TED in India, owing to a perceived lack of incentives and benefits (Boopendranath, Prakash and Pravin, 2010) As a result, NOAA Fisheries and the United States Department of State withdrew their approval of the Indian sea turtle conservation

programme. Extensive outreach and extension efforts were insufficient to overcome the concerns of fishers and additional approaches were evidently required, including improved monitoring, control and surveillance. A key lesson from this outcome is the importance of working closely with fishers at all stages of BRD development, taking care to understand their worries, and actively seeking remedial solutions to erode or eliminate these concerns.

Even when an outreach and extension programme is in place and active, there is usually no guaranteed way to evaluate its impact on the number of fishers using a BRD or their rate of adoption. Due to funding or time shortages, such programmes are usually limited to informing fishers of key developments and encouraging their testing and adoption of a BRD. Usually, the anticipated outcome of these programmes is an increasing number of fishers using BRDs, yet they rarely include monitoring strategies to measure these metrics. Therefore, the effectiveness of most outreach and extension programmes remains unquantified, leading to questions on the programme's effectiveness. Best practice in outreach and extension must include programmes that measure the uptake of BRDs by fishers, perhaps even coupled with an estimate of the associated reduction in bycatch. By doing this, researchers provide a measurable way to evaluate the effectiveness of the programme, and may even accelerate the rate of uptake as the project progresses. In time, this may even help overcome the paucity of literature describing such programmes, because researchers will be able to use BRD uptake rates and an associated improvement in bycatch reduction as a measure of their success. Box 6 describes examples of best practice in outreach and extension.

BOX 6

Best practice in outreach and extension

Examples of best practice in outreach and extension programme include:

- Early and close collaboration with fishers involved in or affected by the bycatch reduction effort. This includes fisher involvement in the identification of bycatch issues and possible gear solutions, the testing and evaluation of BRDs, in addition to data analysis and reporting (including sharing information with other fishers).
- Testing BRDs on a commercial bottom trawler. This builds credibility in the eyes of most fishers and they may be more willing to accept the outcomes of these tests.
- Actively seeking opportunities for fishers to benefit from using a BRD, such as fuel savings, improved shrimp quality, reduced sorting time on deck, access to otherwise closed fishing grounds, and improved market access.
- Providing opportunities for fishers to talk with other fishers and researchers who may have experience in using these devices, preferably on their own boat or in a familiar environment such as on the dock or in a net shed.
- Regular, uncomplicated and brief reports to fishers describing BRD research progress, including a focus on benefits to the sector from using these devices.
- Dockside meetings or workshops for fishers to inspect BRDs, receive literature and information, and ask questions of experts.
- Presentation of simple, easy-to-understand handouts, literature and images describing BRDs, including difficult concepts.
- Underwater videos showcasing how a device performs underwater, and how shrimp, fish and other animals respond to the device.
- Providing opportunities for fishers to test a device on their own boat, free of charge, to build confidence, or to develop their own device that meets agreed performance standards.
- Provision of appropriate training for fishers, net makers, regulatory authorities and others.
- Simple, clear instructions and diagrams indicating how to construct, rig, maintain, and fine-tune a TED or BRD, as well as troubleshooting instructions.

2.7 COMPLIANCE

The successful introduction of BRDs in a fishery relies heavily upon a comprehensive outreach and extension programme, strong monitoring, control and surveillance (MCS), and ultimately, compliance with regulations by fishers. The time and effort associated with the introduction of these devices will be in vain if fishers choose to be non-compliant and ignore regulations. For this reason, best practice in the implementation of BRDs includes working closely with fishers to encourage their active participation in bycatch reduction research as well as compliance with regulations.

Unfortunately, despite significant outreach and extension efforts, and strong monitoring, control and surveillance (MCS) programmes, anecdotal evidence describing poor compliance with fishery regulations abounds, including those pertaining to the use of BRDs. This evidence includes fishers sewing up the escape opening of a TED, or removing the TED entirely. It also includes the use of small-mesh netting panels inside a codend, designed to billow upwards and block the escape openings of a square-mesh window, or sewing a panel of netting over the escape opening of a Fisheye. There is also documented evidence describing poor compliance with BRD regulations. For example, poor compliance and enforcement of a 35 mm minimum codend mesh size regulation resulted in some shrimp fishers in India using mesh sizes as small as 10 mm (Mohamed *et al.,* 2009). In Nigeria, dockside inspection data suggests that less than 85 percent of shrimp fishers are complying with TED and BRD regulation, and that MCS capability is limited and requires further development (Solarin *et al.,* 2011). Anecdotal evidence also suggests that compliance levels are lower when the vessels are at sea.

There is also a body of anecdotal evidence describing how weak monitoring, control and surveillance allows fishers to violate regulations and simultaneously compromise bycatch reduction performance to protect the shrimp catch. For example, fishers in Australia's Northern Prawn Fishery were required by regulation to insert their BRD no more than 120 meshes from the codend drawstring. In response, fishers placed their BRD the full legal distance from the codend drawstring, knowing that shrimp loss and bycatch reduction through the BRD would be minimized. This regulation has proven to be overly conservative, and until recently the performance of BRDs in this fishery was estimated to be lower than 8 percent when compared to a standard trawl (Brewer, *et al.,* 2016). Overcoming such risk-averse behaviour is difficult when loss of income or livelihood is the result. For this reason, best practice in bycatch reduction includes not only the introduction of effective devices and regulations but also the introduction of appropriate performance standards, education for fishers to understand the need for bycatch reduction, and opportunities for them to contribute to bycatch reduction efforts that also take into account the protection of the target catch (both shrimp and commercially viable fish).

BOX 7

Challenges of complying with BRD regulations: a perspective

The reluctance of the tandels [captains] to use the legal mesh size was found to be [a] mind-set problem and was related to performance anxieties. Mostly the tandels are paid based on their experience and reputed ability to bring-in good catches.

Notwithstanding the normal human fear of using something new, they also believe that their reputation would suffer, if they don't bring good catches. There is also peer pressure, as there is comparison among other tandels in vessels owned by the same company. The project did not recognize these fears and anxieties, until much later, and therefore, corrective steps attempted at a later stage did not bear any success. (Mohamed *et al.,* 2009).

2.8 CONCLUSIONS

According to existing literature, best practice for bycatch reduction includes not only the introduction of TEDs and BRDs into a fishery but also the application of appropriate procedures and protocols, the achievement of bycatch reduction against recognized standards or expectations, the introduction of effective regulations, and appropriate outreach and extension programmes. Box 8 summarizes the current state of bycatch reduction.

This report provides evidence that many countries have successfully introduced TEDs and are achieving best practice in the exclusion of sea turtles. Fishers now view TEDs as a normal part of trawl gear, and they appreciate not having to handle sea turtles and other large animals sometimes retained in the codend. However, many other countries are still struggling to introduce TEDs and their use by fishers is far from satisfactory, despite the success seen elsewhere.

There is also ample evidence to suggest that best practice in BRD performance is not being fully or consistently achieved. This report commonly found average fish bycatch reduction rates of 30 percent or less compared to a standard codend, and while higher rates of reduction were sometimes reported, they were often achieved inconsistently within a fishery, or accompanied by significant shrimp loss.

Clearly, much work remains to be done. A first step is to explore where progress is being made, identify key processes and lessons, and then adapt them to suit the local context. It is clear that Australia and the United States of America are leading the way in bycatch reduction, having already achieved significant reductions in bycatch and adopted a suite of best practices to guide future development. While it may be tempting to believe that processes and lessons from these two countries cannot be applied elsewhere, the reality is that many of the bycatch issues, opportunities, lessons and processes are common and can be applied with only minor modification, notably as it applies to fieldwork methodology, data analysis, outreach and extension.

BOX 8

Current state of bycatch reduction efforts

A review of the literature reveals key conclusions with respect to bycatch reduction research in tropical shrimp-trawl fisheries:

- The vast majority of bycatch reduction research has traditionally focused on excluding bycatch from the codend of a shrimp trawl.
- With few exceptions, no new bycatch reduction devices or techniques to reduce bycatch have been developed over the past decade.
- Most tropical shrimp-trawl fisheries use the same or similar bycatch reduction devices, with the Super Shooter TED and the Fisheye most commonly used.
- TEDs are achieving satisfactory performance and reducing the mortality of sea turtles.
- BRDs typically reduce fish bycatch by less than 30 percent compared to a standard trawl.
- Standards of best practice have been developed, primarily in Australia and the United States of America, although further application and improvement is required to improve bycatch reduction rates for fish bycatch.
- Standards of best practice can be readily adapted and applied from one country to another, particularly with respect to experimental design including fieldwork methodology, data analysis and reporting.
- Outreach and extension programmes are not well described in the literature, and regulatory information is also typically lacking in detail.
- Evidence suggests inadequate MCS in many countries, notably with regard to use of TEDs and BRDs and compliance with relevant regulations (if they exist).

Fisher's concerns regarding bycatch reduction initiatives are universal. These include potential loss of income when a TED or BRD is used, the cost to purchase or build a device, and possible handling and operational issues. In the absence of robust outreach and educational programmes, fishers will find creative ways to limit the perceived impact of these devices on shrimp catch, legally or otherwise. They will also, at least initially, treat researchers and others promoting bycatch reduction practices with suspicion because they fear how it will impact their livelihoods.

However, in most instances the opportunities and solutions to these issues are also universal. For example, in terms of the application of basic BRD testing protocols including fieldwork design, analytical tests and standards of reporting. Every experiment must standardize trawl performance so that comparisons between a standard trawl and one that is modified with a BRD are valid. Moreover, consistent data collection and recording techniques must always be applied during fieldwork, and lucid reports describing methods and all findings should be written. All of these needs can be applied by research programmes with limited financial, human and other resources, but they require attention to detail and the application of appropriate protocols to adapt and optimize outcomes. Finally, the application of outreach and extension programmes from other countries can also usually be modified to suit the local context, and interact with local fishers and others. Using the internet to exchange information such as research summaries and videos is an excellent and cost-effective starting point, which makes effective use of the high rate of mobile phone ownership among fishers.

The existing literature suggests that future efforts to reduce bycatch in these fisheries include a greater focus on exploiting behavioural differences between bycatch and shrimp. Several BRDs have already been developed to achieve this outcome, and it appears they commonly have higher rates of bycatch reduction than BRDs that exploit size differences between bycatch and shrimp. It also appears that a focus on the mouth of the trawl has significant potential, particularly when coupled with existing BRDs located in the codend. Concentrating on these areas of research therefore seems to offer the best chance of substantial improvement in bycatch reduction.

3. Progress and accomplishments in bycatch reduction in tropical shrimp-trawl fisheries in selected countries

This section summarizes the best practices in bycatch reduction in tropical shrimp-trawl fisheries, by country. This information covers four categories: TEDs, BRDs, Regulation, and Outreach and Extension.

Information comes primarily from scientific literature, books, technical reports, conference proceedings, brochures and webpages. In many instances, it was possible to validate findings and claims from other sources of information before inclusion in this report. However, these attempts were not always successful, particularly in relation to information that was sourced from non-scientific literature, such as brochures and webpages (Box 9). An additional challenge was that some sources, including those in the scientific literature, contained inadequate information to understand the testing protocol, sampling methodology or performance of the device. Examples include the failure to describe basic details of the TED or BRD such as dimensions (e.g. length and width of a square-mesh panel), size of escape openings (e.g. mesh size or bar length in a square-mesh panel or bar spacing in a TED), rigging details (e.g. grid angle in a TED), or its location in the codend (e.g. number of meshes from the drawstrings). Additional information that researchers commonly omitted included any efforts to standardize the testing protocol, present the number of comparative hauls, describe catch sampling protocols, and use appropriate statistics. Sometimes the available information contained obvious errors, even in several scientific manuscripts and peer-reviewed conference proceedings, and unless the author found an alternative source, the information was discarded. A lack of detailed information was also a reason that monitoring, control and surveillance (MCS) was not used as a category to assess best practice in bycatch reduction, because even a casual glance at the literature indicates that monitoring and surveillance efforts are very poorly described. Subsequently, regulation was used instead as a proxy, and it was assumed that achievement of best practice in the other categories reflected, in part, the presence of an effective MCS programme, particularly with respect to approved TEDs and certification by the Marine Stewardship Council.

Not all countries with a tropical shrimp-trawl fishery are represented in this document. The level of detail for countries described in the document varies because information relevant to the four categories was either too scant, incomplete, vague, unverified, or could not be found. Notwithstanding the possibility that information was missed, it is also conceivable that information was not available because relevant efforts have either not been drafted or the information has not been reported at all. This challenge was particularly evident when reporting relevant regulation and outreach and extension efforts for each country.

In this review the documented performance of TEDs and BRDs was usually limited to proportional differences in catch and bycatch between a standard (control) and modified trawl. These data are the most commonly reported statistics describing bycatch reduction performance and they provide a useful, albeit basic measure of

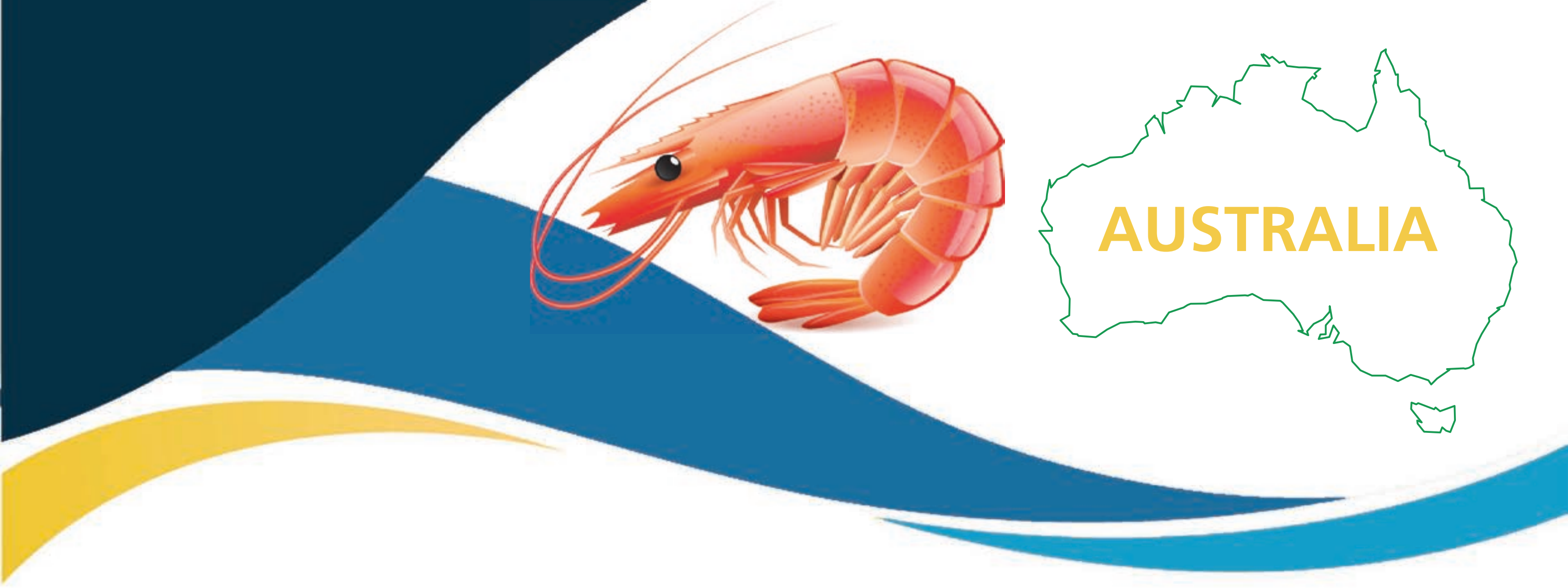
performance. Occasionally, catch data by species or family names is also provided, but not the results of detailed statistical testing; the references at the end of this document will be useful for anyone interested in a deeper evaluation of common statistics to evaluate TED or BRD performance.

BOX 9

Challenges reviewing TED and BRD documents

Reviewing TED and BRD information from a wide array of sources, from scientific manuscripts to websites, and from multiple countries – including those where English is not the first language – has highlighted a number of limitations that challenge understanding of the research contained in the source. They include:

- **Inconsistent or incorrect reporting of details or data within a document, including between text and figures.** This issue also appeared in the scientific literature, highlighting a lack of attention to detail by authors, reviewers and editors.
- **Insufficient information to replicate the study**. In some instances, this is understandable given the type of source (e.g. brochure) but it also appeared in the scientific literature. Missing details often included species and scientific names, fishing location, haul numbers and duration, trawl design, mesh sizes, TED or BRD construction and rigging, testing methodology, and sampling protocol. Catch information was frequently incomplete, and data tables sometimes presented incorrect proportions or other data. It was occasionally not possible to determine whether authors used mesh length or bar length to measure the dimensions of a square-mesh window. In several instances, multiple sources citing the same research presented conflicting data.
- **Inconsistent terminology**. For example, in the absence of clear definitions it was often not possible to determine differences between “bycatch”, “discards, or “trash fish”.
- **Incorrect testing protocols.** Authors often failed to report efforts to test for net bias, sometimes because there was no attempt to understand this phenomenon. Owing to time and financial restrictions, tests were sometimes located close to shore and far from the actual commercial fishing grounds. On occasion, studies compared the performance of a TED or BRD to a standard (control) trawl tested at another time and/or place, ignoring the potential impact of temporal and spatial variation on catch composition.
- **Inappropriate data analysis, including an inappropriate use of selectivity curves**. Sometimes researchers used bycatch-to-shrimp ratios as a measure of TED or BRD performance; this metric failed to appreciate that a reduction in this ratio may be the result of changes in species composition – an increased shrimp abundance or decreased bycatch abundance, for example, independent of the TED or BRD. Multiple studies presented selectivity curves to demonstrate TED or BRD performance based on only a small number of fish across a limited number of size classes. This analysis highlights a failure to understand the importance of an adequate sample size, as well as the difference between a basic and a detailed testing protocol (details are provided in Eayrs, 2012).



3.1 AUSTRALIA

Background

Tropical shrimp-trawl fisheries are located in Western Australia, the Northern Territory and Queensland, although there are sub-tropical shrimp-trawl fisheries in every other coastal state and territory with the exception of Tasmania. Shrimp are landed almost exclusively by industrial trawlers, usually towing between two and four identical small-mesh nets simultaneously. The most valuable shrimp-trawl fishery is the Northern Prawn Fishery (NPF), which extends across much of northern Australia (Mobsby, 2018). A total of 53 vessels are licensed to operate in the NPF, primarily landing white banana (*Fenneropenaeus merguiensis*), red-legged banana (*F. indicus*), brown tiger (*Penaeus esculentus*), grooved tiger (*P. semisulcatus*), blue endeavour (*Metapenaeus endeavouri*), and red endeavour (*M. ensis*) prawns (NPFI, 2019) Total shrimp landings from this fishery are more than 7 000 tonnes annually (Mobsby, 2018).

In Queensland, Western Australia, South Australia and New South Wales (NSW), annual shrimp landings are around 6 500 tonnes, 3 000 tonnes, 2 400 tonnes, and 1 300 tonnes respectively (Mobsby, 2018). Target species in Queensland are similar to the NPF, with the addition of red spot king (*Penaeus longistylus*), eastern king (*Melicertus plebejus*) and bay prawns (*Metapenaeus bennettae*, *M. insolitus*) (Department of Agriculture and Fisheries, 2016). In Western Australia, landings are dominated by western king prawns (*Melicertus latisulcatus*), *P. esculentus* and *M. endeavouri* (DPIRD, 2016), while the fishery in South Australia is exclusively based on western king prawns, *M. latisulcatus* (PIRSA, 2019). In NSW, *Melicertus plebejus* and school prawns (*Metapenaeus macleayi*) dominate landings (NSWDPI, 2004). The bycatch in all fisheries is dominated by small fish, nearly all of which are discarded overboard, since regulations prevent trawlers from landing/selling fish bycatch. A thorough review of Australian shrimp fisheries, including management and enforcement issues, historical landings, bycatch issues, and research is provided in Gillett (2008).

Australia has a longer history of bycatch reduction than other countries. In 2000, TEDs and BRDS became mandatory in many Australian fisheries. Two key developments characterized the efforts to reduce bycatch. One is the removal of the embargo on shrimp exports to the United States of America. This is worthy of note, as Australia is one of only two countries/territories where the embargo has been lifted from one or more discrete fisheries within a country following the implementation of an effective turtle protection programme (the other is French Guyana). Australian fisheries that can export to the United States of America are the NPF, the Queensland East Coast Trawl Fishery, and the Torres Straits Prawn Fishery (Department of State, 2017). The second development is the Marine Stewardship Council's certification of several fisheries as sustainable: these include the Northern Prawn Fishery, the Exmouth Gulf and Shark Bay prawn fisheries in Western Australia, and the Spencer Gulf king prawn fishery in South Australia.

TEDs

TED research in the Northern Prawn Fishery commenced in the 1990s, including the Super Shooter TED, Nordmore grid, AusTED, and NAFTED (Mounsey, 1997; Rawlinson, Eayrs and Brewer, 1997), although performance has been highly variable (Table 3). The Super Shooter is an oval-shaped grid attached to the codend at around 45 degrees. It can be used as an upward- or downward-excluder, although the latter is the preferred option. Bar spacing is around 100 mm and a funnel of netting ahead of the grid guides all animals to the centre of the codend. This helps keep shrimp away from the escape opening, which is covered with a panel of buoyant netting. The Nordmore grid is a rectangular-shaped grid attached to the codend at around 35 degrees. Bar spacing is also 100 mm, and a panel of netting guides the catch toward the bottom of the codend. The Nordmore grid is used as an upward-excluder. The AusTED is an oval grid constructed from flexible wire rope dipped in plastic resin. Bar spacing is 110 mm and a funnel of netting behind the grid prevents shrimp escape during haulback, particularly in a surging sea. The grid angle is around 70 degrees. The NAFTED is also an upward-excluder and was adapted from the Nordmore grid. The bar spacing of the grid is 100 mm. The bars are bent to prevent sponges and other debris from becoming fouled on the horizontal bar at the top of the grid.

The performance of the AusTED and NAFTED in that early research period was encouraging and the exclusion rates of sea turtles and other large animals approached 100 percent. Shrimp loss was variable and often less than 5 percent, although it was generally lower using the Super Shooter TED (Eayrs, Buxton, & McDonald, 1997).

Around the same time that researchers worked in the Northern Prawn Fishery, the AusTED was tested on the east coast of Queensland. It successfully excluded turtles and other large animals with no significant loss of shrimp (Robins-Troeger, Buckworth and Dredge, 1995). Researchers also tested several other TEDs in Queensland around this time, including the Super Shooter TED, Morrison soft TED, and several local designs conceived by fishers (Robins, Campbell and McGilvray, 1999). All of these devices successfully reduced the capture of large animals and other bycatch, sometimes by as much as 55 percent, although shrimp loss usually occurred by 10 percent or more.

TABLE 3
The effect of TEDs and BRDs on small fish bycatch and shrimp in tropical and sub-tropical shrimp-trawl fisheries in the Northern Prawn Fishery (NPF), Queensland and New South Wales (NSW) trawl fisheries

BRD	Proportion (percent)		Location	BRD	Proportion (percent)		Location
	Bycatch	Shrimp			Bycatch	Shrimp	
TED	10	12	Queensland	SS	5	0	NPF
RES	19	9	Queensland	TED + SMW/BE	8	6	NPF
TED + RES	24	20	Queensland	TED	8	6	NPF
SMC	31	0	Queensland	FE	10	8	NPF
STED	32	29	Queensland	FE	15	20	NPF
AusTED	15–49	45–27	Queensland	SS + FE	12–15	2–10	NPF
AusTED	11–59	9–3	Queensland	NG	15	5	NPF
				RES	20	5	NPF
STED	32	1	NSW	AUSTED	27	23	NPF
CSMP	23–41	14	NSW	SMW	17–30	3–17	NPF
CSMP	40	1	NSW	NG + FE	25–30	15–17	NPF
NG + SMP	58	41	NSW	NG + SMW	30–40	17–38	NPF
NG	90	11	NSW	Popeye FB	29–70	2–3	NPF

All proportions represent the reported catch gain or loss (by weight) in a codend fitted with a BRD, as compared 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. TED – turtle exclude device, RES – radial escape section, FB – fishbox, SMW – square-mesh window, FE- Fisheye, SS – Super Shooter TED, NG – Nordmore grate, CSMP – composite square-mesh panel, STED – soft TED.
Source: Eayrs (2012).

Recently, a TED and a 48 mm square-mesh codend were tested in the Queensland deepwater eastern king prawn (*Melicertus plebejus*) fishery and found to reduce total bycatch significantly – 29 percent compared to a standard codend – with no impact on the shrimp catch (Courtney *et al.,* 2014).

In the Exmouth Gulf and Shark Bay prawn fisheries in Western Australia, the development of bycatch reduction devices has a similarly long history, and a variety of TEDs and BRDs have subsequently been tested. Of these, a downward-excluding rectangular TED and a Square-mesh panel (SMP) constructed from 160 mm netting measuring 3 bar lengths wide and 5 bar lengths long are commonly used in the fishery (Kangas and Thomson, 2004; Department of Fisheries, 2014). The TED has reduced bycatch of turtles by over 95 percent and rays by 56 percent (Kangas & Thomson, 2004).

BRDs

Northern Prawn Fishery

Early, limited scientific testing of BRDs in the 1990s led to a reduction in fish bycatch in this fishery of between 10 and 39 percent (Brewer *et al*., 1998), although when used across the entire fishery these devices reduced bycatch by around 8 percent (Brewer *et al.,* 2006). During this time, commonly used BRDs included several versions of the Fisheye, the square-mesh window (or panel), the square-mesh codend, and the radial escape section. These devices are described in Eayrs, Buxton and McDonald (1997), Rawlinson, Eayrs and Brewer (1997), and Brewer *et al*. (1998).

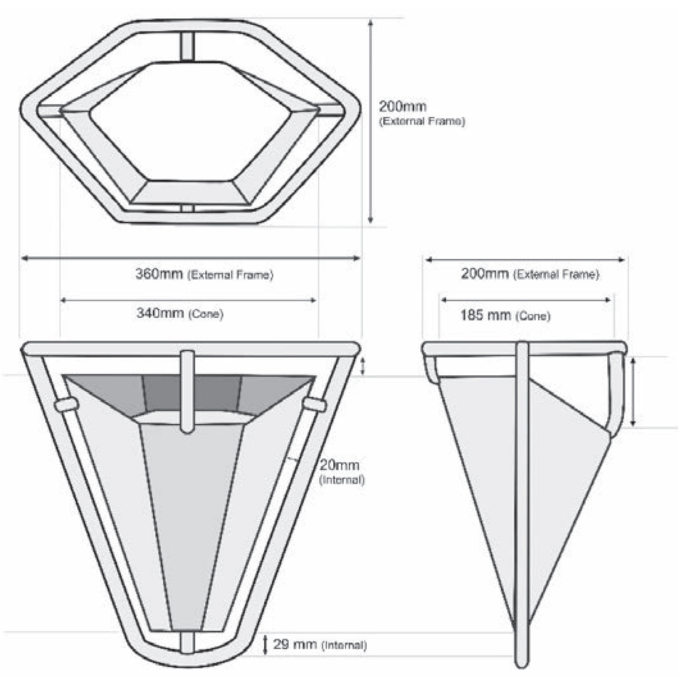
PLATE 2
Tom's Fisheye

©P. Robson

In recent years, a renewed focus on bycatch reduction in this fishery has resulted in efforts to reduce fish bycatch by 30 percent (AFMA, 2014a). In 2009, a square-mesh panel with a Witch's hat BRD enhancer (Plate 2) reduced bycatch by 34 percent when used with a TED (Gerner and Maynard, 2010), although subsequent testing in 2013 and 2014 did not achieve the same success (Laird, Prendergast and Wakeford, 2014). More recently, Kon's Fisheye, Tom's Fisheye (Figure 3; Plate 2) and the FishEX 70 have reduced bycatch by 40 percent when located 60–65 meshes from the codend drawstring (McKillop, 2016; Laird, Cahill and Liddell, 2016; AFMA, 2019b; and Laird *et al*., 2020); the Codend mesh size was 51–56 mm.

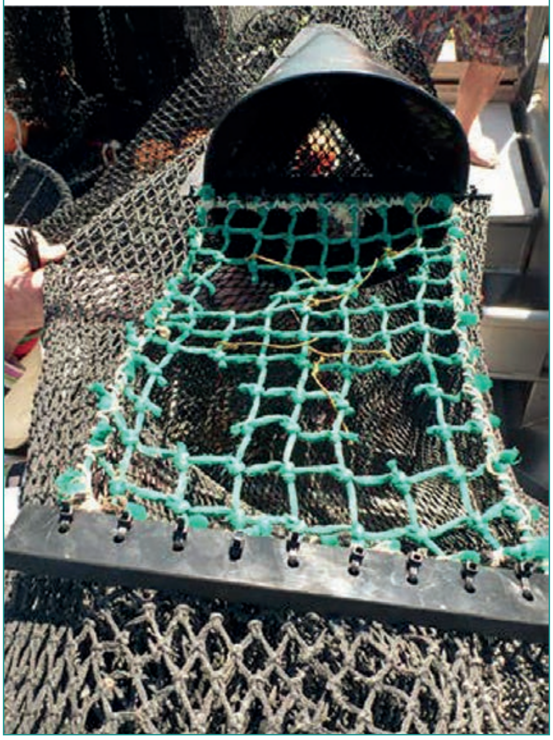
A suite of BRDs are currently approved for use in this fishery, including a square-mesh codend, square-mesh window, radial escape section, Fisheye, FishEX 70, Tom's Fisheye, Yarrow Fisheye, Popeye fishbox, and a modified TED – both AFMA (2014b) and Laird *et al.* (2020) provide diagrams and details.

FIGURE 3
Schematic diagram of the Tom's Fisheye with dimensions



Source: Laird *et al.* (2020).

PLATE 3
The Witches hat excluder and square-mesh panel



©(Laird, Prendergast and Wakeford, 2014)

Until recently almost 64 percent of fishers in this fishery used the square-mesh panel and the remainder used Fisheye (Burke, Barwick and Jarrett, 2012), although almost all fishers now use the FishEX 70 or the Tom's Fisheye (Laird *et al*., 2020). Descriptions of these Fisheyes and associated testing are provided in Laird *et al*. (2020).

Other novel technologies tested in the Northern Prawn Fishery include lights attached to the trawl headrope, an electronic shark shield to deter sharks from shrimp trawls, and use of T-90 netting and electricity to reduce fish bycatch (Rawlinson and Eayrs, 2009). When lights were first tested in the fishery, they reduced bycatch by up to 30 percent and increased prawn catch by 32 percent (Maynard and Gaston, 2010). However, in another location bycatch increased by 51 percent, and the shrimp catch fell to such an extent that the trials were abandoned after five tows. Technical details of the light arrangement are unavailable due to a pending patent application. Another novel consideration is a reduction in the vertical opening of a shrimp trawl. To simulate this modification, researchers tested a multilevel beam trawl (MBT) in the fishery, comprising three horizontal sections: 0–600 mm, 600–1 200 mm, and 1 200–1 800 mm (Eayrs, 2003). Nearly 100 percent of shrimp entered the trawl in the lowest section, while 10 percent of the bycatch entered the trawl in the upper two sections. Despite the performance of this multilevel beam trawl, there have been no further attempts to evaluate the impact of a reduced-opening shrimp trawl.

Queensland East Coast Trawl Fishery

The development of BRDs in the Queensland East Coast trawl fishery began around the same time as the Northern Prawn Fishery, using similar BRD designs. Fishers and net makers designed several additional BRDs, including the bigeye BRD, the monofilament BRD, and the Olsen BRD (Robins, Campbell and McGilvray, 1999).

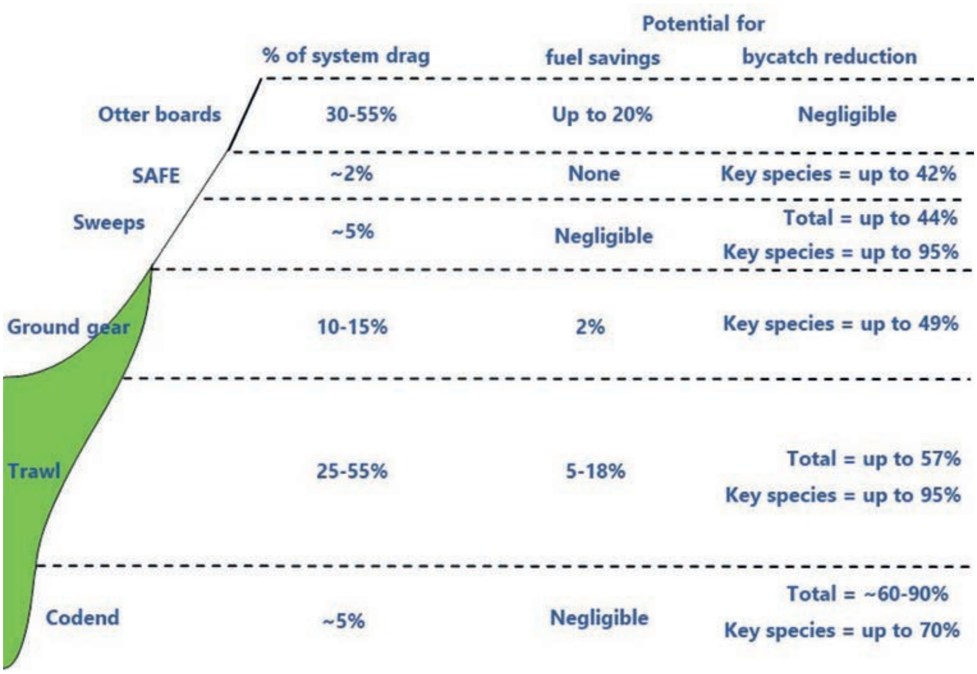
Initially, the bigeye BRD performed favourably, with a reduction in bycatch of up to 40 percent without loss of shrimp. Unfortunately, further tests revealed that it did not exclude turtles and other large animals effectively. Early testing in this fishery also included the AusTED, an innovative flexible grid constructed from wire rope. The AusTED was partly designed to reduce injuries associated with crew being struck by the grid – a major concern expressed by fishers early on in the development of TEDs. The AusTED significantly reduced the capture of sea turtles and stingrays, and reduced fish bycatch by 15–49 percent (Robins and McGilvray, 1999). Shrimp loss was highly variable, ranging from no significant difference to 36 percent. Recently the United States of America Jones-Davis BRD was tested in this fishery and reduced bycatch by 22–24 percent with no loss of shrimp (Prasetyo, Purwoko and Antoro, 2017; Fingerlos, 2012). A radial escape section (RES) and Wick's TED combination was tested and found to reduce bycatch by 24 percent and the shrimp catch by 20 percent (Courtney *et al*., 2000). The Wick's TED featured an aluminium grid with the outer frame curved at the bottom and straight across the top. The bar spacing was 120 mm. The same TED and BRD combination was also tested in the northern area of this fishery, and reduced bycatch by 20 percent with no significant loss of shrimp.

In the Queensland fishery, significant efforts have also been made to reduce the capture and mortality of sea snakes, particularly the spine-bellied sea snake (*Lapemis curtus*), the olive sea snake (*Aipysurus laevis*), and the reef shallows sea snake (*A. duboisii*). These include a Fisheye with an elliptical opening measuring 35 cm wide by 15 cm high, located 50 meshes from the drawstring (codend mesh size was 44.5 mm), a square-mesh panel in the same location constructed from 100 mm mesh (50 mm bar length) and measuring 400 mm wide by 600 mm long, and a 50 mm mesh (25 mm bar length) square-mesh codend measuring 160 bar lengths in circumference and 40 bar lengths long (Courtney *et al*., 2010). The Fisheye was the most effective, reducing sea snake capture by 63 percent compared to a standard trawl. The square-mesh codend reduced sea snake capture by 60 percent, and both BRDs reduced fish bycatch by 33 percent and 31 percent respectively.

New South Wales and South Australia

New South Wales has a long and storied history in reducing bycatch in shrimp-trawl fisheries, even though the latter are located in sub-tropical waters, and examples of research can be found in Broadhurst (2000) and Broadhurst and Sterling (2016). Recently, a major effort was made to evaluate the environmental impacts of shrimp trawling, including bycatch reduction, habitat impact and fuel conservation (Figure 3). This project included testing the efficacy of multiple gear modifications, from the otter boards to the codend, and was the most ambitious, systematic and thorough project of its kind. Some of the modifications to the front of the trawl included a batwing otter board, the SAFE (simple anterior fish excluder), and headline height reduction (Broadhurst and Sterling, 2016). These modifications reduced bycatch by around 40 percent, and up to 95 percent for some key species. In some instances, they improved fuel efficiency by up to 20 percent.

FIGURE 4
Summary outcomes of trawl modification to reduce bycatch and fuel consumption



Source: Broadhurst and Sterling (2016).

Additional changes included ground gear modification, changes to mesh size and body tapers in the trawl, and codend modification, which reduced bycatch by up to 95 percent for some key species and some improved fuel efficiency by up to 18 percent. During these trials, researchers also evaluated the benefits of multi-net trawl systems. This effort has implications for shrimp trawl design globally as the modifications can be applied to other shrimp fisheries using small-mesh nets.

In South Australia, early attempts to reduce bycatch included the use of a T-90 codend and a Nordmore grid to reduce the bycatch of small fish, blue swimmer crabs (*Portunus armatus*), and elasmobranchs (Dixon, Clark and Hill, 2014). The mesh size of the T-90 codend was 46 mm, while the bar spacing and angle of the grid were 45 mm and 20–30 degrees respectively. The T-90 nets were found to reduce the shrimp catch by up to 30 percent and the grids reduced the crab catch by up to 82 percent. In 2014, a Nordmore grid was tested to reduce catches of *P. armatus* and giant cuttlefish (*Sepia apama*) while targeting western king prawns. Initial attempts with a grid measuring 1 m by 2 m and low grid angle (30 degrees) were encouraging, with the exclusion of up to 34 percent of these two species by number (Noell, Broadhurst and Kennelly, 2018). Subsequent testing in 2015 and 2016 included the Nordmore grid with 35 mm, 38 mm and 45 mm bar spacing; the 38 mm grid was also tested with different-sized escape openings and/or guiding panel lengths. Overall, the best performing grid had a 38 mm bar spacing, a 0.81 m^2 or 1.05 m^2 escape opening, and a 2.7-metre-long guiding panel: it reduced catches of *P. armatus* and *S. apama* by approximately 90 percent with no reduction in the shrimp catch.

Regulations

A number of TEDs and BRDs have been approved for use and are mandatory in Australian shrimp-trawl fisheries. In the Northern Prawn Fishery both upward-excluding and downward excluding TEDs are permitted; the grid size must be at least 81 cm by 81 cm, with bar spacing of no more than 120 mm, and a grid angle of between 30–55 degrees from the horizontal. Flotation must be attached to the top half of a bottom-excluding TED, and sufficient to offset its weight – it cannot be attached to an escape cover or flap. A description of TED and BRD specifications is provided in AFMA (2016).

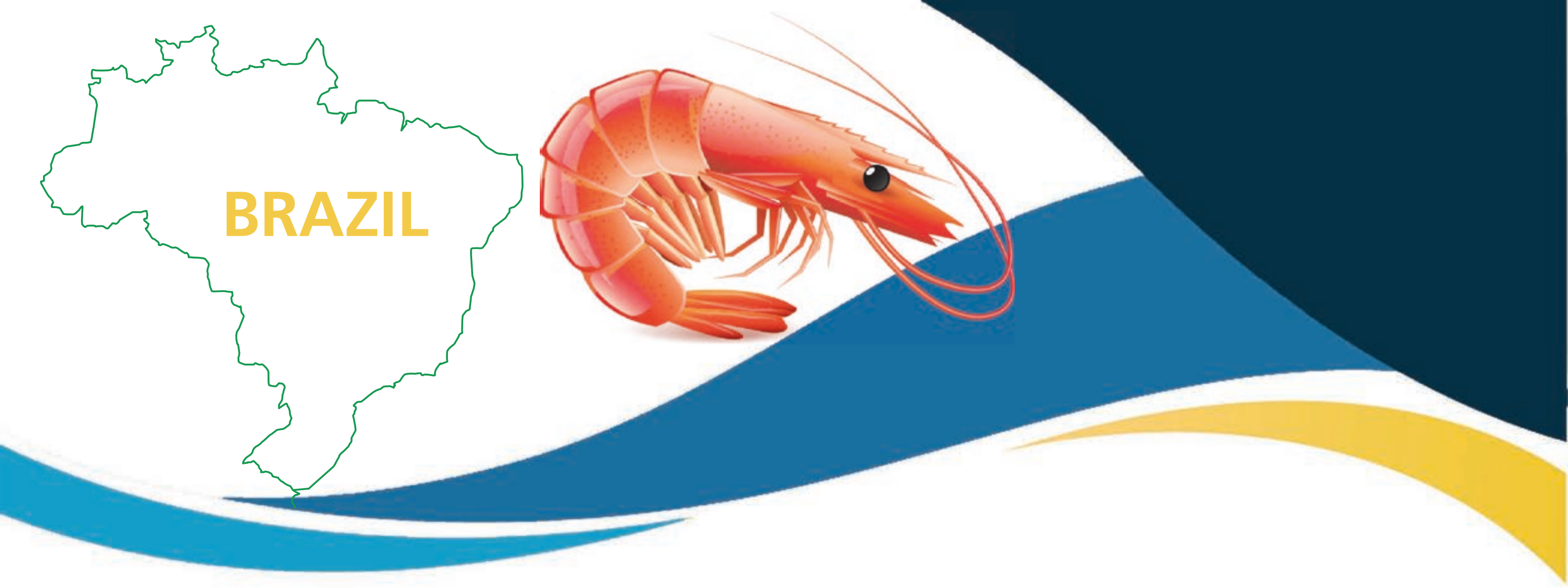
The impact of TED regulations on the Northern Prawn Fishery have been profound. In the late 1980s approximately 5 700 sea turtles were caught each year in the fishery (Poiner, Buckworth and Harris, 1990), but this was reduced to less than 200 per year following the introduction of TEDs in 2000 (Robins *et al*., 2002). The capture of large sharks and rays also fell by 86 percent and 94 percent respectively (Brewer *et al*., 2006). In 2010, only 27 turtles were captured in this fishery, with zero fatalities (Burke, Barwick and Jarrett, 2012). Australia is now one of a small number of countries where the United States of America embargo has been lifted (Eayrs, 2007). The impact of BRD regulations have been less profound, as current BRDs reduce bycatch by around only 8 percent, because of the distance at which fishers place the BRD in the codend, away from accumulated catch (Brewer *et al*., 2004). A voluntary bycatch strategy for this fishery guided recent bycatch reduction efforts and included a target reduction of 30 percent in small fish bycatch by 2018 (AFMA, 2014a).

In the Queensland east coast trawl fishery, TEDs and BRDs are mandatory for all otter trawl nets and all beam trawl nets. Approved BRDs are the square-mesh codend, a composite square-mesh panel, the Fisheye, bigeye, and a V-cut and bell codend combination (Queensland Government, 2017). Regulations relating to TEDs and BRDs are described by the Queensland Government (2010). In the shrimp fisheries in Western Australia, both a TED and a BRD are required to be fitted to a shrimp trawl (Department of Fisheries, 2014).

Outreach and extension

Australia has a long history of TED and BRD outreach and extension for fishers. Over the years significant efforts have been made in all fisheries to report the outcomes of TED and BRD testing to fishers and others. These efforts include gear display workshops, videos, brochures, meetings, and even the presence of a TED and BRD expert to work with fishers at sea when installing, testing and modifying these devices in order to optimize their performance (Brewer *et al*., 2004).

The Northern Prawn Fishery is also one of the few fisheries that appears to have a formalized BRD testing protocol (the other is the United States of America), as described in Burke, Barwick and Jarrett (2012). The protocol is comprised of three phases: initial assessment, visual assessment and at-sea testing. Initial testing involves the fisher providing a TED and BRD to a subcommittee of the Australian Fisheries Management Authority (AMFA) with written details of the new device, including technical details and how it is anticipated to reduce bycatch. If the device is deemed to perform at least as well as currently approved devices, it may be approved for at-sea testing. However, if the device is entirely new or complex, it may need to be visually inspected by the subcommittee before a decision can be made. The next step is normally at-sea testing for a two-week period onboard an operating commercial fishing boat. If a new TED is tested and catches more than two sea turtles it fails the assessment. A new BRD must reduce bycatch by at least 10 percent compared with a control net fitted with a currently approved BRD before it can be approved for use, although this target has recently been increased to 30 percent (AFMA, 2014a).



3.2 BRAZIL

The penaeid shrimp fisheries in Brazil are distributed along the entire coast (Hazin, 2017); they range from handheld gear and fyke nets in the artisanal fishery to double-rigged trawl nets in the small-scale fishery and industrial fishery (twin trawl). At least 70 trawlers operate in the industrial fishery in the north. Annual landings are typically less than 5 000 tonnes (Aragão and de Araujo Silva, 2000) and bycatch is dominated by fish (60 percent) and crustaceans (30 percent). Target shrimp species in the north include pink shrimp (*P. brasiliensis* and *P. subtilis*, including the new specie *Farfantepenaeus isabelae*; (Tavares and Guzmão, 2016). In the South, the industrial shrimp fleet includes at least 140 vessels that target *P. paulensis*, *P. brasiliensis*, seabob shrimp (*Xiphopenaeus kroyerii)*, Argentine red shrimp (*Pleoticus muelleri*), and Argentine stiletto shrimp (*Artemesia longinaris*), as well as fishes and molluscs as byproducts (Duarte *et al*., 2018). The number of small-scale/artisanal trawlers is around 3 000. Besides ecological aspects, human concerns such as food security, gender and fishing household socio-economics (Barreto *et al*., 2020; Edwards *et al*., 2019), can also affect discard rates and fishers' willingness to reduce bycatch (Portella and Medeiros, 2016).

In all penaeid shrimp fisheries the main bycatch species of concern are juveniles of commercially important fish species, as well as elasmobranchs and sea turtles. Bycatch composition varies between areas and fisheries, and some of these species are retained for sale (byproduct), including: southern and northern king weakfish (*Macrodon atricauda* and *Macrodon ancylodon*), striped weakfish (*Cynoscion guatucupa*), acoupa weakfish (*Cynoscion acoupa*) and Brazilian cod ling (*Urophycis brasiliensis*) (Duarte *et al*., 2018; Bentes *et al*., 2017). Discards include small *Macrodon atricauda*, banded croaker (*Paralonchurus brasiliensis)*, *Cynoscion* spp., some threatened elasmobranchs (*Squatina* spp. and *Pseudobatos horkelli*) and sea turtles (*Caretta caretta* and *Chelonia mydas)* (Duarte, Broadhurst and Dumont, 2019). The proportion of shrimp catches to bycatch varies, but amounts to roughly 6.5 kg of fish and other invertebrates (molluscs, cnidarians, ctenophora, etc.) per kilogram of shrimp. In the north, the most abundant bycatch species include: *Ctenosciaena gracilicirrhus* (22.1 percent), *Stellifer microps* (11.8 percent), *Pellona harroweri* (9.2 percent) and *Cynoscion jamaicensis* (7.6 percent) while Scianidae and Haemulidae are the most commonly found families. Among the invertebrates, 73 taxa were found, distributed in 6 phyla: Arthropoda (42 taxa), Echinodermata (14 taxa), Cnidaria (6 taxa), Porifera (4 taxa), Mollusca (3 taxa) and Annelida (3 taxa) (Bentes *et al*., 2020,).

The Brazilian seabob shrimp fishery (*Xiphopenaeus kroyeri*) lands just over 15 000 tonnes annually across several states (Rodrigues-Filho *et al*., 2011). Seabob shrimp are landed primarily by artisanal canoes or trawlers measuring less than 10 m long (Silva *et al*., 2013). Trawl mesh size is typically 26–32 mm, and bycatch comprises over 60 species, dominated by teleosts (82 percent) and crustaceans (10 percent). Bycatch includes juveniles of commercially important species such as *Stellifer* spp. and

Paralonchurus brasiliensis (Rodrigues-Filho, *et al*., 2011). *Portunidae* and *Penaeidae* spp. account for about 74 percent of crustacean bycatch in this fishery (Bochini *et al*., 2019) and around 27 percent of the total catch of crustaceans in Brazil (MPA, 2012). Like the penaeid fishery, most bycatch in the seabob shrimp fishery is discarded.

TEDs

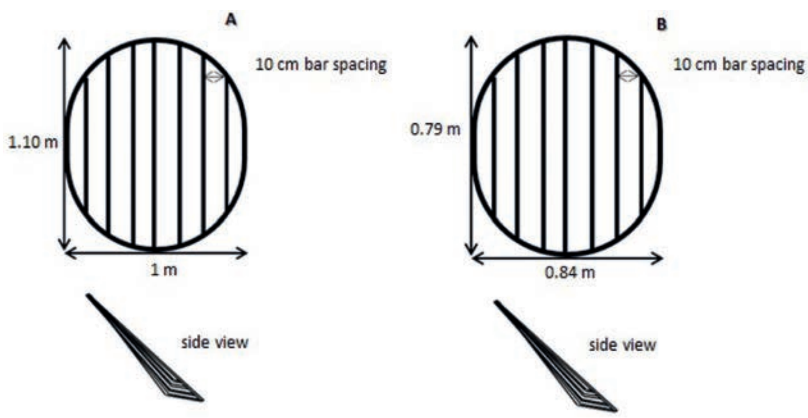
The testing of TEDs has been limited and there is no evidence of TED testing prior to their regulation in the early 1990s (Schroeder *et al*., 2016; Duarte, Broadhurst and Dumont, 2019). In 2013, a TED was tested in the pink shrimp fishery to evaluate its impact on shrimp and fish catches over a four-day period (ten hauls). The TED measured 130 cm long by 110 cm wide, with a bar spacing of 10 cm, and it was tested both as an upward and downward excluder. Overall, shrimp landings fell by 17 percent and fish landings fell by 26 percent, but as an upward excluder (four hauls) the catch of shrimp and fish was reduced by approximately 50 percent. This was the first known attempt to evaluate the performance of a TED in this fishery.

Recent TED testing as part of the REBYC II LAC project occurred in the State of Espirito Santo and the State of São Paulo, each with a minimum of 30 hauls. The smallest grid (Figure 5.B) reduced seabob and pink shrimp catches by 6 percent and 9 percent, but increased catches of white shrimp (the most valued species) by 16 percent. Bycatch reduction was not significant. In São Paulo, a bottom excluding grid measuring 110 cm long by 100 cm wide, with a bar spacing of 10 cm (Figure 5.A.), maintained pink shrimp catches and had a loss of only 6 percent of seabob, while reducing bycatch by 18 percent. Critically, the catch of endangered species such as elasmobranchs (*Squatina* spp., *Pseudobatos horkelii* and *Zapteryx brevirostris*), dropped between 20 percent and 90 percent. All devices were developed in partnership with local fishers and net makers and tested on the vessels nets.

PLATE 4
Super shooter TED sewed by net makers, fishers and researchers in São Paulo

©D. Duarte

FIGURE 5
Super shooter TED models tested in southeast and southern Brazil



Source: Dérien Duarte.

BRDs

Efforts to reduce bycatch date back to at least the mid-1980s, using square meshes in the codend on an industrial trawler (Conolly, 1992). These efforts included replacing 1N2B or 1N4B body tapers with an AB taper to reduce the overall length of the net, so that fish could swim forward and out of the trawl mouth when trawl speed was reduced for hauling. This modification reduced bycatch by 17 percent and increased shrimp catches by 5 percent compared to a standard trawl, although important experimental design details, including the number of hauls conducted, were not reported. Bycatch of small fish and commercial fish was reduced by 15 and 24 percent, respectively. Researchers and fishers also tested a square-mesh panel with 100 mm mesh netting (50 mm bar length), although overall dimensions of the panel were not described. Testing included the addition of a netting guiding panel ahead of the square-mesh panel, in order to guide shrimp and other animals towards the bottom of the codend. The guiding panel was also positioned immediately behind the square-mesh panel – presumably to reduce shrimp loss when the trawl was hauled. Each modification reduced bycatch by 23 and 48 percent respectively, although shrimp loss was as high as 27 percent.

In 2007 and 2009, researchers tested a Nordmore grid off the coast of the State of Paranáin a canoe-trawl fishery targeting *X. kroyeri* (Silva *et al*., 2011). Codend mesh size was 26.3 mm, grid area was 1 881 cm^2, and grid bar spacing was 24 mm. In one experiment, this grid reduced catches of brachyurids and teleosts by 79 percent and 50 percent, respectively. In subsequent experiments, the efficacy of several grid modifications were evaluated, including an increase in grid area, reduction in the length of the extension piece (netting between trawl body and the grid), variation in bar diameter, and presence/absence of a guiding panel. These modifications did not improve bycatch reduction performance compared to that measured in the first experiment, and they had little impact on the catch of *X. kroyeri*. Subsequent research evaluating the efficacy of 24 mm, 20 mm, and 17 mm bar spacing realized a 75, 95, and 97 percent reduction in brachyurids by weight respectively (Silva *et al*., 2012). Catches of *X. kroyeri* were unaffected by these modifications.

As part of the REBYC-II LAC project there have been significant efforts to reduce bycatch in many shrimp fisheries in Brazil. This includes testing a codend square-mesh panel measuring 60 cm long by 50 cm wide (x 3) in the State Pará by industrial trawlers. The bar length for each square mesh was 6 cm and the panel was located approximately 2 m from the drawstrings. Based on 33 hauls, the device resulted in a 40 percent reduction in bycatch, under normal fishing conditions, substantially reducing the catch of King weakfish (*Macrodon ancylodon*), without loss of shrimp. Subsequent efforts using this device in the same region resulted in a 47 percent bycatch reduction without loss of shrimp, including a 70 percent reduction in discards. An important result was the retention of larger shrimp specimens, which have a higher economic value (FAO, 2020a, unpublished data).

Around the same time, five BRDs were tested by artisanal trawlers in the State of Pernambuco, including a square-mesh panel in the trawl body (n = 27 tows), a fish-eye (n = 15 tows), a square-mesh in the codend (n = 29 tows), a grid (n = 37 tows) and a fish-eye with square meshes in the codend (n = 130 tows). Since the income from white shrimp catches represents 80 percent of the total shrimp catch, which also includes the pink shrimp and the seabob shrimp, the goal was to minimize the loss of white shrimp and maximize the exclusion of bycatch. Testing the square mesh panel in the trawl body had no impact on the shrimp catch and did not reduce bycatch. The square-mesh panel in the codend, on the other hand, reduced the bycatch by 47.3 percent, but also reduced the catch of white shrimp by 31.2 percent The grid reduced bycatch 50 percent but lost about 30 percent of the white shrimp catch. The Fisheye with square meshes, however, had a 37 percent bycatch exclusion with only a 13.5 percent reduction of white shrimp – this was the best result among the five devices tested.

PLATE 5
Modified Fisheye or "Vanildo filter" for artisanal trawlers with the addition of multiple parallel rubber strips

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The rest of the devices were placed in the trawl codend. Recent unpublished efforts include a modified Fisheye to prevent the loss of shrimp and valuable bycatch, with narrow vertical rubber strips spaced approximately 10 mm apart (Plate 5). For such small boats, with low winch speed, shrimps tend to escape during net pulling; in this case, the rubber bands prevent their escape much more efficiently than that of fishes. Several fishers are now voluntarily using this BRD and anecdotal reports describing performance are encouraging (V. Oliveira, 2019, personal correspondence).

A mix of research and outreach activities provided support to fisheries management in the Environmental Protected Area of Anhatomirim (EPAA) (IUCN protected area Category VI), on the central coast of the State of Santa Catarina. These activities stemmed from the developments on bycatch reduction research on the coast of Paraná with small-scale trawlers (Guanais *et al*., 2015; Medeiros *et al*., 2013). Fishers prioritized bycatch reduction as one of the management objectives in drafting the management plan for the EPAA, issued in 2013 (Macedo *et al*., 2019).

As a follow-up, researchers and fishers collaborated to find an appropriate BRD for trawl fisheries operating within the EPAA. From 2012 to 2017, 229 one-hour hauls tested different combinations of Nordmore Grids (space bar distance 17 mm, 24 mm, 30 mm), square-mesh webbing on codend, square-mesh escape panels on codend, and complementary net modifications such as a codend with painted webbing, and a "balloon" designed by a local net maker. Considering all BRDs demonstrated in the EPAA, scientific experiments assumed three bycatch excludability levels, considering high, medium and low discard rates. The G17 net has a 17 mm space aluminium Nordmore Grid (750 mm by 50 mm), significantly reduced discards by 65.2 percent ($n = 39$, U-test, $p < 0.001$), otherwise reducing shrimp catch (25 percent) (not significantly). The modified net using a "balloon" and a square-meshed codend, named BALMQ, increased the shrimp catch by 13 percent ($n = 30$, not significant) with an insignificant reduction on discards (13.22 percent). The G30 tested a 30 mm space aluminium Nordmore Grid (750 mm by 50 mm) increased shrimp catch by 30 percent ($n = 30$, t-test, $p = 0.207$) and reduced bycatch by 41 percent ($n = 30$, t-test, $p = 0.08676$). After evaluating the results, fishers approved the results from the G17 and BALMQ nets but rejected the G30 results due to the loss of byproducts, including white shrimp. These results remain unpublished but were delivered as part of the REBYC-II LAC project's annual reports.

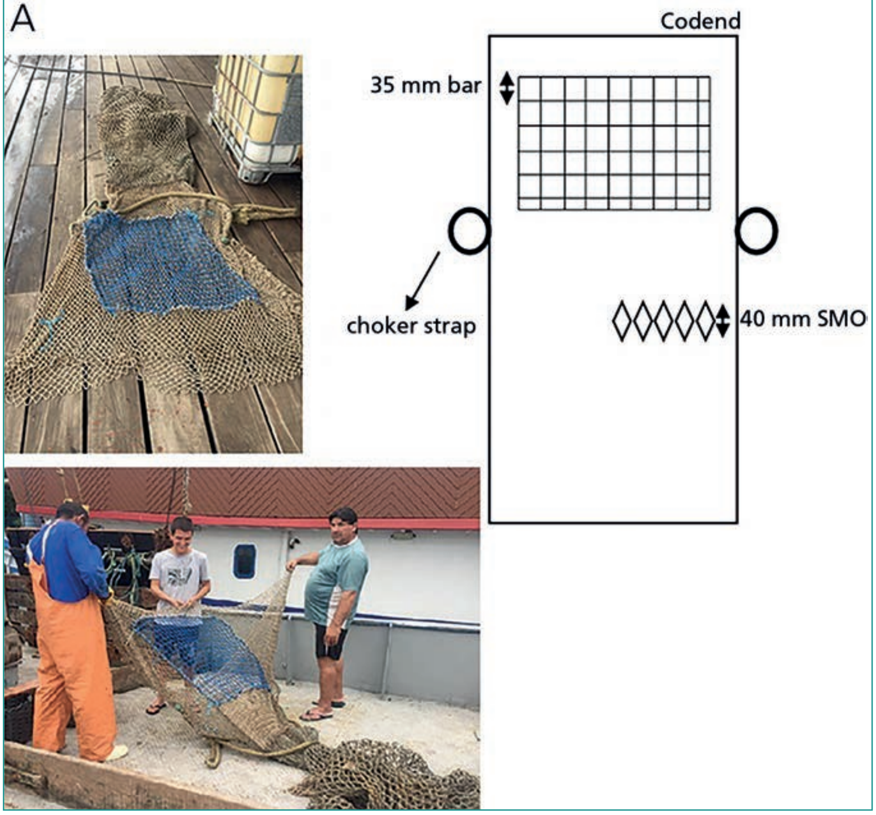
TABLE 4
Percentage of capture of shrimp, byproduct and bycatch of the net with BRD in relation to the control net for the tests carried out with the fleets of the State of Santa Catarina

Shrimp fishery	N Hauls	Diamond mesh (SMO)	Square mesh (bar size)	% Shrimp	% Byproduct	% Bycatch
Artisanal						
Seabob shrimp	30	24 mm	30 mm	5.5	-	↓ 25 *
Seabob shrimp	30	26 mm	25 mm	↓ 4	↓ 10	↓ 8.5
Industrial						
Pink shrimp	28	40 mm	35 mm	↓ 6	↓ 12	↓ 10
Seabob shrimp[1]	30	26 mm	24 mm	↓ 11	↓ 21	↓ 19 *

N hauls = number of hauls each test; SMO = stretched-mesh opening; * Statistical difference ($p < 0.05$) [1] Plate x5, net design.

Outside the EPAA, but still in the State of Santa Catarina, researchers and fishers tested four different types of codend bar square-mesh panels on industrial and artisanal fleets (Table 4). All panels were fitted to the initial part of the top codend (first one third of the codend, Plates 6). Two tests showed a significant reduction in bycatch, while shrimp losses were not greater than 11 percent. Although there was a small reduction in the shrimp catch, this loss was compensated in most cases by the increase in the size of the shrimps caught although these results require revision. They remain unpublished but were submitted to the REBYC-II LAC Steering Committee in 2019 and will be published in 2021. All devices were developed in partnership with local fishers and net makers and tested on the vessels nets.

PLATE 6
Square-mesh window (35 mm bar spacing) located in the initial portion of a pink shrimp codend used by the Santa Catarina industrial fleet



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In the same State, partners tested the novel Kite Escape Device (KED) (Vieira *et al*., 2017), which features a panel of square-mesh netting attached to the lower part of a Fisheye. The square-meshes measured 66 mm in stretched mesh, while the escape opening of the Fisheye measured 35 cm wide by 15 cm high. This BRD was placed 105 meshes from the end of the codend. Codend mesh size was 20 mm. The KED was tested for six hauls and reduced fish bycatch by 75 percent but requires additional hauls to confirm results.

In the State of Paraná, following lessons from EPAA and considering the low dependence on bycatch, researchers and fishers designed a net called a G17 with 17 mm bar spacing and a Nordmore grid (Plate 7). In contrast to the net from Santa Catarina, this net featured an opening cover instead of a guiding panel. Such a change was necessary since fishers hauled the net onboard by hand, which often causes shrimp loss (Cattani *et al.*, 2012). Despite shrimp loss, fishers showed interest in using the G17 in daily fishing, noting that it was "worth losing some shrimp for the reduction in discards.

TABLE 5
G17 net performance in Paraná

Parameters tested	Control	G17	Statistical significance
Shrimp (kg)	5.21	4.61(11.50%)	t-test (p = 0,3464)
Bycatch (kg)	12.61	4.60 (-63.56%)	U-test (p < 0.001)
Total length (mm)	**88.37**	**89.43 (+1.20%)**	**t-test (p = 0.01729)**

Tests conducted with a 18 hp engine double-rigged trawler, using a 10-metre foot rope trawl net. Grid dimensions: 630 mm x 420 mm, grid angle: 53°.

PLATE 7
Nordmore grid used in the State of Paraná, Brazil

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Regulations

Efforts to mandate TED use by the industrial trawl fleet started in the early 1990s, although their adoption by fishers was poor. In 2004, new regulations were introduced based on similar requirements for the United States of America (da Silva *et al*., 2010; Duarte, Broadhurst and Dumont, 2019). These regulations specifically related to the minimum grid width (≥ 81 cm), bar spacing (≤ 10 cm), the dimensions of the escape opening (width: ≥ 142 cm; length: ≥ 51 cm), the width and length of the escape cover (≥ 228 cm), the minimum guiding panel length (≥ 228 cm), and a grid angle of between 30 and 55 degrees. Adoption by fishers remains poor owing to a perceived lack of evidence regarding the need for TEDs and inadequate performance information. Industrial fishers were granted 180 days to test and implement TEDs prior to their use becoming mandatory. Artisanal trawlers of less than 11 m are not required to use a TED.

BRDs are not in use and there are no regulations associated with bycatch reduction (Hazin, 2017). In the industrial fishery fishers often use 26 mm codends, although 30 mm is the minimum regulated (Duarte *et al*., 2018). All industrial shrimp fishing is prohibited in the south and southeast of Brazil between March and May, in accordance with Normative Ordinance No. 189/2008 (IBAMA, 2008). Rio Grande do Sul, banned industrial trawling within 12 nautical miles of the shore all year around (OCEANA, 2018) but the Supreme Court of Brazil overturned this law (STF, 2020). Research and outreach activities supported by REBYC led to the inclusion of BRDS in the EPAA management plan, and the local fishery regulation in its marine zoning (Guanais *et al*., 2015; Macedo *et al*., 2019). Fishers, researchers and managers are currently working together to develop agreements to regulate and implement recommendations derived from the gear tests supported and developed through the REBYC-II LAC project.

Outreach and extension

Recently, researchers (Duarte, Broadhurst and Dumont, 2019) surveyed 19 shrimp trawler captains in Rio Grande, Rio Grande do Sul and Itajaí, Santa Catarina, to understand their attitude towards adopting and implementing TEDs and BRDs. Of the 19 captains surveyed, 13 of these indicated they had never tried a TED despite their use being mandatory (researchers hypothesized the other six may have lied about using a TED due to fear of prosecution or embarrassment). A fear of losing shrimp or income were the main reasons for not using TEDs. Other issues included a lack of technical expertise to rig and operate a TED, fear of grid blockage, fear of net damage and disagreement with TED design. Most captains believed TEDs are unnecessary because turtles are rare in their fishery and are released alive following capture. By contrast, fishers retain elasmobranchs for sale and the fear of losing these by using a TED dampened their enthusiasm for the devices. It remains unclear how many of the technical problems cited by these individuals are real or perceived, particularly when so few have used a TED. This evidence suggests that outreach and extension efforts to date have been insufficient, and that in the absence of any significant MCS capability their behaviour is understandable. When fishers do use TEDs there is clear evidence they are doing so incorrectly. Locally made TEDs with inconsistent bar spacing (Plate 8), an incorrect grid

PLATE 8
Locally built TED with inconsistent bar spacing. Brazil

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angle and excessively stretched escape covers (Plate 9) all suggest that fishers lack the skills to operate and maintain these devices correctly to ensure optimal performance. This suggests an urgent need for improved outreach and extension efforts and a strengthening of MCS capability (Hazin, 2017). Outreach, besides demonstrating the use of BRDs, includes assisting fishers on installing the devices and on evaluating results from their use.

The above issues notwithstanding, the combined experience of research and outreach efforts led by the REBYC–II LAC Project have already yielded very positive results, creating opportunities for the engagement and stewardship of fishers. For example, one of the project partners, a local fisher and net maker, developed a PVC Nordmore Grid (Plate 10) with the aim of making the grid affordable to fishers at a low price. From sharing his experience using the G17 net on his social media (Facebook), more fishers showed interest in testing it (Plate 11). With support from REBYC-II LAC, a series of videos on a YouTube channel (youtube.com/saberesmarinhos) motivated fishers to build their own PVC Nordmore Grid. At the time of publication, about 20 fishers were using this grid voluntarily, and it is the first documented experience in Brazil where fishers have taken the initiative to develop and use BRDs by themselves.

PLATE 9
Excessively stretched escape opening

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PLATE 10
Development and installation of a PVC Nordmore Grid by a fisher from Paraná

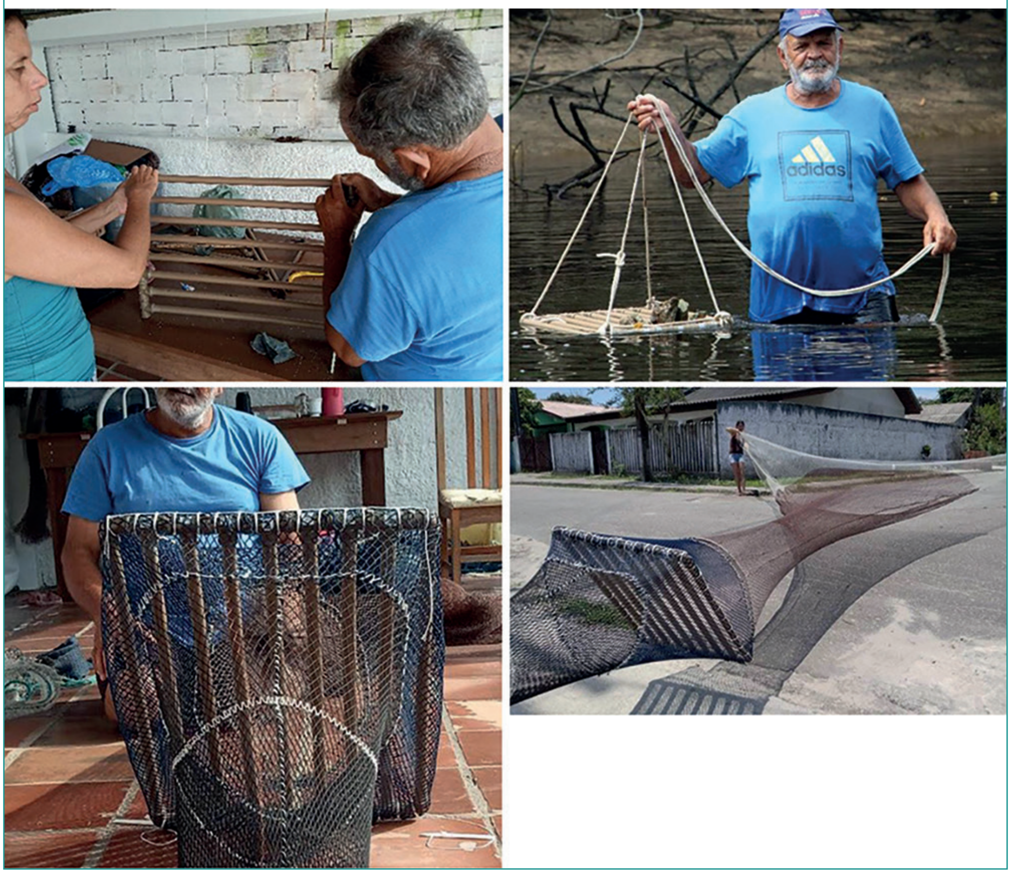

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PLATE 11
A fisher installing his own PVC Nordmore grid (left) and showing his satisfaction after testing it with the assistance of the REBYC team (right)

©R. Pereira Medeiros

3.3 COLOMBIA

Shrimp trawling in Colombia started in 1956 on the Pacific coast (Rueda, 2007) and in 1972 in the Caribbean Sea (Rueda *et al*., 2006). The maximum landed annual shrimp catch in the Caribbean Sea was 2 200 tonnes in 1986, with an average catch of 1 090 tonnes until 2019. However, since 2014 annual landings have not exceeded 200 tonnes. The shrimp catch is dominated by *Farfantepenaeus notiales* (96 percent) a shallow-water species, followed by *F. subtilis, Litopenaeus schmitii* and *Xiphopenaeus kroyeri*. In the Caribbean shrimp fishery, the main landed bycatch is *Lutjanus synagris* (13 percent) and *Bagre marinus* (10 percent) (Rueda and Escobar, 2014). Landed bycatch also includes *Upeneus parvus*, while discards are dominated by *Lupella forces*, *Diapterus rhombeus*, and *Porichthys plectrodon* (Rueda *et al*., 2019).

On the Pacific coast, the shrimp catch in the shallow-water fishery is dominated by *L. occidentalis* (71 percent) and *X. riveti* (16 percent) (Rueda and Escobar, 2014). The maximum landed catch was 1 020 tonnes in 1960, with an average of 372 tonnes until 2019. However annual landings have not exceeded 200 tonnes since 2009. Here, *Pomadasys panamensis*, *Diapterus peruviana*, *Selene peruviana* and *Polydactylus aproximatus* dominate the retained bycatch of the shallow-water fishery, while discards are dominated by *Selene peruviana*, *Chloroscombrus orqueta*, *Cetengraulis mysticetus* and *Cyclopsetta guerna* (Rueda *et al*., 2019). In the Pacific coast deepwater fishery, the shrimp catch is dominated by *Farfantepenaeus brevirostris* (60 percent), *Solenocera agassizi* (34 percent) and *F. californiensis* (6 percent). The maximum catch was achieved in 2006 (1 208 tonnes) with average catch of 683 tonnes until 2019. The landed bycatch is dominated by *Peprilus medius*, *Larimus pacificus*, *Peprilus snyderi* and *Cynoscion* spp., while discards are dominated by *Peprilus medius*, *Cynoscion spp*., *Ophichthus reminger* and *Trichiurus lepturus*.

Annual estimated bycatch from all shrimp fisheries was around 7 000 tonnes (Duarte, Manjarres and Escobar, 2010), although an almost 90 percent drop in fishing effort has now reduced discards to less than 50 tonnes annually (Rueda *et al*., 2019). The overall landed bycatch of fish from these fisheries is 43 percent (Caribbean) and 27 percent (Pacific) of the total catch, and total discards are approximately 52 percent and 65 percent respectively (Duarte, Manjarres and Escobar, 2010). The deepwater shrimp fishery on the Pacific coast provides a different picture, where the target shrimp is approximately 66 percent of the total catch, while bycatch amounts to 2 percent and discards approach to 32 percent (Rueda *et al*., 2019). Mesh size in the trawl body is typically 50.4 mm and 44.5 mm in the codend (Escobar, Duarte and Rueda, 2016).

TEDs

A TED with and without a Fisheye was tested as part of the FAO/UNEP/GEF project (REBYC I) (Table 4) but it performed poorly, with significant losses of shrimp and commercial fish (Rueda, 2007). On the Pacific coast the TED was designed with an oval upper section and square lower section (tombstone-shaped), measuring 132 cm by 102 cm with a bar spacing of 95 mm (Rueda *et al*., 2006). Grid bars were bent 45 degrees near

the escape opening in order to help weed and other debris pass through it. The TED tested in the Caribbean Sea was a Super Shooter, measuring 1.295 m by 1.067 m, with a bar spacing of 100 mm.

BRDs

In 2005, a Fisheye measuring 32 cm wide and 22 cm high was tested both with and without a Super Shooter TED, over two different testing periods (Table 5) (Garcia *et al*., 2008; Manjarres *et al*., 2008). Total landings of bycatch fell significantly when both were tested simultaneously, as did landings of *F. notialis* and *X. kroyeri.*

As part of the REBYC-II LAC project, the performance of a square-mesh panel measuring 40 meshes long by 40 meshes wide was evaluated in the fisheries on the Pacific coast and in the Caribbean Sea (Table 6) (Escobar and Rueda, 2018). The size of the mesh was 50.8 mm, and data was collected from 30 paired tows for each location. There was no significant difference in the catch of either shrimp or incidental species in all three testing locations, and discards were reduced by an average of 31 percent.

Additional research efforts included comparing catch rates between a traditional trawl and one with an increased mesh size in the trawl wings and body. The traditional trawl was constructed with a mesh size of 50.8 mm in the wings and body, while the codend mesh size was 44.5 mm. The modified trawl was constructed with a mesh size of 57.2 mm in the wings and trawl mouth, and 50.8 mm in the trawl body. Shrimp catch significantly increased in the Caribbean Sea but there was no significant difference on the Pacific coast, in both the shallow and deepwater fisheries. There was a modest reduction in incidental catch but a significant reduction in discards in all areas tested.

Biological, social and economic baselines for these fisheries are systematized in the Colombian Fisheries Statistics System (SEPEC), which allows researchers and government officials to track the impact of bycatch management measures, and adjust norms and regulations as necessary. With this data, officials have seen a 46 percent reduction in discards since the introduction of BRDs and a 24 percent reduction in fuel consumption (M. Rueda, personal correspondence, 2020).

TABLE 6
Catch reduction (percent) for each TED and BRD combination compared to a standard trawl in Colombia

Region	Catch type	BRD		
		Fisheye	TED	Fisheye + TED
Caribbean	Shrimp	5.2	22.5	23.3
	Fish	30.0	20.7	49.5
	Discards	18.7	50.6	57.7
Pacific	Shrimp	11.0	7.0	12.0
	Fish	35.0	44.0	78.0
	Discards	40.0	22.0	59.0

TABLE 7
Mean catch rates and standard error (kg h^{-1}) using data from four treatment codends during two separate testing periods (N = haul number)

Catch	Test	N	Treatment			
			Control	TED	BRD	TED/BRD
Shrimp	1	43	1.93 (0.10)	1.50 (0.09)	1.70 (0.10)	1.33 (0.09)
	2	31	1.56 (0.06)	1.20 (0.05)	1.48 (0.07)	1.17 (0.05)
Bycatch	1	39	11.74 (0.52)	9.70 (0.57)	8.91 (0.41)	7.41 (0.37)
	2	27	12.51 (0.88)	7.49 (0.59)	9.28 (0.56)	5.46 (0.42)
Commercial fish	1	40	2.29 (0.19)	2.12 (0.24)	1.50 (0.13)	1.60 (0.16)
	2	30	3.49 (0.38)	3.20 (0.32)	2.39 (0.21)	1.70 (0.18)
Discards	1	43	9.47 (0.44)	7.90 (0.48)	7.25 (0.35)	5.70 (0.29)
	2	28	9.73 (0.86)	4.73 (0.46)	7.38 (0.58)	4.14 (0.45)

TABLE 8
Comparison of catch per unit area (median in kg/km²) from two treatments in three locations

Catch	Location	Treatment		P value
		Traditional net without BRD	Traditional net with BRD	
Shrimp	Caribbean	18.3	20.2	P > 0.05
	Pacific (S)	131.7	102.5	P > 0.05
	Pacific (D)	705.9	470.5	P > 0.05
Incidental catch	Caribbean	39.7	35.1	P > 0.05
	Pacific (S)	215.9	188.1	P > 0.05
	Pacific (D)	49.2	37.3	P > 0.05
Discards	Caribbean	110.6	59.5	P < 0.05
	Pacific (S)	922.1	790.3	P < 0.05
	Pacific (D)	786.5	524.3	P < 0.05

S: shallow-water fishery; D: deepwater fishery.

Regulations

Since 1994, TEDs have been mandatory in Colombia's bottom trawl shrimp fisheries (Clavijo, Altamar and Manjarres, 2006; Westlund, 2006; Zuniga, Altamar and Manjarres, 2006). Efforts are also underway to regulate the use of BRDs (Rueda, 2007), although there is limited MCS activity and no requirement for fishers to report bycatch (Duarte, Manjarres and Escobar, 2010). Other related regulations include a trawling ban within a specified distance from the shoreline.

Supported by the REBYC-II LAC Project, Colombia has improved its institutional and regulatory frameworks for shrimp trawling. This includes a Management Plan for bycatch in the shrimp trawl fishery (Escobar *et al.*, 2020) aligned with the International Guidelines on the Management of Bycatch and Discards, which was published and adopted by the Fisheries Authority (AUNAP) through Resolution 2587 of 23 December 2020 (AUNAP, 2020). The plan calls for the improved implementation of TEDs and the development of appropriate BRDs, in collaboration with fishers and stakeholders.

AUNAP Resolution 02111 of 2017 enforces the fishing agreements between industrial fishing fleets and local stakeholders, while the Agreement's Monitoring Committee (Resolutions 970 of 2019 and 837 of 2020) provides support for bycatch reduction measures, including the appropriate use of TEDs.

Additionally, AUNAP Resolution 1970 of 2018 (updated in 2020 with Resolution 035) led to the creation of the National Committee for the co-management of incidental catches, which provides recommendations for regulations on the development, use and monitoring of TEDs and BRDs, among other things.

Outreach and extension

Besides the REBYC and REBYC-II LAC projects, there is limited literature on outreach and extension work. During the FAO/UNEP/GEF project (REBYC), several workshops were held for fishers, which provided training in trawl net design and bycatch reduction (Rueda, 2007). The high level of engagement by fishers in this project (Hermes, 2009) suggests outreach efforts have been successful and comprehensive. Outreach and extension was also expansive in the case of REBYC-II LAC, reaching both industrial and artisanal trawl fisheries. This included construction workshops, participatory testing and joint net development, as well as the effective participation of fishers in consultative processes to develop the bycatch management plan and subsequent AUNAP resolutions (Escobar and Rueda, 2018).

Many of the recommendations from REBYC-II LAC were incorporated into administrative acts that institutionalized co-management initiatives as well as traditional management measures for these bottom trawl fisheries. Nevertheless, bycatch reduction outreach and extension programmes that are independent from international development projects are still under development.

PLATE 12
Installation of the square-mesh window on the prototype net

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3.4 COSTA RICA

Trawling for shrimp in Costa Rica commenced in the 1950s (Wehrtmann and Nielsen-Munoz, 2009) and by the 1990s approximately 70 trawlers were landing 2 000 tonnes of shrimp annually on the Pacific coast (FAO, 2000). In decreasing order by volume, shrimp landings are dominated by *Solenocera agassizii*, *Penaeus occidentalis*, *P. vannamei*, *Heterocarpus vicarious*, *P. brevirostris*, *Xiphopenaeus riveti*, and *H. affinis* (Wehrtmann and Nielsen-Munoz, 2009). Bycatch is estimated at 3 000 tonnes per year, of which nearly 70 percent is discarded (FAO, 2000).

Costa Rica's Supreme Court banned the issuing and renewal of bottom trawl fishing licences in 2013 pending improvements in bycatch reduction technology and requested that updated legislation reflect these improvements. At the time of writing, Costa Rica's National Assembly had approved an updated law to mandate bycatch reduction devices and other management measures. The President of Costa Rica vetoed this Law and so the fishery remains suspended.

TEDs

TEDs are used with a maximum bar spacing of 15.2 cm (Gearhart *et al.*, 2015). During testing in the United States of America this TED excluded five of six juvenile leatherback turtles exposed to the grid, with an average escape time of 83.5 seconds. Costa Rica is the only country that can export shrimp to the United States of America caught in a net with a TED featuring maximum bar spacing of 15.2 cm.

BRDs

Some recent studies have alluded to tests conducted with a Fisheye and square-mesh window (Hermes, 2009; FAO, 2017b). Details of this testing have not been found, however – although fishers did show the authors pictures suggesting that some vessels had been using a Fisheye device for several years, up until the suspension of the fishery. Nevertheless, these claims do not seem to have been recorded in any publication.

Regulations

TEDs are mandatory when fishing in coastal waters of less than 80 fathoms deep (FAO, 2000). Vessels must also carry two replacement TEDs at all times. Since 2013, Costa Rica regulation AJDIP/453-2013 mandates the use of Fisheye bycatch reduction devices on industrial shrimp trawlers. However, the regulation does not specify the exact location of the device beyond the top of the codend. This means that fishers could place it far in front of the catch, diminishing its effectiveness.

In 2013, the Constitutional Court of Costa Rica suspended the issuance of new bottom trawl fishing licenses and prohibited the renewal of existing licenses once they expired. The Court found that these licenses violated Costa Rica's Constitutional principle for democratic sustainability as a result of what it understood as the activity's negative environmental consequences. In particular, it highlighted both the impacts on the seabed and the high levels of bycatch as the main sustainability issues connected to

bottom trawling. The Court further noted that the issuance of licenses for this fishery could resume when it had received appropriate scientific evidence on the sustainability of bottom trawling, accompanied by an updated legal framework. In 2020, the National Assembly of Costa Rica passed a new Law for the Sustainable Use of Shrimp Fisheries in Costa Rica. This legislation mandated the reduction of bycatch to the greatest extent possible, based on technical criteria approved by the Costa Rican Fisheries and Aquaculture Institute (INCOPESCA). Citing technical shortcomings and a lack of evidence regarding the reduced environmental impact the Law was subsequently vetoed by the President of Costa Rica. At the time of writing, bottom trawling remains suspended in the country and bottom trawl gear is de facto banned.

Outreach and extension

Costa Rica participated in the FAO/UNEP/GEF project (REBYC) and the GEF/FAO (REBYC-II LAC) projects. Training activities and workshops were a key activity when building capacity and raising awareness (Hermes, 2009). As part of their engagement in the recent REBYC-II LAC project, there have been significant attempts to provide fishers with information related to managing bycatch and reducing discards (FAO, 2019b). This includes training over 160 fishers in the options available to them to reduce bycatch.

3.5 FRENCH GUYANA

The shrimp fishery commenced in the 1950s, with the arrival of shrimp trawlers from the United States of America (Chaboud and Vendeville, 2011). The fishery presently targets two main species: brown shrimp (*Farfantepeneus subtilis*) and pink spotted shrimp (*F. brasiliensis*) (FAO/Western Central Atlantic Fishery Commission, 2000; Martinet and Blanchard, 2009). Landings are dominated by *F. subtilis* (Chaboud and Vendeville, 2011) which now represents more than 85 percent of all shrimp landings (Sanz *et al*., 2017). Over 80 percent of the catch is discarded, while the remainder is comprised of shrimp and valuable fish (Chaboud and Vendeville, 2011).

TEDs

Efforts to test TEDs included a comparison between a Super Shooter with a bar spacing of 102 mm and a trash and turtle exclusion device (TTED) with a bar spacing of 50 mm (Plate 13). The TTED was designed to exclude sharks, rays and fish from the trawl in addition to sea turtles. Based on the comparison, the TTED retained no sea turtles (Nalovic, 2014). It also reduced elasmobranch bycatch by up to 99 percent in comparison to the Super Shooter when tested in the United State of America under controlled conditions. When tested locally, it reduced total bycatch by an average of 30 percent without loss of shrimp and large animal bycatch by as much as 91 percent (WWF, 2010).

PLATE 13
The TTED used in French Guyana

©T. Nalovic (French Guiana Regional Fisheries Committee)

BRDs

Efforts to reduce the bycatch of fish and other species, other than research with a TTED, are unknown. Anecdotal evidence suggests that some vessels have voluntarily tested and adopted BRDs of their own creation, but they have been neither formally tested nor published (T. Nalovic, personal communication, 2019).

Regulation

The shrimp catch is controlled using TACs and limiting the number of trawlers, and a minimum codend mesh size of 45 mm is used in order to reduce the catch of small animals (FAO, 1999.). The presence of other gear regulations to minimize bycatch is unknown, and there are ongoing calls for the introduction of TED regulations in European Union markets similar to those in the United States of America (Leslie *et al*., 2018). Currently, French Guyana is considered to have an effective sea turtle protection programme and can export shrimp to the United States of America.

Outreach and extension

As a result of collaborative testing, fishers have adopted the TTED voluntarily as a standard part of their fishing gear (Virginia Sea Grant, 2013), although details describing how information was shared with fishers – and other related outreach and extension efforts – are unknown. Nevertheless, voluntary adoption of the TTED suggests that fishers were adequately informed and accepted the need to reduce bycatch, particularly as they have now requested mandatory use of this device (Leslie *et al*., 2018).

3.6 GUYANA

The bottom trawl shrimp fishery commenced in the late 1950s (MacDonald *et al*., 2015), targeting brown shrimp (*Penaeus subtilis*), pink-spotted shrimp (*P. brasiliensis*), pink shrimp (*P. notialis*), and white belly shrimp (*Nematopalaemon schmitti*) (FAO/Western Central Atlantic Fishery Commission, 2000; FAO, 2005; MacDonald *et al*., 2015). Bycatch and discards include juvenile croakers, snapper, as well as squid, lobster and other species. Total shrimp production is around 1 000 tonnes annually (FAO, 2013).

In the early 1980s, some bottom trawlers started targeting seabob shrimp (*Xiphopenaeus kroyeri*) and several species of finfish (MacDonald *et al*., 2015), opening a new fishery. About 88 industrial trawlers are currently licensed to operate in this fishery, landing around 15 000 tonnes of seabob shrimp annually (Garstin and Oxenford, 2018). Seabob trawlers use a TED and a square-mesh panel BRD, and their efforts to reduce bycatch is one of the critical elements for which they received Marine Stewardship Council certification in 2018 (Willems, 2018). An inshore artisanal fishery, comprising around 1 200 vessels, also lands seabob shrimp plus a variety of fish species, although most seabob is landed by the industrial fleet and exported to the United States of America and the European Union. Bycatch in this fishery includes penaeid shrimp and juvenile fish (CRFM, 2006). Traditionally, approximately 25 percent of the total catch has been discarded (MacDonald *et al*., 2015).

TEDs

The industrial seabob trawl fleet typically uses an oval-shaped TED measuring 860 mm by 1 070 mm (Garstin and Oxenford, 2018). Bar spacing does not exceed 102 mm, although some fishers use a bar spacing of 89 mm. The bars of the grid have a diameter of 13 mm. A detailed comparison between several bottom-excluding TEDs, each with a different bar spacing, reported that a TED with a 45 mm bar spacing reduced the elasmobranch catch by 40 percent when compared to TEDs with the larger bar spacing (Garstin, Oxenford and Maison; 2017). The mean disc-width of rays caught was significantly reduced by the TED with the smaller bar spacing, although the overall composition of elasmobranchs was unchanged. The impact of these TEDs on sea turtles was not reported, presumably because none were encountered by the gear.

BRDs

In both fisheries (Penaeid and seabob) the industrial trawl fleet uses a trawl with a 40–50 mm mesh size and a codend with a 25–35 mm mesh size (Garstin, Oxenford and Maison, 2017; Garstin and Oxenford, 2018). Fishers in both fisheries also use a square-mesh panel constructed from 100 mm stretched mesh, measuring 20 bar lengths long and 20 bar lengths wide (Garstin and Oxenford, 2018). This BRD is located on the top of the codend panel.

Regulations

There is no known mesh size regulation in the penaeid shrimp fishery (FAO, 2005a), while both a TED and a square-mesh panel are mandatory in the industrial seabob fishery. The square-mesh panel is constructed from 100 mm mesh netting measuring 20 bar lengths by 20 bar lengths (FAO, 2013; Garstin, Oxenford and Maison, 2017). The Department of Fisheries is responsible for monitoring compliance with TED requirements (CRFM, 2006), although efforts to manage these fisheries are challenged by inadequate resources and a rise in IUU fishing activity (SOFRECO, 2013).

Outreach and extension

Outreach and extension efforts to inform fishers, boat owners and others about reducing bycatch, as well as TED and BRD design and performance, are unknown. However, given the current use of these devices by fishers and associated efforts to achieve Marine Stewardship Council certification, fishers are presumably well informed and communication with other stakeholders is frequent and appropriate. Recent collaboration with fishers have included the creation of a working group to begin developing a seabob management plan; the latter includes the implementation of an inshore no-trawl zone, the adoption of CCTV cameras aboard trawlers, and the establishment of an industry code of practice (MSC, 2019).

3.7 INDIA

Shrimp trawling was introduced to India in the 1950s (Boopendranath, Prakash and Pravin, 2010). In 2011, shrimp trawling was responsible for about 60 percent of total shrimp landings, although in some regions trawling may account for over 85 percent of landings (Rajakumaran and Vaseeharan, 2014). A variety of shrimp species are targeted, including white prawn (*Penaeus indicus*), tiger prawn (*P. monodon*), pink shrimp (*Metapenaeus dobsoni*), king prawn (*M. affininis*), marine or kiddi shrimp (*Parapenaeopsis stylifera*) (Intodia, 2017), as well as green tiger prawn (*Penaeus semisulcatus*) and banana prawn (*P. merguiensis*).

Shrimp trawlers today are small-to-medium-sized vessels measuring less than 16 m in length (Madhu *et al*., 2015). While the trawl gear is designed to target shrimp, large quantities of fish bycatch, including juveniles or sub-adults of commercially valuable species are also caught (Boopendranath, 2009). Typically, the catch composition is made up of less than 35 percent shrimp, and the remainder is either discarded or used for human consumption, fishmeal, or manure (Mathew, 2004; Boopendranath, 2009; Madhu *et al*., 2015). Fish species dominate bycatch, and discards are usually comprised of juveniles of commercially important species, or animals of no commercial value (Madhu *et al*., 2015). Boopendranath *et al*. (2012) provides a detailed summary of the magnitude of bycatch in the shrimp fishery, while Madhu *et al*. (2015) provides a description of studies quantifying bycatch and discards.

Attempts to reduce bycatch date back to the 1970s (Davis *et al*., 2009), although interest in the field accelerated from the mid-1990s onwards (Mathew, 2004; Boopendranath *et al*., 2006; Roa, 2011), partly as a response to the embargo on shrimp imports into the United States of America from countries where approved TEDs were not being used. Greater interest was also driven by concerns that many bycatch species were being overfished, notably as a result of the sharp decline in catch rates, which sometimes fell by more than 80 percent in just a few years (Mohamed *et al*., 2009). The Central Institute of Fisheries Technology (CIFT) set up a bycatch reduction programme that has included TED and BRD testing on research and commercial fishing vessels, training workshops, conferences, publications, and outreach programmes aimed at fishers and others. The programme identified three key approaches to bycatch reduction: i) reduce fishing effort, ii) use BRDs, and iii) introduce bycatch limits and other management actions. In addition, the partners involved identified a need to develop a shrimp-specific trawl similar to that used in other countries (Boopendranath, 2007).

TEDs

In the mid-1990s, CIFT tested a Super Shooter TED of American design, using a research vessel as a testing platform (Boopendranath *et al*., 2006; Pravan *et al*., 2011). The TED measured 1.0 m by 0.9 m, with a 90 mm bar spacing, and it was configured with the escape opening in the top panel of the trawl (upward-excluding). A small codend was placed over the escape opening to retain all animals that would normally

escape capture. Six 90-minute hauls were completed, and the total catch weight was 676 kg (469 kg in the main codend). On average, this TED reduced finfish bycatch by 31 percent (range: 15–50 percent) and no turtles were encountered.

Researchers then tested a Super Shooter TED on a shrimp trawler in both an upward- and a downward-excluder configuration. As an upward excluder there was a 43 percent loss of total catch, including a 41 percent loss of demersal fish, a 51 percent loss of pelagic fish, a 35 percent loss of shrimp, and an 84 percent loss of low-value fish. As a downward excluder there was a 14 percent loss of total catch, including a 24 percent loss of demersal fish, a 43 percent loss of pelagic fish, a 1 percent loss of shrimp, and an 11 percent loss of low-value fish. Fishers did not accept the loss of demersal and pelagic fish, the majority of which is commercially valuable.

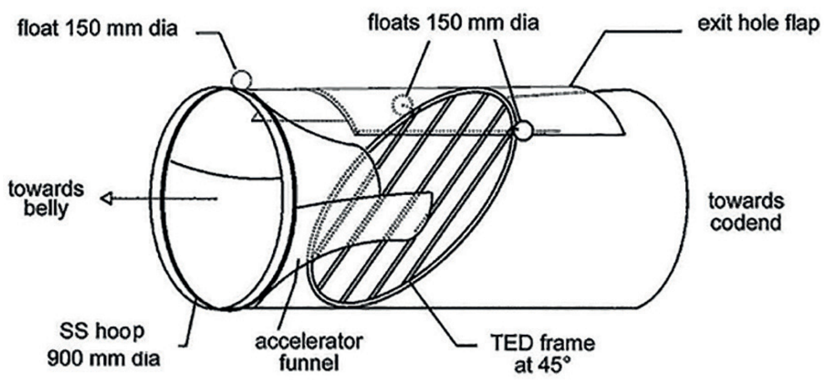
Subsequently, CIFT developed their own TED (Figure 4) measuring 1 000 mm by 800 mm, with a bar spacing of 142 mm (150 mm from the centre of the bar to the centre of the adjacent bar). It was rigged as an upward excluder at an angle of 45 degrees. A total of 19 hauls were completed on a research vessel, during which time 4 turtles were excluded, finfish loss was 3 percent, and shrimp loss was 1 percent. This was followed by testing on a commercial shrimp trawler (Prakash, Boopendranath and Vinod, 2016). After 60 hauls at a time, conducted in a location where turtles are more prevalent, the CIFT-TED excluded all turtles (capture rate averaged one for every 15 hauls) and total catch loss and shrimp loss amounted to 3 percent each. In another study, the CIFT-TED reduced total catch by 2–10 percent (Gopi, Panday and Choudhury, 2002). A total of 51 hauls were completed and all 21 turtles encountered were excluded from the trawl. Fish bycatch reduction was less than 4 percent.

In 2010 the CIFT-TED was tested off Dhamra, Odisha, and catch data from 60 hauls was collected (WWF, 2011; Prakash, Boopendranath and Vinod, 2016). Overall, shrimp loss amounted to less than 3 percent, and the non-shrimp catch averaged a reduction of 2.5 percent. The TED successfully excluded all sea turtles.

BRDs

Attempts to reduce fish bycatch date back to the 1960s, through efforts to evaluate the impact of various mesh sizes in the trawl body and codend (Madhu, 2018). Significant efforts have been made recently with regard to BRD development, notably to reduce the capture of small fish (Table 9): these include testing of the Bigeye, Fisheye, oval grid, sieve nets, square-mesh windows, a separator trawl and a locally designed JFE-SSD (Figure 6). A detailed history of bycatch reduction efforts is provided in Madhu (2018), including comments regarding the problem of inconsistent experimental design, data analysis and information transfer.

FIGURE 6
The CIFT-TED



Source: CIFT (2003).

TABLE 9
BRD performance summary

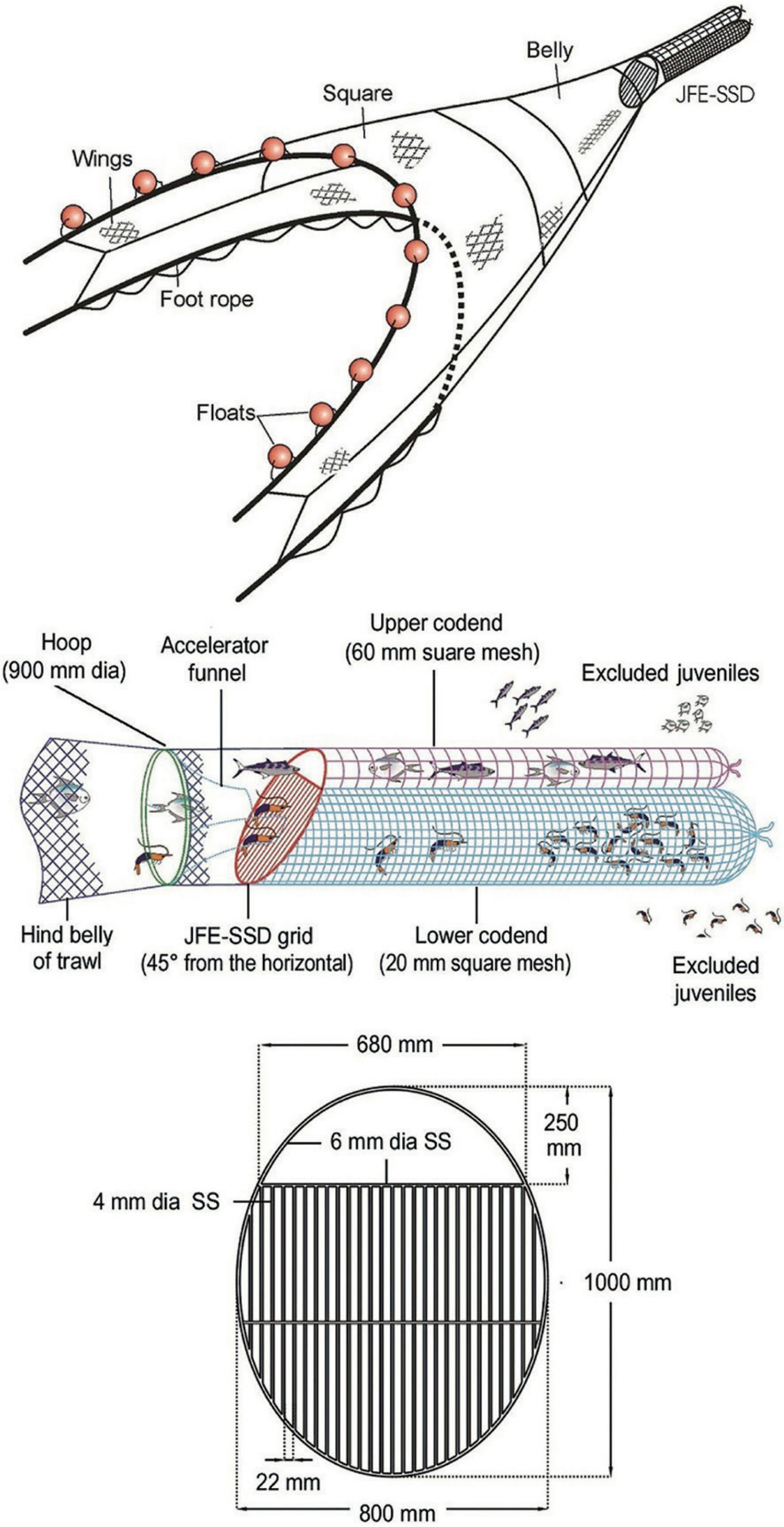
Type	Specifications	Results (percent)	
		Bycatch	Shrimp
Bigeye		8–37	2–4
Fisheye	300 x 200 mm semicircular (horizontal orientation)	46–63	1–4
	300 x 200 mm oval (horizontal orientation)	46	5
	300 x 200 mm oval (vertical orientation)	26	45
Flat grid	Oval grid; 1 000 x 800 mm; 45º; 22 mm bar spacing	64	10–13
	Rectangular grid; 1 000 x 800 mm; 45º; 22 mm bar spacing	54	10–13
	Oval grid; 1 000 x 800 mm; 45º; 26 mm bar spacing	58	8
Sieve net	60 mm diamond mesh funnel + 80 mm diamond mesh outlet codend	37	5
	50 mm diamond mesh funnel + 60 mm diamond mesh outlet codend	33	19
Oval grid	1 000 x 800 mm; 4 mm dia. s/steel rod; 45 degrees; 26 mm bar spacing	58	6–8
JFE-SSD	1 000 x 800 mm; 4 mm dia. s/steel rod; 45 degrees; 26 mm bar spacing; 60 mm square-mesh upper codend; 20 mm square-mesh lower codend	43	5

Source: Boopendranath *et al.* (2008); Sabu, Gibinkumar and Boopendranath (2011).

The Bigeye consisted of a 0.3 m opening cut in the upper panel of the codend, approximately 1.5 m before the rear extremity of the codend (Boopendranath *et al*., 2012; Sabu, Gibinkumar and Boopendranath, 2011). The opening of the Bigeye was maintained by use of flotation attached to the rear edge of the slit, with weights added to its leading edge. As the catch entered the codend, fish were able to turn and swim through the escape opening. This BRD achieved bycatch reduction rates as high as 37 percent, with only a 4 percent loss of shrimp (Boopendranath, 2012). Several different Fisheye BRDs have also been tested with good success (Table 9). This device consists of an oval or semi-circular framework constructed of aluminium or stainless-steel rods of 4–6 mm in diameter, which is positioned in the codend ahead of the accumulated catch (Boopendranath *et al*., 2008), in a similar location to the Bigeye (Boopendranath *et al*., 2012). Oval grids, based on the Nordmore grid design, were also found to be very effective, although shrimp loss was excessive and clogging by plastic and vegetation was observed (Boopendranath *et al*., 2013).

The JFE-SSD consisted of an oval, upward-excluding grid rigged at 45 degrees. In this device, a netting funnel guides the catch toward the bottom of the grid, which has a bar spacing of 22 mm. Shrimp and other small animals pass through the grid and are retained in a square-mesh codend. The mesh size of the codend was 20 mm. Larger animals are guided through an opening in the top of the grid measuring 250 mm by 680 mm. These animals enter a second square-mesh codend with a mesh size of 60 mm, through which small finfish and other animals can escape. This device was tested on a research vessel and catch from 31 one-hour hauls was retained (Boopendranath *et al*., 2013). From a total catch of 317 kg, 58 percent was retained in the lower codend and 18 percent in the upper codend. Meanwhile, 24 percent was excluded from the upper codend and retained in a small-mesh cover net specifically placed over the upper codend to retain escaping animals. Almost 97 percent of the shrimp catch was retained in the lower codend, and shrimp loss was 5 percent.

FIGURE 7
The JFE-SSD



Source: Boopendranath *et al.* (2013).

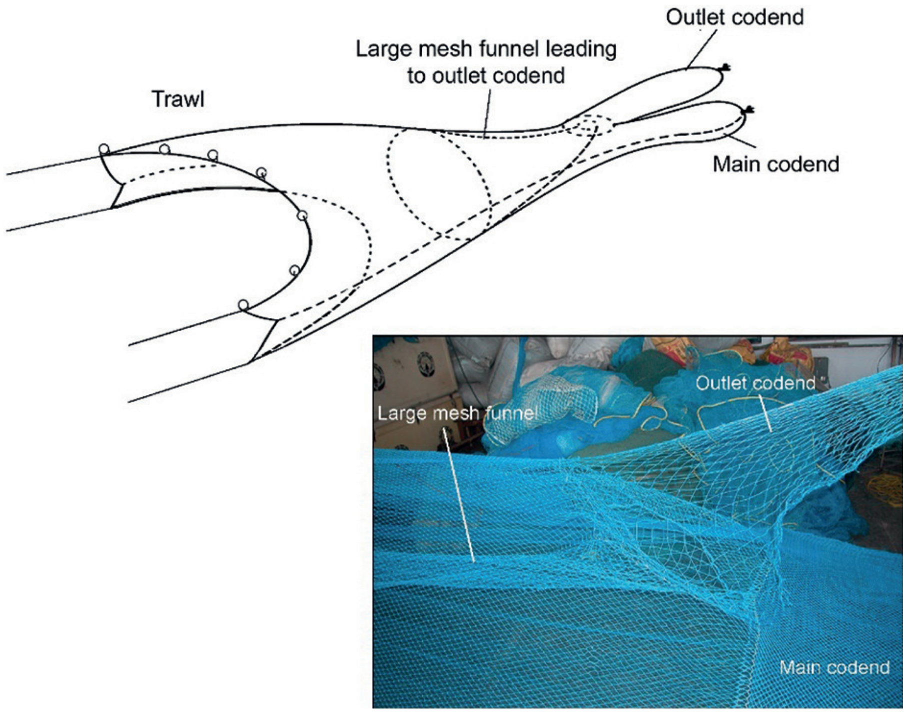
The Sieve net consisted of a large funnel of netting to guide large animals toward an escape opening in the top panel of the trawl (Figure 7). Shrimp and other small animals pass through the meshes of the funnel and enter the codend. Two versions of this net were tested: a 60 mm diamond mesh funnel and a 50 mm diamond mesh funnel (Sabu *et al*., 2013). A specially designed codend was placed over the escape opening to retain valuable fish and other animals escaping from the trawl (Figure 7). Using the 60 mm funnel, 18 hauls were completed and 106 kg of shrimp, fish and other animals were retained. The BRD retained 95 percent shrimp and the bycatch reduction rate was 37 percent. Using the 50 mm funnel, 16 hauls were completed, and 290 kg of shrimp, fish and other animals were retained. This BRD retained 81 percent of shrimp and bycatch reduction rate was 33 percent.

Madhu *et al*. (2015) attempted to evaluate the effectiveness of a separator panel to establish the vertical distribution of shrimp, fish and other animals as they enter a trawl. This involved inserting a horizontal netting panel to divide the trawl into two compartments, each culminating in a separate codend. Catch results based on 27 hauls found that 98 percent of benthic fish and 96 percent of shrimp entered the lowest compartment of the trawl. Approximately 60 percent of *Sardinella longiceps* and other pelagic fish were retained in the upper compartment, suggesting that an adjustment of the vertical opening could be used to reduce the bycatch of these pelagic species. However, there is no evidence to indicate that either of these BRDs are used across the fleet.

Regulations

The use of TEDs has been required on trawlers since 2001 (Mathew, 2004; Prakash, Boopendranath and Vinod, 2016). Approximately 54 percent of traditional fishing grounds have also been closed to fishing, in part to reduce the capture and mortality of sea turtles. However, TED use is low, notably due to concerns by fishers that the devices will significantly reduce landings of shrimp and fish. There is also a lack of

FIGURE 8
The Sieve net with its outlet codend and cover net



Source: Sabu *et al.* (2013).

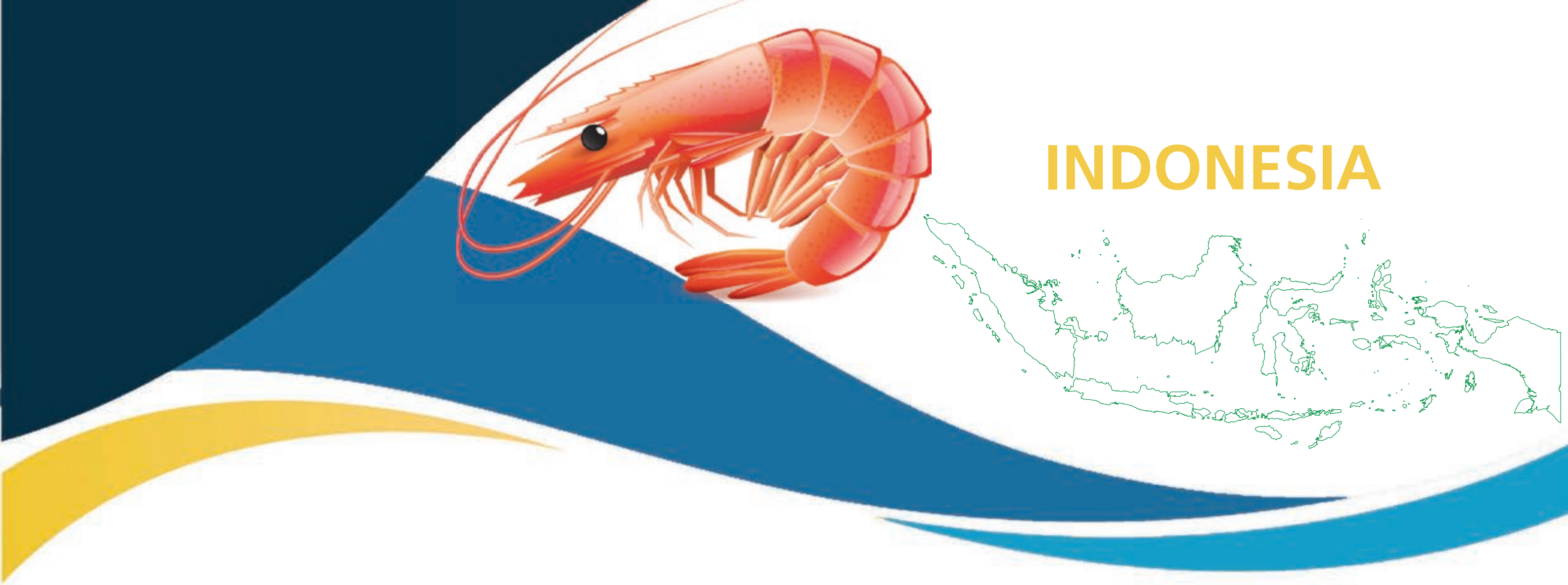
incentives to encourage their use, inadequate enforcement of regulations, and a lack of political will to enforce this requirement (Boopendranath, 2007; WWF, 2011; Davis 2016). Specifically, fishers expressed concerns that large aggregations of turtles may block TEDs and result in catch loss (Mathew, 2004). They also felt it was unreasonable to expect a TED to be fitted to every trawl when multiple trawls are operated simultaneously; that TED efficiency has not been tested using all types of trawl used in the fishery; and that TED performance has not been tested with different turtle aggregations, bottom habitats and water depths. Apparently, fishers would rather tie up their vessels than use a TED (Mathew, 2004).

Outreach and extension

Efforts to train fishers in the need, operation and installation of TEDs commenced at least as early as the mid-1990s (Mathew, 2004). Between 2008 and 2010, workshops with fishers, researchers and others were held to discuss the adoption of TEDs (WWF, 2011). In coastal areas CIFT facilitated 40 workshops with over 1300 fishers, netmakers, and others to demonstrate TED design, as well as the construction, installation and operation of the CIFT-TED. A variety of publications in English and local dialects were produced, as well as several videos demonstrating the benefits of bycatch reduction.[5] This series of initiatives also included TED demonstrations and performance evaluation at sea, together with the distribution of 500 CIFT-TEDs to fishers free of charge.

In another initiative, fishers were involved in the key stages of bycatch reduction research, including the comparative tests of two codend mesh sizes (a 20 mm diamond mesh and a 40 mm square mesh), in addition to a survey of fisher attitudes and perception towards sustainable fisheries, and the development of outreach material such as videos (Mohamed *et al.*, 2009). Following fisher concerns about lost profitability, the impact of the larger mesh size on catch landings and value, fuel, and ice was also evaluated. Fishers were then provided with information about the impact of the larger mesh size on their fishing operation, so that they could appreciate how this modification impacts catch value and profit.

5 One example can be viewed at www.youtube.com/watch?v=AUaixPHjpSk&t=11s)



3.8 INDONESIA

Trawling for shrimp and other animals in Indonesia began in the late 1960s (Bailey, 1997). In 2002, 482 registered trawlers operated in the fishery (SEAFDEC, 2003), and approximately 20 000 tonnes of banana shrimp (*Penaeus merguiensis*, and *P. indicus*), tiger shrimp (*P. semisulcatus*), and endeavor shrimp (*Metapenaeus ensis*) were caught each year. Approximately 80 percent of the total catch was discarded (Gillett, 2008). A thorough review of the shrimp fishery, including management and enforcement issues, historical landings and bycatch issues is provided in Gillett (2008) and FAO & SEAFDEC (2010). Since 2015, industrial shrimp trawling has been banned in Indonesian waters.

TEDs

Efforts to reduce turtle bycatch in shrimp trawls date back to the early 1980s (Hermes, 2009), when a locally designed TED called a bycatch excluder device (BED) was tested in the fishery (SEAFDEC, 2003). Shrimp loss was as high as 30 percent, but the sampling design and the impact on fish and other animals was not reported. In the late 1990s the Super Shooter TED was introduced and found to reduce bycatch by approximately 40 percent. Approximately 30 percent of shrimp was lost, and poor rigging – including inadequate flotation and the grid angle – were deemed to be the cause. In 2004, the Super Shooter was found to reduce fish bycatch by 5 percent when bar spacing was 12 cm, and 60 percent when bar spacing was 4 cm (Purabayanto, 2015). Further tests of the Super Shooter in 2007 resulted in shrimp loss of over 20 percent.

BRDs

In 2002 three versions of the JTED – a rigid sorting grid, a simple flat rectangular-shaped window, and a semi-curved three-panel grid (**Figure 8**) – were tested in the fishery (Chokesanguan, 2004). The bar spacing of each grid was 40 mm. The catch was sampled from four one-hour hauls with each version of JTED, and of all the major catch categories the escape rate was highest with the rigid sorting grid (Table 10). In 2004, a JTED was re-tested in the fishery and excluded 33 percent of all fish bycatch (Purabayanto, 2015), although the design and dimensions of the JTED and the species that comprised the bycatch were unspecified. In 2007, a square-mesh window and a Fisheye were tested in the fishery.

TABLE 10
Escape rate of major catch categories for each JTED

JTED	Catch category			
	Trash fish (percent)	Shrimp (percent)	Pelagic fish (percent)	Demersal fish (percent)
Rigid sorting grid	69	94	97	70
Semi-curve	4	9	53	5
Rectangular window	18	16	49	40

Source: Chokesanguan (2004).

While bycatch was reduced by 6 percent and 13 percent respectively, both devices led to a shrimp loss of over 20 percent (Purabayanto, 2015). Fishers were questioned about the performance of each device, including their ease of operation and acceptability, and the square-mesh window and Fisheye scored 27 from a total of 40 points, compared to 20 points for the SS.

Regulations

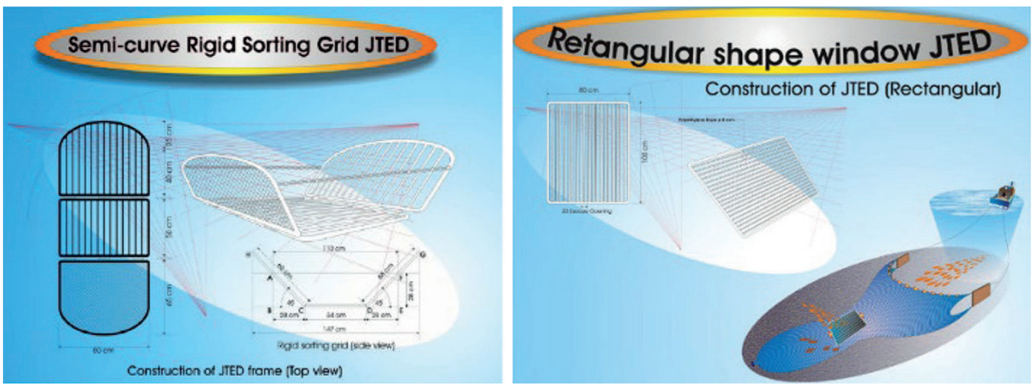
In 1980, Presidential Decree No. 39/1980 banned shrimp trawling in the Malacca Straits and north coast of Java (Bailey, 1997). In 1983, the ban was extended to all Indonesian waters (Endroyono, 2017). However, shortly thereafter Presidential Decree No. 085/1982 eased this ban and permitted shrimp trawling in limited areas, including the Arafura Sea, providing bycatch was utilized and that a modified TED known locally as a Bycatch Efficiency Device (BED) was used with a minimum bar spacing of 76.2 mm. A second national ban on shrimp trawling was subsequently introduced in 2015, although the inshore, small-scale fishery remained open provided headrope length was less than 60 m and minimum mesh size was 50.8 mm. It is unclear whether these smaller trawlers require TEDs or BRDs.

The history of the shrimp fishery and the impact of the trawl bans on fishery resources and the fishing industry is described in Bailey (2007), Endroyono (2017), and Tirtadanu and Suprapto (2017). In the inshore fishery there is a lack of awareness of existing regulations, the enforcement of which is weak, and there are few incentives for fishers to use a bycatch reduction device (Gillett, 2008; Davis 2016).

Outreach and extension

Up until the late 1990s, few attempts had been made to provide fishers with training in responsible fishing technology (Haluan and Monintja, 1997). In 1996, training on the use and operation of TEDs was provided by American experts (Zainudin and Pet-Soede, 2005). Between 2002 and 2006, the Indonesian Department of Fisheries worked closely with SEAFDEC to host fishers and local authorities as part of the REBYC-I project, describing JTED rigging, operation, performance and benefits (Chokesanguan *et al*., 2010). This was accompanied by field testing onboard a local trawler, often for only one or two days. A cover net surrounding the JTED and codend was used to retain escaped fished to demonstrate the device's performance.

FIGURE 9
Two versions of the JTED



Source: B. Chokesanguan, (2010).

IRAN (ISLAMIC REPUBLIC OF)

3.9 IRAN (ISLAMIC REPUBLIC OF)

In 2014, the combined shrimp landings of Iran (Islamic Republic of) in the Persian Gulf and Gulf of Oman were just over 8 000 tonnes (FAO, 2014). The shrimp trawl fleet is characterized by industrial trawlers of 20–30 m in length, as well as smaller, timber or fibre-reinforced plastic trawlers (dhows) (Mojahedi, 2001). Shrimp landings are dominated by banana shrimp (*Penaeus merguiensis*), green tiger shrimp (*Penaeus semisulcatus*), and jinga shrimp (*Metapenaeus affinis*), and usually account for around 20–27 percent of total catch weight (FAO, 2000; (Eighani and Paighambari, 2013). Juvenile fish make up 40–60 percent of bycatch landings by weight (FAO, 2000), and are often dominated by Spanish mackerel (*Scomberomorus commerson*), Croaker (*Otolithes ruber*) and Silver pomfret (*Pampus argentus*), (Paighambari and Eighani, 2016). The bycatch of juvenile fish and small fish is usually discarded overboard (FAO, 2000). Commercially important species include Indian halibut (*Psettodes erumei*), Fourfinger threadfin (*Eleutheronema tetradactylum*), and Silver sillago (*Sillago sihama*) (Kazemi *et al.*, 2016). A review of the bycatch in this fishery was provided in Paighambari and Daliri (2012) and Kazemi, Paighambari and Naderi (2013).

TEDs

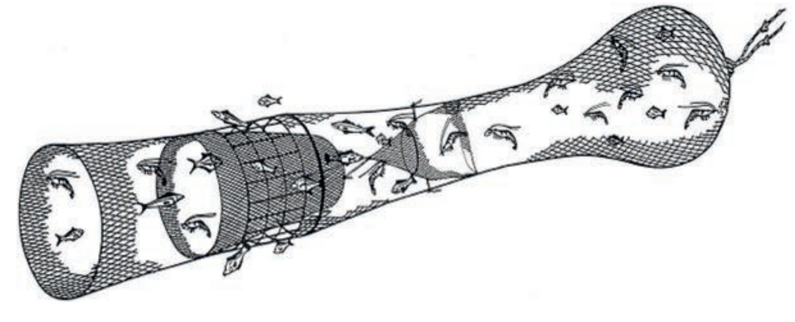
No known attempts have been made to use a TED to reduce the impact of shrimp trawling on sea turtles.

BRDs

Bycatch reduction efforts started in the early 1990s to reduce bycatch of fish and large animals using a square-mesh window (Eayrs and Prado, 1998). These efforts were a response to concerns over high bycatch-to-catch ratios (Eayrs and Prado, 1998), in addition to the capture of large numbers of juveniles of commercially important species and small, non-commercial adult fish (Paighambari and Eighani, 2016; FAO, 2000).

The original square-mesh window tested in this fishery was constructed from a panel of 100 mm (50 mm bar length) netting measuring 45 bar lengths wide and 75 bar lengths long (Eayrs and Prado, 1998). As part of a comparative experiment against a standard (unmodified) trawl, the square-mesh window was placed in the upper panel of the trawl with its trailing edge located 15 meshes ahead of the codend, and then tested by 10 boats (n = 210 hauls). The results indicated a reduction in the catch of juvenile fish (27 percent), small fish (24 percent), and shrimp (20 percent), as well as a 4 percent gain in large marketable fish, when using the SMW. In 1997, the original SMW and a radial escape section (RES) were tested with and without a cone fish stimulator (Eayrs and Prado, 1998). The RES consisted of a panel of 200 mm mesh (100 mm bar length) netting, measuring three bars length deep, which extended radially around the codend (Figure 9). A guiding funnel was used to guide catch past the large mesh netting. The cone was constructed from two triangular-shaped sections of netting attached to a 10 mm diameter wire hoop, the circumference of which measured 1000 mm. The purpose of the cone was to stimulate fish to turn, swim toward the large mesh netting,

FIGURE 10
The Radial Escape Section (RES) with cone fish stimulator



Source: Eayrs (2007).

and escape through the mesh openings. In some hauls the cone fish stimulator was located 13 meshes behind the guiding funnel of the RES and the SMW. Construction details for the RES and cone were provided in Eayrs (2007).

The SMW and cone (n = 5 hauls) reduced large marketable fish bycatch by 44 percent and small fish bycatch by 41 percent compared to the standard trawl, with no loss of shrimp.

The RES retained 65 percent more shrimp and 50 percent more large fish compared to the SMW and cone (n = 2 hauls). Only two days were available to complete the tests and so only a small number of hauls with each BRD and cone combination were possible.

In late 1997, additional BRDs were evaluated, including a Fisheye and a NAFTED (Eayrs and Prado, 1998). The Fisheye consists of a rigid metal framework attached to the top of the codend, while the framework provides an elliptical escape opening through which fish can swim and escape capture. In this study the elliptical opening measured 400 mm across and 200 mm high. The NAFTED is an upward-excluding bent-bar TED with a bar spacing of only 40 mm and no escape flap over the escape opening (Plate 8). Construction details for the Fisheye are provided in Eayrs (2007), while those for the NAFTED are available in Eayrs, Buxton and McDonald (1997). Compared to a standard codend, the Fisheye (n = 10 hauls) reduced total bycatch by 32 percent and shrimp by 22 percent without loss of commercial fish. The NAFTED was compared to the SMW and cone (n = 3 hauls) and it reduced large, non-commercial fish bycatch by 50 percent, other fish bycatch by 35 percent, and shrimp by 2 percent. The catch of stingrays was reduced by 95 percent due to the narrow bar spacing in the NAFTED (Eayrs and Prado, 1998).

The NAFTED with a Fisheye was then tested against a standard codend in 1998–99 (FAO, 2000; Eayrs, 2004). In this configuration (n = 180 hauls) fish bycatch was reduced by up to 75 percent without loss of shrimp. Paighambari and Eighani (2016) recently reported additional testing of the NAFTED and Fisheye combination as well as testing of a Nordmore grid. Both grids were constructed with a bar spacing of 60 mm and the catches compared against a standard codend (n = 15 hauls each). Both grids reduced catches of *O. ruber* and *P. argentus* by around 45 percent and 55 percent respectively, while catches of *S. commerson* were reduced by 53 percent by the NAFTED and Fisheye combination, and by 59 percent by the Nordmore grid.

Another study compared the selectivity of a 75 mm and a 90 mm SMW. The 75 mm SMW measured 57 bar lengths wide and 34 bar lengths long, while the 90 mm SMW measured 48 bar lengths long and 28 bars lengths wide (Kazemi *et al.*, 2016). The windows were inserted into the top of the codend, 1.8 m from its trailing end. The codend mesh measured 25 mm. A small-mesh cover net attached to the codend retained individuals that escaped through each SMW. Catch data were collected from

PLATE 14
The NAFTED

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21 hauls using the smaller SMW and 16 hauls using the larger SMW. Approximately 14 percent of the total catch (shrimp and fish) escaped through the smaller SMW and 17 percent of the catch escaped through the larger SMW. Just over 6 percent of targeted *P. merguiensis* escaped the smaller SMW and 9 percent from the larger SMW.

Recent attempts to reduce bycatch in this fishery included two separate studies evaluating the performance of a juvenile and trash fish excluder device (JTED) and a square-mesh panel (SMP) located in the codend (Eighani and Paighambari, 2019).

The JTED was designed to exclude small fish from the trawl, usually juveniles and trash fish, and consisted of three rigid metal frames hinged together. The first two frames were designed with multiple, rigid parallel bars 30 mm apart to allow small fish and other animals to escape from the codend. The third frame was designed with a panel of 5 mm netting to prevent fish from re-entering the codend. Each frame was constructed out of a 12 mm diameter metal rod, while the parallel bars were built with 6 mm diameter rods. Full details of the construction of the JTED are given in Eayrs (2007).

The SMP was constructed of 90 mm polyethylene netting measuring 35 bars long by 19 barswide, and inserted into the top of the codend. In each study, both BRDs were tested for 21 hauls, each lasting 90 minutes, and a 15 mm diamond mesh cover net was attached to the escape opening of each device to retain those escaped from the SMP. In the first study, the JTED and the SMP reduced catches of *O. ruber* by 30 percent and 45 percent respectively; catches of *P. argentus* by 15 percent and 19 percent respectively; and catches of *S. sihama* by 24 percent and 34 percent respectively (Eighani, Paighambari and Eayrs, 2016). The effect of these BRDs on the shrimp catch was not reported. In the second study, catch results found that both devices reduced discards by 45–49 percent, with losses of commercially valuable species by 32–38 percent, and shrimp by 12–16 percent (Eighani and Paighambari, 2019). The JTED and the SMP reduced catches of *O. ruber* by 31 percent and 45 percent respectively, catches of *P. argentus* by 15 percent and 18 percent respectively, and catches of *S. sihama* by 23 percent and 35 percent respectively. For many other commercially important fish species the SMP reduced more bycatch (by weight) than the JTED, by up to 14 percent depending on species. Each BRD lost 12–16 percent of *P. merguiensis* by weight, which included around half the undersized catch of these shrimp.

Regulations

There is no evidence that authorities currently require Iranian fishers to use TEDs or BRDs (Pramod and Pitcher, 2006). In the past, fishers in the industrial fleet were required to use TEDs such as the NAFTED with a 60 mm bar spacing, but this sector is no longer active, and the use of a TED or BRD is not required in the artisanal sector (Eighani, *personal communication, 2018*). Number or regulations are in place, including: a prohibition on trawling within 6 nautical miles of the coastline, prohibition on night-time trawling, a no-discard policy and minimum mesh size regulations for the small-scale trawl fishery (Kelleher, 2005; Eighani and Paighambari, 2019). It is unclear whether the no-discard policy and other fishery regulations are enforced, and if discarding in this fishery still remains high. At-sea enforcement of regulations in the domestic fishing fleet is limited and there is no known at-sea observer programme to monitor catch and gear (Pramrod, 2018). The minimum mesh size that can be used in this fishery is unknown.

Outreach and extension

Efforts to train fishers in bycatch reduction across the entire fishery are unknown.

3.10 KUWAIT

Commercial shrimp trawling in Kuwait commenced in the early 1960s (Gillett, 2008). The fishery consists of industrial trawlers and smaller dhows. Shrimp landings are dominated by green tiger prawn (*Penaeus semisulcatus*), jinga shrimp (*Metapenaeus affinis*), and kiddy shrimp (*P. stylifera*) although green tiger prawns account for more than half of total shrimp landings (Chen *et al*., 2013). Annual shrimp landings are approximately 2 000 tonnes; this figure accounts for 24–45 percent of total fishery landings and up to 50 percent of total fishery value. Similar to many other tropical shrimp fisheries, bycatch in the Kuwait shrimp fishery is dominated by finfish species. Up to 55 000 tonnes of bycatch are caught each year. Approximately 60 percent of bycatch is made up of low-value finfish species (Al-Baz and Chen, 2014), and nearly all bycatch is discarded at sea (Chen *et al*., 2013). Discards are dominated by undersized Ilisha melastoma, *Pomadasys stridens*, *Nematalosa nasus*, *Saurida tumbil* and *Upeneus doriae*, as well as non-commercial species such as catfish, sharks and rays. Retained bycatch is usually less than 16 percent of total catch, and is dominated by *Saurida tumbil*, *Nematalosa nasus*, *Sphyraena flavicauda*, *Acanthopagus latus* and *Otolithes ruber* (Al-Baz & Chen, 2014), and sometimes amounts to less than 2 percent (Ye, Alsaffar, & Mohammed, 2000). A review of the shrimp fishery in Kuwait, including management issues, historical landings and bycatch issues is available in Gillett (2008).

TEDs

In 2003, concerns over sea turtles and the associated United States of America embargo on fisheries that are not using approved TEDs resulted in a comprehensive bycatch reduction effort by the Kuwait Institute for Scientific Research and the Australian Maritime College (Al-Baz and Chen, 2014). This included testing the performance of a TED and two BRDs on three separate occasions during the fishing year.

The TED was made up of an oval aluminium grid measuring 1.2 m by 1.0 m operated at 55 degrees from the horizontal (Al-Baz and Chen, 2014). The bars were constructed from 20 mm diameter tubing and the bar spacing was 100 mm. A funnel of netting behind the grid served to prevent catch washing back through the grid from the codend and escaping. The escape opening was in the top of the codend. The performance of the TED is indicated in Table 5. Haul duration was usually two hours, although during the third trip it was reduced to 30 minutes. No large animals were caught in the control net or the net with the TED. There was no significant difference in shrimp catch between codend with TED and the control, although the control caught fewer shrimp. There was no significant difference in the mean length of *P. semisulcatus*, although the mean length of *M. affinis*, and *P. stylifera* was significantly larger in the codend with TED.

BRDs

The two BRDs tested were a square-mesh codend and a Fisheye (Al-Baz and Chen, 2014). The square-mesh codend was constructed from 45 mm netting (22.5 mm bar length) and measured 100 bar lengths in circumference and 164 meshes lomg. The

Fisheye was designed with an elliptical opening measuring 450 mm by 150 mm. It was located 60 meshes ahead of the codend drawstring in the top of the codend. Table 11 summarizes BRD performance. The mean weight of the shrimp catch per tow was not significantly different between BRD and control, although the catch of *M. affinis*, and *P. stylifera* was significantly reduced when the Fisheye was tested. The mean length of *P.semisulcatus*, *M. affinis*, and *P. stylifera* were significantly larger in the square-mesh codend, possibly due to the escape of smaller individuals from the latter. The mean length of *P.semisulcatus* was significantly larger in the codend with the Fisheye, but there was no significant difference in catches of the remaining two species between the codend with Fisheye and the control codend.

Regulations

There is no legislation requiring the development of fishery management plans in Kuwait, and there are no fishery management plans for any fishery (De Young, 2006). However, catches are regulated through the use of closed seasons, protected areas, 45 mm minimum mesh size regulation, minimum landing size for some commercially important species, and fishing effort control. Enforcement of these regulations is considered a significant issue (FAO, 2003b) and illegal fishing is common (De Young, 2006). There is no legislation requiring shrimp trawls to be fitted with a TED or BRD (Gillett, 2008) and there is a lack of incentives for reducing bycatch (Kelleher, 2005). Updated information on regulations to manage bycatch in bottom trawl shrimp fisheries is unknown.

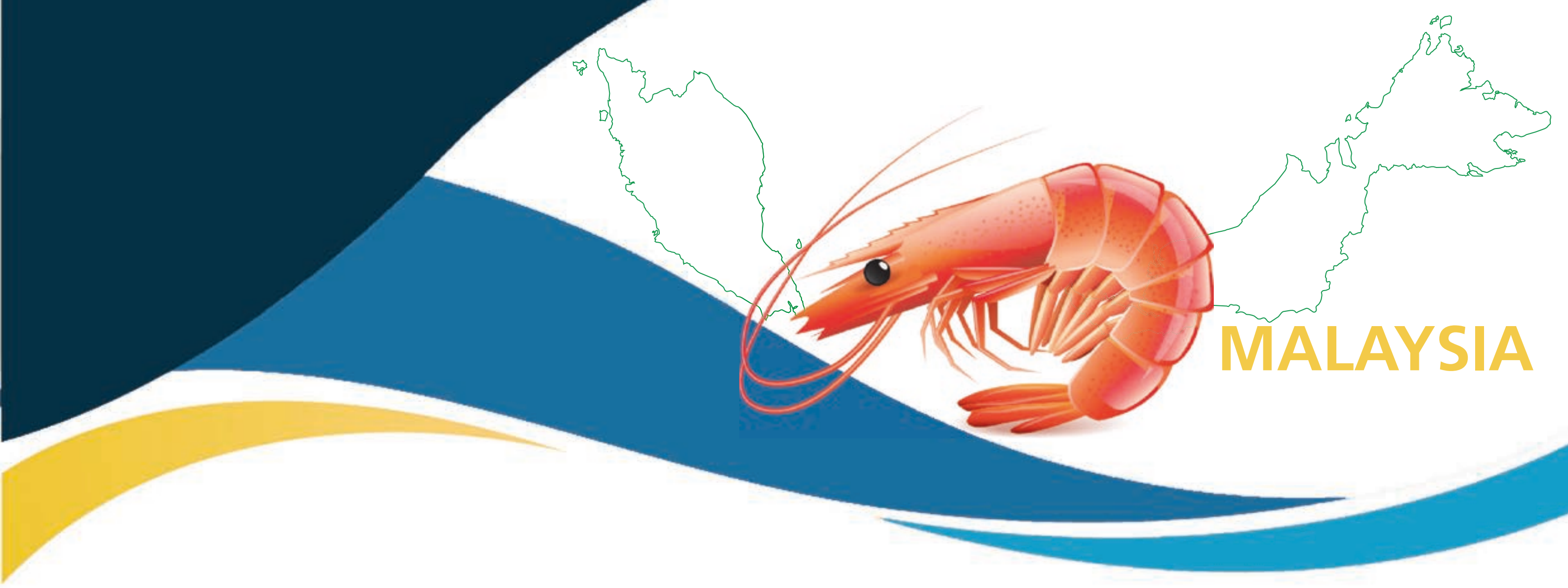
Outreach and extension

Outreach and extension efforts to inform fishers, boat owners, and others about reducing bycatch, as well as TED and BRD design and performance, are unknown.

TABLE 11
Performance of the TED and BRDs during comparative testing against a traditional (control) shrimp trawl (all trips combined)

Gear	Shrimp (kg)			Bycatch (kg)		
	TED/BRD	Control	Difference (%)	TED/BRD	Control	Difference (%)
TED (n = 24)	124	117	6.3	852	906	-6.0
Sq. mesh (n = 26)	113	124	-8.7	1 034	1 147	-10.0
Fisheye (n = 26)	137	175	-21.3	997	1 378	-27.6

The control codend was constructed from 45 mm diamond mesh. n = number of sampling tows.
Source: Al-Baz & Chen (2014).



3.11 MALAYSIA

Trawling was introduced to Malaysian waters in the early 1960s to catch shrimp and finfish (Teh and Teh, 2014). A variety of fishing gears are used to land penaeid shrimp in Malaysian waters, in addition to trawl nets. Shrimp landings in 2003 amounted to 46 000 tonnes (Davis, 2016), and these accounted for approximately 8 percent of total fishery landings (Ali and Ananpongsuk, 1997). Commonly landed shrimp species include banana shrimp (*Penaeus merguiensis*), jinga shrimp (*Metapenaeus affinis*), yellow shrimp (*M. brevicornis*), rainbow shrimp (*Parapeneopsis sculptilis*), and spear shrimp (*P. hardwickii*) (Nuriddin and Fong, 1994). Bycatch from the trawl fleet is estimated at 718 480 tonnes per annum (Davis, 2016), much of which is retained for human consumption. A significant proportion of the catch is trash fish, which is usually landed and used for fishmeal and as a food source for fish culture operations.

TEDs

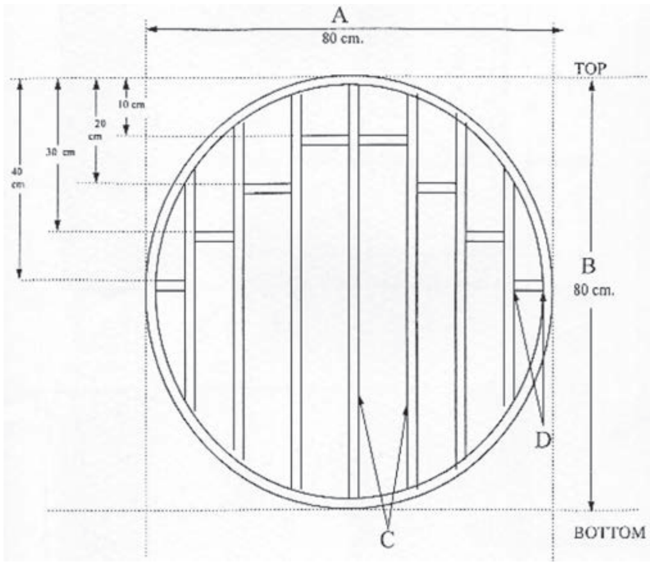
In the late 1990s efforts commenced to introduce TEDs, primarily in response to the United States of America shrimp import embargo. In 1997 a small and medium-sized oval Thai turtle-free device (TTFD) was tested to exclude sea turtles from the trawl (Ali and Ananpongsuk, 1997; Chokesanguan *et al.*, 1997; Chokesanguan, 2000). The small TTFD was circular in shape, 80 cm in diameter (**Figure 10**) and the medium TTFD was oval, and measuring 80 cm wide by 100 cm high. The bar spacing was 90 mm, while the grid angle was approximately 50 degrees for both TTFDs, both of which were orientated upwards. The TTFDs were tested on a small boat towing a single net, and catch data were collected from a total of 15 hauls with a standard trawl, 16 hauls with a TTFD and a small-mesh cover net, and 16 hauls with a TTFD and no cover net. Testing occurred both during the day and night at a speed of 2.5–3.0 knots (Ali and Ananpongsuk, 1997; Chokesanguan, 2000). The shrimp catch retained in the cover net was no more than 8 percent, irrespective of the size of the TTFD, although the combined total catch of all animals (shrimp, fish, other) weighed no more than 10 kg during the day or night.

During one haul a turtle was retained in the cover net. Recent efforts to exclude turtles include the testing of a number of locally made TED designs featuring horizontal openings in the bottom of the grid to facilitate the entry of stingrays, target species, into the codend.

BRDs

Efforts to reduce fish bycatch date back to the early 1980s with the testing of the Bycatch Excluder Device. (Bin Ali, 1986). This BRD is essentially a box-shaped rigid framework that houses an inclined grid with a detachable door attached to the top, through which turtles and other large animals can escape. The design of this BRD is very similar to the original NMFS TED described in Jenkins (2012). The bar spacing of the grid was 80 mm. A funnel of netting guided shrimp and fish past the grid, and a large escape opening either side of the grid was designed to allow fish to escape. Two

FIGURE 11
The small Thai turtle free device (TTFD)



A - TED width, B - TED height, C - bar spacing (90 mm), D - bar spacing between bar and frame (75 mm).
Source: Chokesanguan *et al*. (1997).

boats tested this device on two fishing grounds, during which shrimp loss amounted to 40–47 percent, commercially important fish were reduced by 63–77 percent, and trash fish were reduced by 41–66 percent. The performance of this BRD was considered unsatisfactory, particularly given the challenges in handling the device and its high purchase cost.

In 2001 and 2007 the JTED was tested in Malaysian waters by SEAFDEC and the Department of Fisheries Malaysia. In 2001, two versions of the JTED (Figure 11) were tested with 12 mm and 20 mm bar spacing both at night and during the day (Chokesanguan, 2004). The catch was sampled from 12 hauls, each lasting one hour. Both grids reduced the capture of trash fish by at least 70 percent. Over 60 percent of all pelagic fish, including 40 percent of short mackerel (*Rastrelliger brachysoma*), escaped the JTED with a 20 mm sorting grid. This grid also suffered a loss of shrimp (*Penaeus merguiensis* and *P. semisulcatus*) by 44 percent. Less than 10 percent of shrimp and pelagic fish, though not short mackerel, escaped the JTED with 12 mm sorting grid. The escape rate of demersal fish from the 20 mm and 12 mm sorting grids was 34 percent and 11 percent respectively. The JTED was also tested in 2007 (Chokesanguan *et al*., 2010). This effort was more a demonstration for fishers and others than research, and the performance of the JTED was not reported. No other known attempts have been made to use a BRD to reduce fish bycatch in the shrimp fishery.

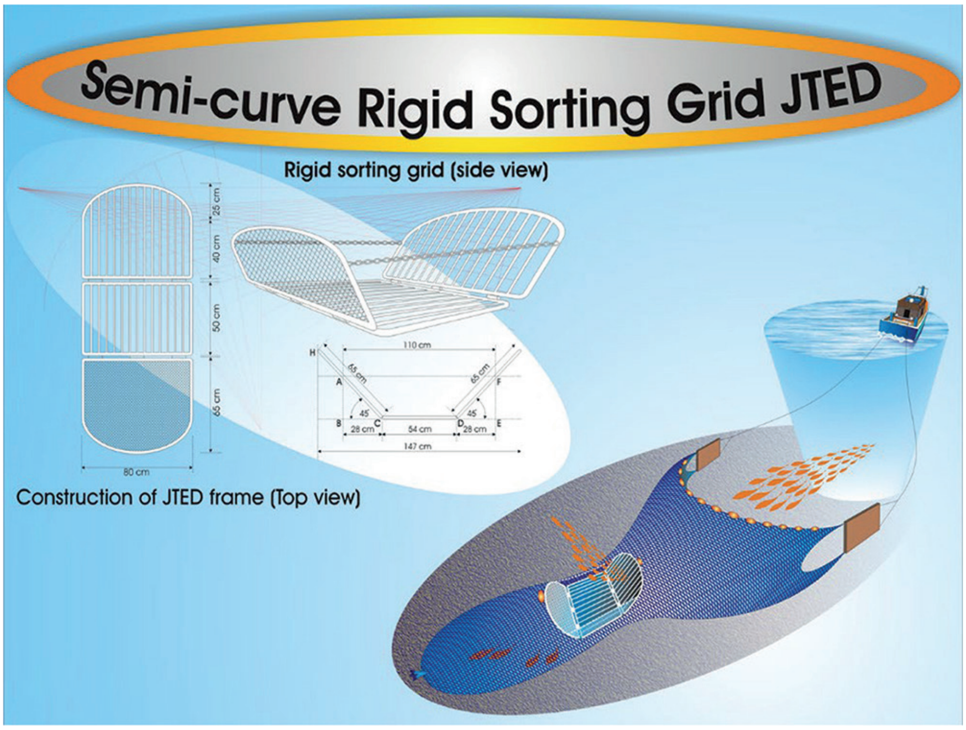
Regulations

A no-trawling zone within 5 nautical miles of the coastline is designed to protect juvenile fish from trawling activity (FAO, 2000). The Fisheries Act 1985 specifies that codend mesh size should measure no less than 38 mm and attempts to enforce this regulation in 2006 resulted in mass protests by trawl fishers (Nuruddin & Mohd. Isa, 2013). There is anecdotal evidence that this regulation is now being enforced. There is no management plan for Malaysian trawl fisheries (Nuruddin and Mohd. Isa, 2013), and the trawl catch is effectively unmanaged (Davis, 2016).

Outreach and extension

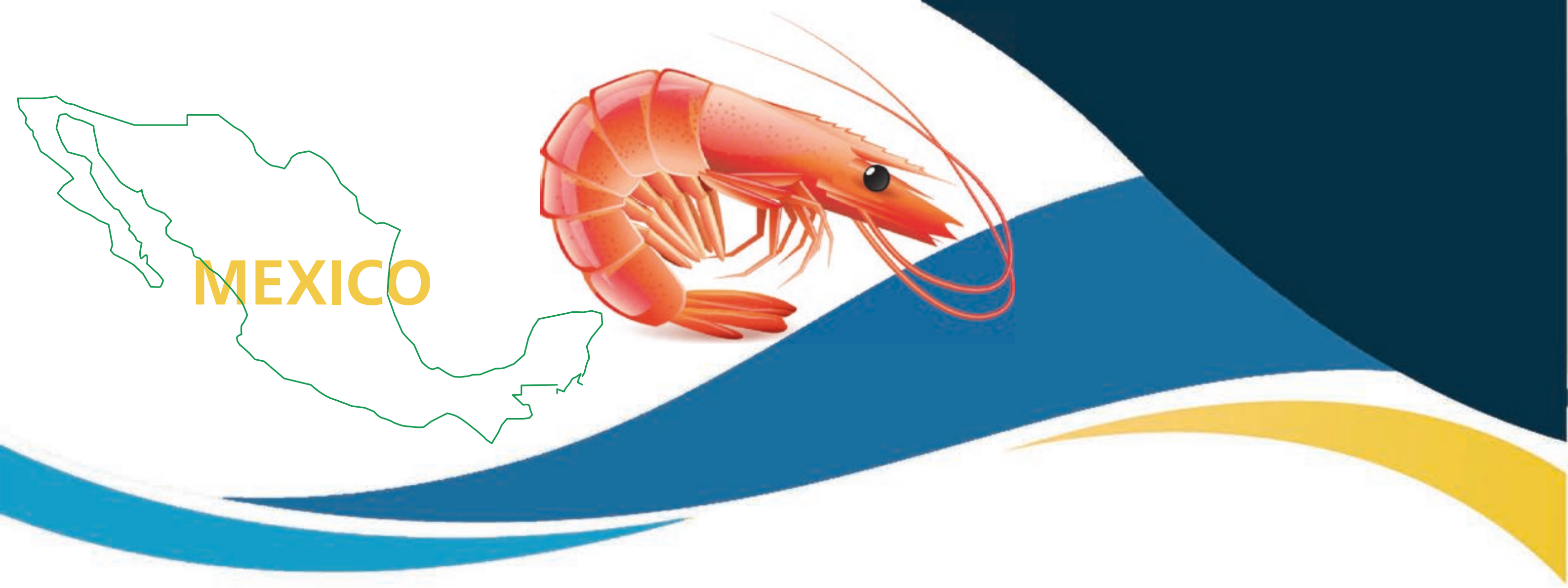
The Department of Fisheries Malaysia hosted a TED training programme for fishers in 2015, including field tests and demonstrations of TED performance, as well as the transfer of rigging and operational information (DOF, 2016). Testing of the JTED by SEAFDEC and the Department of Fisheries Malaysia included workshops with fishers and local authorities, which described JTED rigging, its operation, performance and benefits, usually as part of the REBYC-I and REBYC-II CTI project.[6] This also included the production of a video demonstrating JTED testing and associated construction and performance handouts. These efforts were also accompanied by field testing onboard a local trawler, often for only one or two days. A cover net surrounding the JTED and codend was used to retain escaped fish to demonstrate JTED performance.

FIGURE 12
The JTED tested in Malaysia



Source: B. Chokesanguan (2010).

6 See www.seafdec.or.th/home/rebyc-cti/about-rebyc-ii-cti for details.



3.12 MEXICO

Trawling for shrimp in Mexico commenced in the 1930s (Gillett, 2008). There are four main shrimp fleets, including an offshore fleet of large (18–25 m) industrial trawlers on the Pacific coast, in the Gulf of Mexico and the Caribbean Sea. Elsewhere, there is an inshore fleet of smaller (6–9 m) vessels based on the Pacific coast and Gulf of Mexico, which use small trawl nets and other gear, a fleet of similar-sized vessels targeting Atlantic seabob (*Xiphopenaeus kroyeri*) in the Gulf of Mexico, and a further Magdalena fleet, also of similar-sized vessels. There are around 316 industrial trawlers and over 2 500 artisanal vessels targeting shrimp in the Gulf of Mexico and Caribbean Sea, despite significant declines in vessel numbers recently (Di Cintio and Moreno, 2017) (CONAPESCA 2018). While it's difficult to estimate the number or artisanal vessels in the Gulf of Mexico, 5 009 *charangas* (fixed fishing gear) are registered in Laguna Madre Tamaulipas and Laguna Tamiahua Veracruz (SAGARPA, 2010). Likewise, for the Coast of Tabasco and South of Campeche about 300 smaller vessels operate to catch seabob (INAPESCA2014). Shrimp fishing in coastal lagoons is prohibited in Campeche.

The main target species on the Pacific coast are blue shrimp (*Litopenaeus stylirostris*), whiteleg shrimp (*L. vannamei*), yellowleg shrimp (*Farfantepenaeus californiensis*) and crystal shrimp (*F. brevirostris*). In the Gulf of Mexico, trawling in the regions of Tamaulipas and Veracruz predominantly lands brown shrimp (*F. aztecus*), while in the Campeche region the most important species is pink shrimp (*F. duorarum*), and to a lesser extent Atlantic seabob (*Xiphopenaeus kroyeri*). In the Caribbean Sea, trawling predominantly lands redspotted shrimp (*F. brasiliensis*) and rock shrimp (*Sicyonia brevirostris*) (INAPESCA, 2014).

Combined shrimp landings averaged 71 097 tonnes per year from 2009 to 2018 (CONAPESCA 2018). The ratio of fish to bycatch varies depending on the area, depth and season of the year. For example, in studies carried out in the Northwest Gulf of Mexico, the values fluctuated between 1:1.4 and 1:2.9 (Corripio, 1985), 1:2.9 (García, 1990), 1:3.4 (Palomino, 1996 and 1998), 1:2.9. (Giadans, 1998) and 1:6 (Wakida-Kusunoki 2013). In the Campeche Sound, REBYC-II LAC supported monitoring trips during the 2016–2018 seasons, during which bycatch ratios varied between 1:1.9 and 1:2.6, with the variations reflecting different seasons and fishing areas (Quiroga-Brahms *et al*., 2019). About 30 percent of bycatch is landed, while combined total discards from all Mexican shrimp fisheries amount to more than 130 000 tonnes annually, almost 90 percent of which originates on the Pacific coast fleet (Kelleher, 2005) – although a more recent estimate suggested total discards could reach 190 000 tonnes (Ibarra, 2017). A review of the shrimp fishery, including management and enforcement issues, bycatch issues and historical landings, is provided in both Gillett (2008) and Ibarra (2017).

TEDs

The development of TEDs has a history dating back to at least the early 1990s, when the then Instituto Nacional de La Pesca (INP) and the National Marine Fisheries Service (United States of America) tested the Super Shooter (Plate 15) and Anthony Weedless TED in Mexican waters (Jenkins, 2012). This also included testing a trawl net with baffles attached to each wing to guide shrimp towards the outer codends, prior to reaching the TED. Another locally designed TED was the FEDINP TED, a top opening TED with a rectangular grid. Overall, bycatch was reduced by approximately 14 percent using these TEDs, with minimal loss of shrimp (Aguilar and Grande-Vidal, 1996). An early history of TED development in Mexico is provided in Seefoo Ramos, Nafate and Ramirez (2001).

BRDs

Early efforts to reduce bycatch started in 1987 (Hermes, 2009), although no specific evidence of this has been found. Later efforts included testing several Fisheyes in the northern Gulf of California in 1993. In 1997, a square-mesh, extended-funnel BRD was tested in the same waters during two research cruises (Garcia-Caudillo, Cisneros-Mata and Balmori-Ramirez, 2000). In the first cruise, catch data was collected from 42 hauls, while in the second cruise data was collected from 26 hauls. In the first cruise the BRD reduced fish bycatch by 40 percent, although there was a 7 percent loss of shrimp. Several fish species such as croaker (*Micropogonias altipinnis*) were reduced by almost 55 percent. During the second cruise, the BRD reduced fish bycatch by 38 percent and shrimp loss was 5 percent.

In the early 2000s, INAPESCA developed the RSINP trawl, which included the use of hydro-dynamically efficient otter boards, a Super Shooter and Fisheye, ground gear modification, and variable mesh size from trawl mouth to codend (INAPESCA, 2010). Results to date indicated some, albeit limited, bycatch reduction (Aguilar-Ramirez and Rodriguez-Valencia, 2012; Aburto-Oropeza *et al.*, 2017). It is not widely used.

PLATE 15
A Super shooter TED used in the Mexican shrimp fishery

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PLATE 16
A Fisheye used in the Mexican shrimp fishery

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In 2008, efforts were made to test a modified ENIP90NN trawl as well a Fisheye (Plate 16) and a large mesh panel to reduce bycatch (Galindo, 2012). The modified trawl was designed with 20 cm drop chains extending between the trawl footrope and the ground chain; this modification was designed to allow benthic animals to pass under the footrope and avoid capture. The Fisheye was designed with an elliptical opening measuring 230 mm high by 475 mm wide, and two identical Fisheyes were tested side by side. The large mesh panel measured 13 meshes long and 25 meshes wide, while its mesh size was 152.4 mm; the mesh size of the trawl net was 50.8 mm. In the first experiment, the ENIP90NN trawl was compared to a standard shrimp trawl, and the catch of fish and invertebrates fell by almost 50 percent and 25 percent respectively. There was no difference in the shrimp catch. In the second experiment the Fisheyes were installed in the new trawl, although no improvement in bycatch reduction was detected. The invertebrate catch was also reduced by approximately 40 percent and the shrimp catch by 6 percent. In the final experiment, the Fisheyes were replaced with the large mesh panel. This modification resulted in bycatch reduction of approximately 47 percent, a 45 percent reduction in invertebrates, and a 6 percent loss of shrimp. A detailed review of other ideas to improve the selectivity of shrimp trawls in Mexico was made in Villaseñor-Talavera (2012).

The FAO/UNEP/GEF REBYC project continued efforts to reduce bycatch through Fisheyes, JTEDs and other BRDs (Hermes, 2009). In some instances these devices reduced fish bycatch by as much as 60 percent.

TABLE 12
Four net configurations tested in Campeche, Mexico, 2020

Design name	Codend mesh size (mm)	Net opening (m^2)	Headline length (m)	Material	Double Footrope	Drag chain	TED	BRD
Campeche (current net)	38	16.6	13.7	Sapphire™	No	Yes	Super Shooter (upward opening)	No
Adjusted Campeche	38	16.6	13.7	Sapphire™	No	Yes	Super Shooter (upward opening)	Fisheye
Fantasma prototype	38	27.3	15.2	Spectra™	Double	No	Super Shooter (upward opening)	Fisheye
Fantasma prototype with drag chain	38	27.3	15.2	Spectra™	No	Yes	Super Shooter (upward opening	Fisheye

TABLE 13
Preliminary bycatch reduction results from Campeche, Mexico

Design name	Shrimp (kg/hr)	Retained bycatch (kg/hr)	Discarded bycatch (kg/hr)
Campeche (current net)	3.97	2	8.1
Adjusted Campeche	2.87	0.9	3.5
Fantasma prototype	3.92	1.3	4.5
Fantasma prototype with drag chain	3.32	0.9	5.2

As part of the REBYC-II LAC project in 2020, INAPESCA partnered with vessel owners and crew to evaluate the performance of four net configurations (see Table 12) in the Campeche Sound (Aguilar-Ramírez et *al*., 2020).

Researchers completed 28 paired hauls of 3.5 hours each on a quad rig, using all four net configurations, periodically adjusting their positions. Preliminary results show the following average catches per unit of effort, defined as kg/hr of towing (Aguilar-Ramírez *et al*., 2020).

This design was chosen because previos cruises failed to maintain a consistent track when conducting parallel trawls with two vessels. However, more tows – based on a simpler experimental design and with less potential sources of bias and variance – are required in order to confirm these findings, and identify the real percentage reduction in bycatch with this new net. Researchers from the National Institute of Fisheries and Aquaculture (INAPESCA) felt sufficiently confident in the results and fishers showed sufficient openness for change – notably in relation to potential fuel savings and better net resistance – that at the time of writing INAPESCA had launched a training programme to enhance voluntary adoption of the prototype Fantasma net.

Regulations

In the offshore fisheries, codend mesh size is typically 38–45 mm and TEDs are required to reduce sea turtle mortality (Gillett, 2008). Shrimp trawlers in the Gulf of Mexico have been required to use TEDs since 1993 (Gillett, 2008) and since 1996 in the Pacific (FAO, 2000). Mexico is one of the countries that has been recognized by the United States of America as having an effective sea turtle conservation programme and can therefore export shrimp to the United States of America (Kelleher, 2005; Federal Register, 2016a). In 2004, new TED regulations were adopted requiring the use of large escape openings, using a single or double cover. These modifications are designed to facilitate the exclusion of leatherback turtles, and comply with United States of America requirements. Meanwhile, official Mexican regulation NOM-002-SAG/PESC-2013 also requires several bycatch mitigation measures:

- bottom trawl fishing is prohibited in areas less than 5 fathoms deep (except for the *X. kroyerii* fishery in the Gulf of Mexico);

- trawl fishing is prohibited within a radial area of 5 nautical miles around certain critical bays, lagoons and estuaries; and
- all vessels are obliged to install and utilize approved TED devices, as approved by regulation NOM-061-PESC-2006.

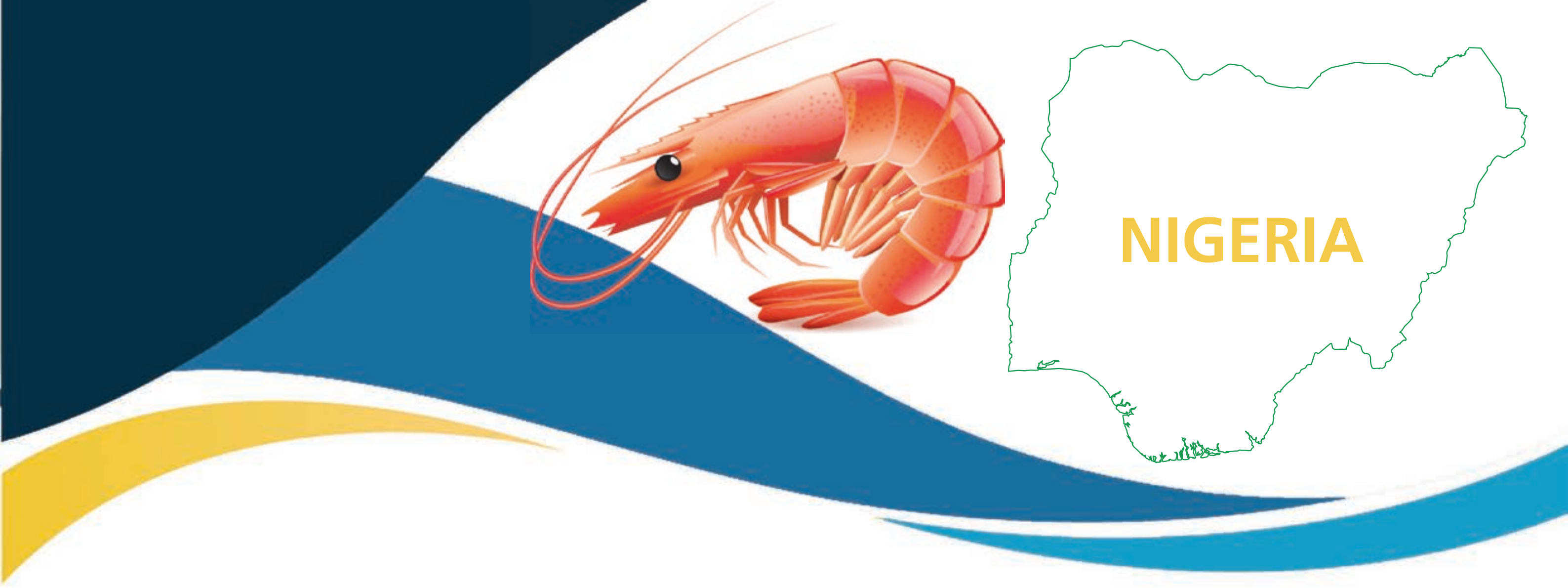
The regulation also obliges trawl vessels of more than ten tons and operate in the Pacific Ocean to install and utilize a Fisheye BRD with the following specifications: 520 mm along its major axis, 200 mm along its lower axis, featuring a 630 mm arm with a minimum opening of 400 mm.

The same regulation (NOM-002-SAG/PESC-2013) recommends the use of other bycatch mitigation measures such as a double footrope, but this remains optional. However, for vessels operating in specific protected areas in the Northern Gulf of California, the double footrope is obligatory. These vessels must also install a smaller Fisheye Device (320 mm diameter on its major axis, 130 mm diameter on its lower axis and an arm length of 305 mm, built with 6 mm diameter stainless steel rebar) located 3.4 m in front of the tie-off rings.

Beyond the above, there are at present no specific regulations to avoid bycatch in the shrimp fisheries, and bycatch is generally discarded and not utilized (Ibarra, 2017).

Outreach and extension

Only 7 percent of shrimp fishers have voluntarily adopted a BRD (Bates, 2006). However, partly as a result of their involvement in the FAO/UNEP/GEF REBYC project, and more recently the REBYC-II LAC project, a number of industry workshops, training courses and technical support documents have been produced for fishers to increase their knowledge and raise awareness of the project. These have led to greater fisher involvement in the development and design of BRDs, but has yet to result in voluntary uptake of the devices.



3.13 NIGERIA

Fishing for shrimp commenced in the 1950s, although it wasn't until the 1980s that fishing effort escalated rapidly (Ogbonna, 2001). In 2009, there were 163 vessels licensed to trawl for shrimp (Solarin *et al*., 2011). Several shrimp species are targeted, including *Penaeus notialis*, *P. mondon*, *P. kerathurus*, and *Parapenaeopsis atlantica* and *P. longirostris*. Annual shrimp landings are typically less than 10 000 tonnes (Gillett. 2008). Retained bycatch includes croakers (*Pseudotolithus* spp.), threadfins (Polynemidae), sole (Cynoglossidae) and grunter (Pomadasyidae). Efforts to reduce bycatch in this fishery date back to at least the mid-1990s, and in particular the development of TEDs to reduce sea turtle mortality (Solarin *et al.,* 2011). A thorough review of the shrimp fishery, including management and enforcement issues, bycatch issues and historical landings, is provided in Ogbonna (2001) and Gillett (2008).

TEDs

The Super Shooter TED has been adopted by the industrial shrimp fishery (Solarin *et al*., 2011). This TED typically measures at least 860 mm high and has a bar spacing of 100 mm. The grid is set at an angle of approximately 45–55 degrees. For a TED with a single escape cover, the escape opening measures 1 820 mm wide by 660 mm long. If a double-cover TED is used, the opening measures at least 1 420 mm wide by 510 mm long. The design and attachment of the escape opening covers is described in Solarin *et al*. (2011). The TED was primarily designed to facilitate the escape of sea turtles and the retention of shrimp. With limited testing in both its upward- and downward-excluding configurations, the TED was considered satisfactory, with a limited loss of shrimp and commercial fish.

BRDs

Relatively little focus has been directed towards reducing fish bycatch, in part because fishers rely on this bycatch to supplement their income. There is some evidence of fishers using a 60 mm codend mesh size, despite most others using 44 mm mesh (FAO, 2000). In one study, the performance of a Nordmore grid with a guiding panel and 20 mm bar spacing was found to reduce the bycatch of juvenile fish by 72 percent, with a non-significant 3 percent loss of shrimp (Ambrose and Lebo, 2009). However, the grid also significantly reduced catches of the commercially important croaker, while catches of *Pseudotolithus elongatus*, *P. senegalensis*, and *P. typus* were reduced by 73 percent, 67 percent and 68 percent respectively. In another study, a rectangular grid with a bar spacing of 20 mm was found to reduce pelagic fish catch by 40 percent with only a 2 percent loss of shrimp compared to a standard codend (Ambrose, Enin and Lebo, 2009). Catches of *P. elongatus* were reduced by 47 percent. A flexible netting grid was also tested in this fishery, and an 82 percent reduction in catches of juvenile fish was recorded. Shrimp loss was 27 percent (Ambrose and Enin, 2010). There was also a significant reduction in most commercially important fish families, such as Sciaenidae, Trichiuridae and Carangidae, although not of families of flatfish such as Carcharhinidae

and Dasyatidae. Catches of *P. typus* were significantly reduced, by 97 percent. There is anecdotal evidence of the JTED, square-mesh window, and T90 codend also being tested in this fishery, although the extent of this testing and the performance of these devices is unknown.

Regulations

In 1996, the use of a TED was mandated in this fishery under the Turtle Conservation Regulations of the Fisheries Act of Nigeria (decree) No. 71 (Gillett. 2008; Solarin *et al.,* 2011); and later under The Sea Fisheries Regulation No. 1 of 2006 (Kelleher, 2005; Solarin *et al.,* 2011). In 1998, the Nigerian Institute for Oceanography and Marine Research developed local TED designs similar to the Super Shooter and Anthony Weedless TED, which resulted in certification and export approval to the United States of America. This certification was lost in 2003 as a result of poor compliance by fishers (FAO, 2000), but was regained in 2007 following dedicated efforts to train them in the use of TEDs (Solarin *et al.,* 2011; Federal Register, 2016a), which was linked in part to their involvement in the REBYC project (Westlund, 2006).

Requirements stipulate a minimum codend mesh size of 44 mm and a trawling ban within 5 nautical miles of the shore, although there is concern over illegal fishing in the 5 nautical mile no-fishing zone (FAO, 2001; Hermes, 2009) and potential economic losses for crew members who tend to sell bycatch directly (FAO, 2004a). Efforts to avoid bycatch are also challenged by a requirement for all shrimp trawlers to land 75 percent of the bycatch at a designated fishing port (Kelleher, 2005; Gillett. 2008), although there is strong evidence that bycatch is transferred to canoes at sea (Gillett. 2008). There is little discarding at sea.

Outreach and extension

Since the mid-1990s the Nigerian Institute for Oceanography and Marine Research has hosted multiple TED training programmes for fishers, including field tests and demonstrations of TED performance, as well as the transfer of rigging and operational information (Solarin *et al.,* 2011). Much of this work has been a part of the FAO/GEF/UNDP REBYC project. A significant challenge with the adoption of BRDs in particular is the impact on the landings of bycatch species, which are important for the local economy and food security (Njifonjou, 2008). The current rate of adoption of BRDs in Nigeria is unknown, but is likely to be low given the economic importance of bycatch to crews.

PHILIPPINES (THE)

3.14 PHILIPPINES (THE)

Trawling for shrimp, fish, and other species commenced in earnest in the Philippines in the 1950s (Ramiscal *et al*., 2017). Annual shrimp landings from trawlers amount to approximately 6 000 tonnes, although this is only about 15 percent of the total shrimp catch (Dickson, 2001). Approximately 400 trawlers are in operation in the Samar Sea, one of the most important fishing grounds in the country; they target a variety of shrimp species including *Penaeus merguiensis*, *P. semisulcatus*, *P. latisucatus*, *P. monodon*, *Metapenaeus ensis*, *M. endeavouri*, and *Trachypenaeus fulvus* (FAO, 2000; Ramiscal *et al*., 2017). Demersal finfish bycatch makes up around 10 percent of the total catch and is typically used for human consumption. This bycatch is often dominated by lizardfish (*Sauridaa* spp.) and threadfin bream (*Nempiterus* spp.) (Ramiscal and Dickson, 2013). Approximately 40 percent of the catch comprises trash fish, including juveniles of commercially important species and species of low or no commercial value, which are often used in fishmeal and the culture of high-valued species (Ramiscal *et al*., 2017).

TEDs

The introduction of TEDs into trawl fisheries in the Philippines was largely a result of the United States of America embargo on shrimp imports (Dickson, 1997). During this initial stage in the 1990's three TEDs were tested: the Thai Turtle Free Device (TTFD), Super Shooter, and the Hooped TED - a large, box-shaped framework with a hinged escape opening. Over a two-month period catch data from a total of 32 hauls was collected, including 8 hauls using each device. A cover net was placed over the escape opening of each TED. All TEDs reduced the shrimp catch by 8 percent or less, and fish loss by 16 percent or less (Dickson, 1997). There was little difference in the performance between the various TEDs. The lowest escape rate for the total catch was 12 percent using the TTED, which also had the lowest shrimp loss (Chokesanguan, 2002). This TED is considered the most suitable design for the fishery (Ramiscal and Dickson, 2013). No evidence was found that this research has continued or that fishers in the Philippines are currently using TEDs.

BRDs

Between 2003 and 2006, several JTED designs were demonstrated to fishers and others; these included the rigid sorting grid with 10, 15, 20, and 30 mm bar spacing, a horizontal rigid sorting grid with 10 mm and 15 mm bar spacing, a square-mesh sorting grid with 40 mm and 50 mm bar lengths, and the semi-curved grid with 2 cm bar spacing (Chokesanguan *et al*., 2010; Dickson *et al*., 2004). A cover net surrounding the JTED and codend was used to retain escaped fish and demonstrate JTED performance. This was followed by testing the same JTEDs near Calbayog City. All JTEDs reduced the capture of juvenile fish by at least 57 percent, while the commercial catch (composed of fish and shrimp) were reduced by at least 9 percent. The rigid sorting grid reduced the commercial catch by 50 percent. Some concerns were raised over the JTED (though

the proportion of respondents was not provided), namely concerns over increased fuel consumption, blockage by garbage and other debris, its negative impact on towing speed, and the cost of JTED construction. This work was implemented under the REBYC project (Dickson *et al*., 2008)

To understand fisher perspectives, Suasi (2016) interviewed 16 fishers from the Calbayog fishing port who had experience with the JTED (Suasi, 2016). Results indicated that 63 percent of respondents felt the device reduced the capture of juvenile fish, and 81 percent were satisfied with the catch in spite of the exclusion of some small, commercially important fish species. Only 75 percent of respondents were satisfied with the design of the JTED, and only 70 percent were sufficiently convinced to continue using the JTED and promote its use to other fishers. Other concerns with the JTED included potential increases in fuel consumption and construction costs.

Regulations

In recent years, significant concerns have been raised over the reduced biomass and CPUE of commercial vessels (FAO & SEAFDEC, 2015; Ramiscal *et al*., 2017). These concerns contributed to the introduction in 2010 of a mandate requiring commercial fishers to use the JTED, in line with Fisheries Administrative Order No. 237 (Hermes, 2009; Pido, 2012). Two variations of the JTED are mandated, one with vertical bars 12 mm apart and the other with horizontal bars 15 mm apart. A minimum mesh size for the codend is also stipulated, of 27.5 mm (FAO, 2000).

Outreach and extension

Early efforts to inform and raise awareness of bycatch issues and bycatch reduction devices include local meetings and workshops in the Samar Sea region, and as well as a related national workshop (Ramiscal and Dickson, 2013). Those attending these events included fishers, boat owners, government officials including members of law enforcement agencies, researchers, NGO representatives, and others. The events were also an opportunity for attendees to express their views, concerns and identify possible solutions.

Following these meetings and workshops, the JTED was tested to reduce the catch of juveniles and trash fish. The Bureau of Fisheries and Aquatic Sciences (BFAR) and SEAFDEC led this initiative as part of the REBYC-II CTI project.[7] The programme included workshops with fishers and others describing the rigging, operation, performance, and benefits of the JTED, as well as literature and videos describing JTED construction and performance, and field testing onboard a local trawler, though often only for one or two days.

Following the introduction of JTED regulations, fishers were asked to prioritize issues affecting their fishing operations (Ramiscal *et al*., 2017). One of the issues given the lowest priority was compliance with JTED regulations, and this choice was attributed to the fishers' participation in the REBYC and the REBYC II-CTI projects. The latter included the planning, implementation and monitoring of the projects, as well as associated experience in JTED rigging and operation; an example of this collaboration is provided in FAO (2004b).

[7] Additional information on the REBYC-CTI project can be found at: www.rebyc-cti.org.

3.15 SURINAME

The industrial fishery for Atlantic seabob shrimp (*Xiphopenaeus kroyeri*) commenced in the late 1990s (MAAHF, 2013; Willems, Babb-Echteld and Yspol, 2016). In total, 26 trawlers now operate in this fishery (MSC, 2019) and landings vary between 6 000 and 10 000 tonnes annually (Willems, Babb-Echteld and Yspol, 2016). Catches are dominated by seabob shrimp (approximately 60 percent), fish and elasmobranchs (approximately 31 percent), as well as jellyfish and benthic invertebrate bycatch. Discarded bycatch consists mainly of fish with a total length of around 100 mm. Retained bycatch represents around 4 percent of total catch volume, and includes Bangamary (*Macrodon ancylodon*), trout (*Cynoscion virescens*), butterfish (*Nebris microps*) and brown shrimp (*Penaeus subtilis*). This fishery has been certified by the Marine Stewardship Council (MSC) since 2011 (Willems, Babb-Echteld and Yspol, 2016; Garstin, Oxenford and Maison, 2017), although a key ongoing concern is the capture of globally endangered elasmobranch species, all of which are discarded overboard (Willems *et al.,* 2016). A full description of bycatch is provided in Meeremans, Babb-Echteld and Willems (2017).

A penaeid shrimp fishery in Suriname commenced in the 1960s and targets brown shrimp *(Penaeus subtilis),* Hopper *(Penaeus brasiliensis*), pink shrimp *(Penaeus notialis)* and white shrimp *(Penaeus schmitti)* (MAAHF, 2013; Willems, Babb-Echteld, & Yspol, 2016). The fleet consists of around 20 active vessels, which land between 400 and 600 tonnes annually (Meeremans, Babb-Echteld and Willems, 2017). The vessels and fishing gear are similar to that employed in the seabob fishery. The catch composition is not well reported, and it is thought that up to 70 percent of bycatch is discarded (Babb-Echteld, 2016). Retained bycatch includes snapper and croaker species.

There is also a large deepwater shrimp fishery that targets orange shrimp (*Solenocera acuminate*) and scarlet shrimp (*Pleisopenaeus edwardsianus*), although only four licences have been granted to vessels to operate in this fishery (MAAHF, 2013).

Finally, Suriname has a trawl fishery targeting demersal finfish. The fleet consists of around 45 trawlers, which include a variety of vessel and gear types. Stern trawlers use a single net or a double net in a twin-rig configuration, while converted Penaeid shrimp trawlers deploy two trawls from the outriggers. The fishery mainly targets croakers and weakfishes (Sciaendae), snappers (Lutjanidae), grunts (Haemulidae) and catfishes (Ariidae). On average, 49 percent of the catch in the fishery is discarded, including undersized or damaged individuals of retained species (56 percent) and non-target species (44 percent). The fishery interacts with several vulnerable marine species, which are either discarded or retained, including rays, sharks and marine turtles (Meeremans, Babb-Echteld and Willems, 2017). The Surinamese demersal finfish fishery has been included here because it was part of the REBYC-II LAC project, and because the lessons learned show how best practice can improve outcomes in tropical bottom trawl fisheries.

PLATE 17
A TED with reduced 2-inch bar spacing (left, also referred to as a TTED) alongside a conventional 4-inch TED (right), during sea trials in the Suriname seabob trawl fishery

© T. Willems

TEDs

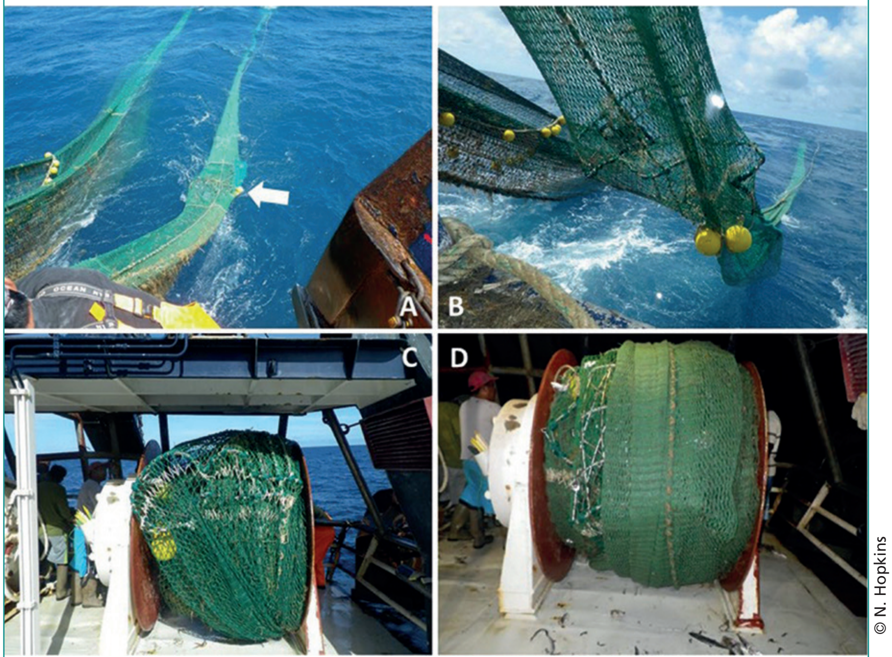
The regulated use of approved TEDs has been a feature in the seabob and penaeid shrimp fishery since 1999 (Willems, Babb-Echteld and Yspol, 2016). Trawl nets are required to be equipped with a Super Shooter TED, installed as a downward excluder and with a bar spacing of 10.2 cm (Figure 11). No guiding funnel is used, and the escape opening and cover nets are consistent with United States of America regulations for the protection of sea turtles.

Anecdotal information from fishers indicates that sea turtle bycatch has been virtually eliminated since the introduction of TEDs (Willems, Babb-Echteld and Yspol, 2016). These devices also reduce the ray catch by 36 percent and that of some other species by over 70 percent. The mean size of rays retained in the codend is 21 percent smaller, on average, than rays caught in a trawl without a TED (Willems *et al*, 2016).

Additional efforts to reduce the capture of rays includes using trash and turtle exclusion devices (TTEDs) with a bar spacing of 50.8 mm and 76.2 mm (Willems and Meeremans, 2017) (Plate 17). The TTED with the smaller bar spacing reduced commercial fish catch by 23 percent compared to a standard TED and increased the shrimp catch by 20 percent (n = 31). The TTED with the larger bar spacing reduced total bycatch by 17 percent, ray bycatch by 44 percent, and increased shrimp catch by 16 percent. A comparison between upward-excluding and downward-excluding grids found the effect of grid orientation had little impact on catch composition.

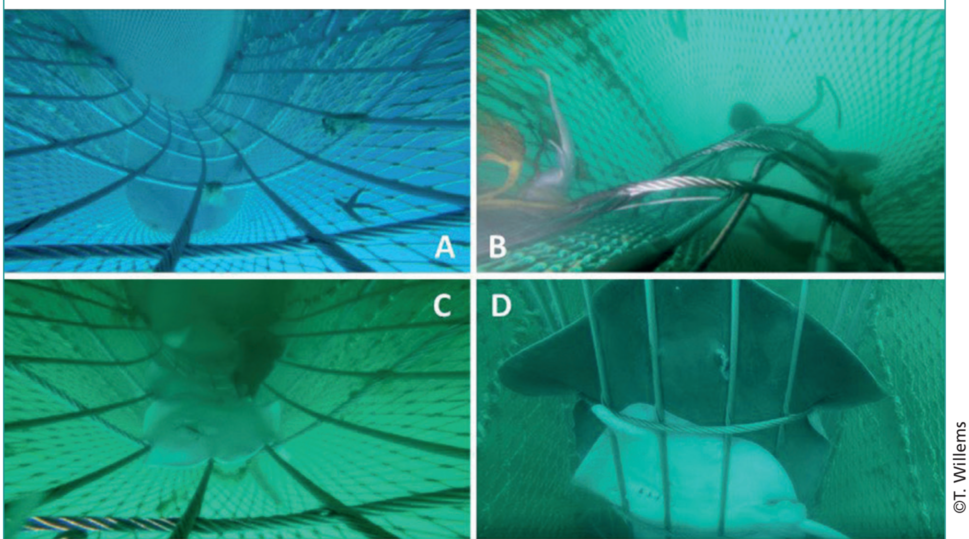
In recent years, significant efforts have been made by the Surinamese government, in collaboration with the fishing industry, WWF and NOAA, to develop a TED or sorting grid for the finfish trawl fishery. Experiments have been carried out with a flexible grid design that can wrap around a net reel when the trawl is hauled onboard (FAO, 2017c). Results in terms of the deployment and user-friendliness of the grids

PLATE 18
Flexible sorting grid during the sea trials in the Suriname demersal fish trawl fishery



(A) position of the grid (arrow) in the portside trawl; (B) close-up of grid in trawl; (C) grid being wound on the net reel; (D) complete net with grid packed onto the net reel.

PLATE 19
Underwater video stills of early prototype flexible sorting grids during sea trials in the Suriname demersal fish trawl fishery

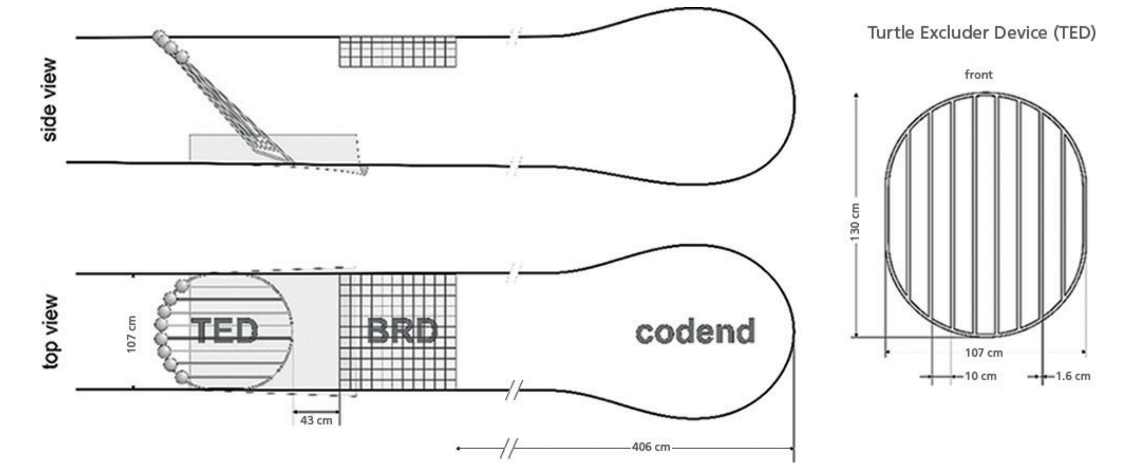


(A) top-down view, 5-inch grid; (B) bottom-up view, 7-inch grid; (C) top-down view, 5-inch grid; (D) top-down view behind 7-inch grid.

have been good since the start (Plate 18), but early prototypes suffered from excessive catch loss, mainly due to fouling of the grid with rays (Plate 19). This issue has been overcome by using a downward-excluding grid with a lower angle and an enlarged

sorting area (Figure 13). Sea trials with the latest prototype have shown significant reductions in discards (mainly rays, sharks and marine turtles), while the target finfish catch remains unaffected (T.Willems, personal communication, 2020) An outreach

FIGURE 13
TED and square mesh panel configuration, as used in the Suriname seabob trawl fishery



Source: T. Willems (National Project Coordinator, REBYC-II LAC).

Final prototype flexible sorting grid for the Suriname demersal fish trawl fishery

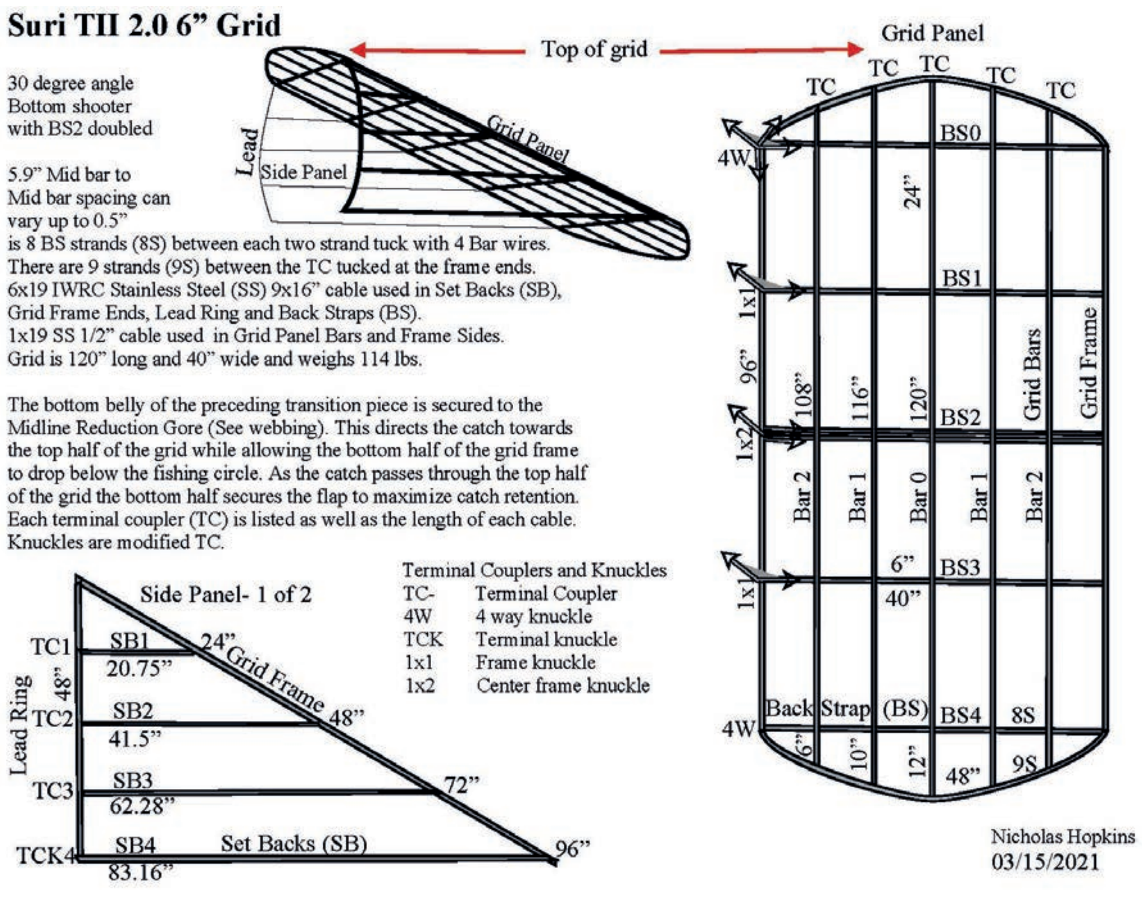


PLATE 20
Square-mesh panel BRD installed in a trawl in the Suriname seabob trawl fishery

©Heiploeg Suriname N.V.

programme for adoption of the device by the fleet is currently being rolled out. The development of sorting grid for the demersal finfish fishery is considered one of the REBYC-II LAC project's key achievements in the country.

A full description of TED (and BRD) research in Suriname, including a description of experimental design such as testing and sampling protocols, is provided in Willems, Babb-Echteld and Yspol (2016), a publication developed under the REBYC-II LAC project.

BRDs

The use of a square-mesh panel in the seabob fishery has been a regulatory requirement since 2009 (Willems, Babb-Echteld and Yspol, 2016). The panel measures minimum 11 by 11 meshes and is constructed with a stretched mesh size of 150 mm (Plate 20). This BRD is located approximately 60 cm behind the TED and has demonstrated an ability to reduce fish bycatch (by weight) by an average of 34 percent compared to an unmodified trawl. As part of the REBYC-II LAC project, a modification to the BRD was tested to further reduce finfish bycatch by reducing the water flow in front of the BRD. Although preliminary results appeared positive, no conclusive results were available at the time of writing (T. Willems, personal communication, 2020).

Regulation

Mesh size in the seabob fishery ranges from 57 mm in the wings and body to 45 mm in the codend (Willems, Babb-Echteld and Yspol, 2016). These trawls are similar to the ones used in the penaeid and deepwater shrimp fishery. Demersal fish trawls are required to have a minimum codend mesh size of 80 mm. A regulatory requirement to use TEDs and BRDs in the seabob fishery has been vital to achieving MSC certification (Southall *et al*., 2011). Certification also reflects confidence in Suriname's monitoring, control and surveillance programme, as well as compliance by fishers with this and other regulations, including the no-fishing zones. Details of regulations specific to this fishery are provided in MAAHF (2010; 2013). The use of TEDs is also required in the penaeid shrimp fishery in Suriname, but not in the deepwater shrimp fishery, where

no turtle interactions have been reported. One of the objectives of the 2021–2025 national fisheries management plan is to introduce TEDs into the demersal fish trawl fishery and to expand the use of BRDs to all trawl fisheries (T. Willems, personal communication, 2020).

Outreach and extension

Substantial collaborative efforts have been made between fishers, researchers and managers to obtain MSC certification for the seabob fishery, including the development of a Code of Practice requiring compliance from skippers and crew (Southall *et al*., 2011). The code describes sustainability goals, including a strategy to avoid fishing impacts on endangered, threatened and protected species, and includes a range of reporting templates for fishers to document important information. Failure to comply with the code can result in disciplinary action by the employer. A seabob working group has also been formed to develop the seabob fishery management plan, and to monitor the fishery's performance against this plan closely (CRFM, 2019; MAAHF, 2019). The concept of the seabob working group has recently been expanded to a national shrimp and groundfish working group, which acts as a stakeholder platform to keep track of the implementation of the new 2021–2025 fisheries management plan (MAAHF, 2021).

3.16 THAILAND

Bottom trawling for shrimp commenced in the 1960s (Supongpan and Boonchuwong, 2010; DOF, 2015; Derrick *et al*., 2017). In 2007, the catch from bottom trawlers amounted to approximately 650 000 tonnes; it was made up of fish for human consumption (46 percent), trash fish (42 percent), shrimp (3 percent), and crabs, cephalopods and shellfish. Most of the trawl catch is retained and landed, with little discarding.

The shrimp catch is largely comprised of *Penaeus* and *Metapenaeus* prawn species (Janekitkosol *et al*., 2003; Supongpan and Boonchuwong, 2010). Trash fish is comprised of at least 40 species groups, dominated by the family Leiognathidae (25 percent) (Khemakorn *et al*., 2005). It is also primarily made up of small, juvenile or adult fish (FAO and SEAFDEC, 2017). The codend mesh size on shrimp trawlers can be as small as 15 mm (DOF, 2015). A detailed description of Thai fisheries, including those that land shrimp, is provided in DOF (2015), together with a detailed national policy for fisheries management.

TEDs

Testing of TEDs dates back to at least 1996, when several TED designs were tested in two fishing locations (Table 10) (Chokesanguan *et al*., 1997). In the first experiment, all TEDs except the TTFD were tested. Each TED was tested for eight hauls (four during the day and four at night) and the Super Shooter TED, Georgia Jumper TED, and Thai KU were found to provide superior catch retention both during the day and at night. Shrimp loss with the Super Shooter was less than 2 percent and lower than all other TEDS. The escape of pelagic and demersal fish was also lowest with this device. In the second experiment, the Super Shooter, Bent Pipe, Georgia Jumper, Mexican, Thai KU, and TTFD were tested. The Anthony Weedless TED was not tested due to poor performance during the first experiment. Each TED was tested for eight hauls, and the Super Shooter and TTFD were the most effective at retaining the total catch during the day and at night. Shrimp loss for the Super Shooter, TTFD and Georgia Jumper was 1 percent or lower, and the escape of valuable pelagic and demersal fish was 4 percent or lower with all three TEDs.

BRDs

There is a relatively long history of developing bycatch reduction in Thai trawl fisheries. In these fisheries, bycatch generally consists of juveniles of commercially important fish, unwanted fish, and endangered, threatened and protected species such as marine turtles and some bottom invertebrates (FAO & SEAFDEC, 2017). Early efforts considered the use of Fisheyes and square-mesh panels, although in the late 1990s the Juvenile and Trash Excluder Device (JTED) was developed by SEAFDEC specifically to reduce the capture of small juvenile fish and unwanted trash fish (Plate 21). This device has been widely tested in Thai waters (FAO, 2000), including as part of the FAO REBYC and REBYC-II CTI projects (Chokesanguan, 2002), as well as in

TABLE 14
The effect of TEDs on total catch (fish and shrimp) in Thailand

TED	Bar spacing (mm)	Dimensions (height. by width) (cm)	Experiment 1 Total catch escape (percent)		Experiment 2 Total catch escape (percent)	
			Daytime	Night-time	Daytime	Night-time
SS	100*	90 x 80	8.4	5.3	2.7	1.9
AW	100	115 x 90	49.0	36.0		
BP	80*	110 x 80	4.0	18.9	2.2	13.5
Mexican	130	128 x 83	19.9	9.6	1.9	11.5
GJ	90	115 x 80	5.9	11.0	6.2	0.1
Thai-KU	110	120 x 80	8.0	2.8	8.8	11.1
TTFD	90	100 x 80			1.8	1.0

**Estimated from design schematics.* All proportions represent the reported catch loss (by weight) in a codend fitted with a TED in comparison to a standard codend (no TED fitted). SS - Super Shooter TED, AW - Anthony Weedless, BP - Bent bar, GJ - Georgia Jumper, Thai KU - Thai Kasetsart University TED. Testing took place in the Chumporn province (Experiment 1) and Songkhla province (Experiment 2).
Source: Chokesanguan *et al.* (1997).

TABLE 15
Percent reduction in commercial catch, cephalopods and trash fish for each JTED and bar spacing

Rectangular window JTED				Semi-curved JTED			
Bar spacing (mm)	Comm. sp.	Cephalopod	Trash fish	Bar spacing (mm)	Comm. sp.	Cephalopod	Trash fish
8	37.4	98.4	5.2	4	29.1	44.1	9.0
12	59.5	100.0	19.9	6	36.0	25.5	5.2
16	35.4	81.7	19.9	8	33.0	19.3	12.4
24	32.4	78.7	6.1	12	33.0	23.2	10.1

early efforts off the coast of Prachub kirikan and Chumporn in the Gulf of Thailand (Chokesanguan *et al*., 2000; Chokesanguan, 2004; Chokesanguan *et al*., 2010). Two types of JTED have been tested: a rectangular-shaped window and a semi-curved window. Both were attached to the top of the codend (Table 15). The rectangular-shaped window measured 100 by 80 cm and was fitted with parallel polypropylene ropes; it was tested with 8 mm, 12 mm, 16 mm, and 24 mm bar spacing. The semi-curved window was also constructed with parallel polypropylene ropes and tested with 4 mm, 6 mm, 8 mm and 12 mm bar spacing. A fine-mesh cover net was used to encapsulate the entire codend and retain animals that escaped through the bars of the JTED. Each device was tested for eight or nine hauls, with each haul lasting one hour.

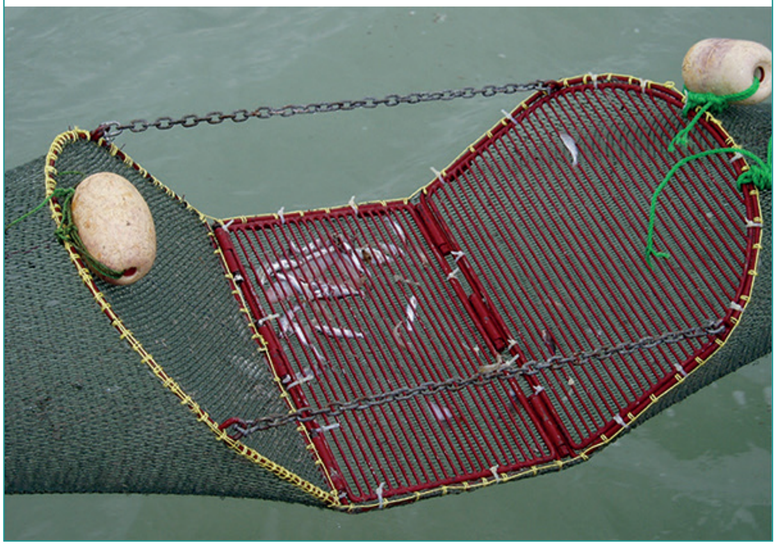
Regulations

Illegal fishing in Thai waters is a source of major concern (Chullasorn and Chotiyaputta, 1997) as is regulation, in light of weak monitoring, control and surveillance, and indeed poor enforcement (Pimoljinda, 2002). No measures have been mandated to reduce bycatch in Thai trawl fisheries, although some consideration has been given to using TEDs in shrimp-trawl fisheries (Supongpan and Boonchuwong, 2010). There is also no minimum mesh size in the trawl fishery (Supongpan and Boonchuwong, 2010; Derrick *et al*., 2017) although a 20–25 mm codend mesh size is not uncommon (Eiamsa-ard and Amornchairojkul, 1997). The Department of Fisheries, Thailand, recently set a target to reduce the proportion of juvenile fish caught by 50 percent by 2019, while also establishing a new minimum codend mesh size of 50 mm, with the aim of achieving 100 percent compliance with this regulation from fishers.(DOF, 2015).

Outreach and extension

In the 1990s the Department of Fisheries Thailand commenced multiple outreach efforts in the country's fishing ports to familiarize fishers with the TTFD (Thubthimsang, 1997). The development and testing of the JTED by SEAFDEC and the Department of Fisheries, Thailand, included multiple domestic workshops with fishers and local authorities describing the rigging, operation, performance and benefits of the JTED. These usually took place as part of the REBYC-II CTI project, and were accompanied by field testing onboard a local trawler, often for only one or two days. The project demonstrated JTED testing and its associated construction and performance, as well as producing videos, brochures and other handouts. There is currently no evidence of Thai fishers using the JTED.

PLATE 21
The Thai JTED



© Eayrs (2012)

TRINIDAD AND TOBAGO

3.17 TRINIDAD AND TOBAGO

Shrimp fishing in Trinidad and Tobago is carried out by artisanal, semi-industrial, and industrial vessels (Gillett, 2008). The total shrimp catch is around 1 000 tonnes annually (Mohammed and Chan A Shing, 2003; Gillett, 2008), and is dominated by white shrimp (*Litopenaeus schmitti*), brown shrimp (*Farfantepenaeus subtilis*), pink shrimp (*F. notialis*), seabob shrimp (*Xiphopenaeus kroyeri*) and red-spotted shrimp (*F. brasiliensis*) (FAO/Western Central Atlantic Fishery Commission, 2000; Hutchinson, 2008). The bycatch-to-shrimp ratio can be as high as 15:1 (Maharaj and Recksiek, 1991). Landed bycatch exceeds the shrimp catch by 20 percent in the artisanal fleet, and by 260 percent in the semi-industrial fleet. (Gillett, 2008).

Artisanal vessels discard an estimated 90 percent of the bycatch, comprised mainly of juveniles of commercially important species, while semi-industrial vessels discard an estimated 70 percent of bycatch (Kuruvilla, 2001; Gillett, 2008). Information on the industrial fleet is scant, although it is estimated that approximately 30 percent of bycatch is discarded by this fleet and the rest is retained for sale (Kuruvilla, 2001). The bycatch is dominated by the families Carangidae, Gerreida, Lutjanidae, Portunidae, Sciaenidae, and Triglidae (Gillett, 2008). Many fish stocks are overexploited (Hutchinson, 2008), including the juveniles of commercially important species (Ferreira and Soomai, 2013). Records indicate a low incidence of turtle capture. A review of the shrimp fishery, including management and enforcement issues, historical landings, bycatch issues, and bycatch reduction research is provided in Gillett (2008) and Ferreira and Soomai (2013).

TEDS

The semi-industrial and industrial trawl fleets are required to use approved TEDs (Hutchinson *et al*., 2007; Gillett, 2008). These are composed of a rigid grid orientated to exclude large animals through the bottom of the codend. Bar spacing is 100 mm and the grid angle is 30–55 degrees. The performance of this TED is unknown.

BRDS

There have been increasing efforts to test BRDs in the fishery. In 2007, the Fisheye and square-mesh panel BRDs were tested in the artisanal and industrial trawl fleets (Soomai, 2007). Tests on an artisanal trawler were limited to five hauls with the Fisheye installed; the ensuing bycatch reduction was 24 percent on average, while average shrimp loss was 50 percent. Two hauls were completed with the Fisheye on an industrial trawler; on average, bycatch reduction was 31 percent and shrimp loss was almost 50 percent. Three hauls with the square-mesh panel resulted in an average bycatch reduction of 27 percent and a 14 percent reduction in shrimp.

As part of the FAO REBYC–II LAC project in 2017, Trinidad and Tobago tested the performance of a square-mesh panel (SMP on an industrial double-rigged trawler). The panel was composed of 50 mm (bar length) square meshes. It was 14 meshes long, and 6 meshes wide (71.1 cm by 30.5 cm) and placed 1.23 m from the bag tie.

PLATE 22
Square-mesh panel for 2019 trials in Trinidad and Tobago (left); Researcher stitching a flap over a BRD to serve as control net (right)

© I. Khan

TABLE 16
Summary of the results of the bycatch reduction device gear trials in Trinidad and Tobago onboard industrial double-rigged trawlers

Dates	Square-mesh panel specifications	Panel position	Percentage (%) reduction in discards by weight
2017	A panel of 50 mm square meshes, 14 meshes long and 6 meshes wide (71.1 cm x 30.5 cm),placed 1.23 m from the bag tie	1.23 m in front of the bag tie, topside of codend	24.5%
2019	A panel of 50 mm square meshes, 24 meshes long, and 8 meshes wide (121.92 cm x 40.64 cm)	2.13 m in front of the bag tie, topside of codend	46.6%
2020	A panel of 50 mm square meshes,18 meshes long, and 8 meshes wide (91.44 cm x 40.64 cm)	2.49 m in front of the bag tie, topside of the codend	60.2%

Source: Imran Khan, personal communication, 2020.

(R. Mohammad, net builder, personal communication, 2019). Data from 29 hauls of 4 hours each (with 19 hauls fully sampled) showed an almost 25 percent reduction in discards and a 3 percent loss in shrimp (the latter number, however, was not considered statistically significant). Since the overall catch was considered low compared to historical records, and based on stakeholder inputs regarding regular catches, subsequent SMP tests with updated designs were conducted in 2019 and 2020. Table 1 summarizes all three tests. Information and data on the 2019 and 2020 tests have not yet been published and are based on personal communications from researchers (I. Khan, personal communication, 2020). Design changes reflect feedback from fishers on the best placement and size of the SMP.

With regard to the 2020 trials: after 26 hauls, discards were reduced overall by just over 60 percent; the overall marketable shrimp catch was reduced by just over 21 percent. There was only a modest reduction in marketable bycatch when using the experimental net. The data from the trials in 2017–2020 and shown in Table 16 requires further review and publishing.

Regulations

Trinidad and Tobago requires non-artisanal (semi-industrial and industrial) shrimp fishers to use TEDs in order to conform with the United States of America embargo on shrimp imports from countries that do not use approved TEDs (FAO, 2000; Ferreira and Soomai, 2013), though this was not well received by local fishers (Kelleher, 2005;

Gillett, 2008). This requirement has been in place since 1994 (Solomon, 2018). Since 1999 the Fisheries Division and the Coast Guard have undertaken dockside and at-sea inspections to ensure compliance with TED regulations.

Shrimp fishers are under considerable pressure to reduce bycatch because they are blamed for the depletion of local demersal fish stocks (FAO, 2001; Gillett, 2008). There is no evidence of BRD regulations (FAO, 2001; Gillett, 2008), with the exception of a minimum mesh size of 38 mm and a requirement for chafing gear to make up no less than 25 percent of the codend (Ferreira & Soomai, 2013). The primary legislation governing fishing activity governs mesh size, closed areas and fishing seasons (Solomon, 2018) as well as minimum landing sizes for major commercial species, but is considered outdated and inadequate (FAO, 2015).

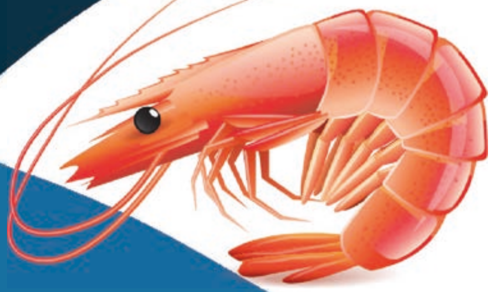
A draft fisheries management bill (which, once finalized, will repeal the Fisheries Act of 1916, as well as the relevant sections of the Archipelagic Waters and Exclusive Economic Zone Act of 1986) was introduced in the Trinidad and Tobago Parliament in October 2020 and referred to a Joint Select Committee for reporting by end December 2020. The bill makes provisions for the management of bycatch through the development of management plans and accompanying regulations. Technical regulations on BRDs, TEDs and other measures are the responsibility of the competent authority.

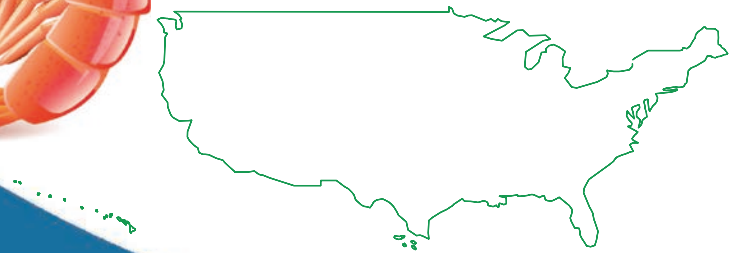
A draft national fisheries policy was established in 2011, requiring the use of BRDs to reduce discards by up to 50 percent, but this policy has not been formally ratified (Ferreira and Soomai, 2013). Primarily due to lack of funds, the entire fisheries sector is poorly monitored and controlled; regulations are not enforced (Soma, 2003) and compliance rates are low, including regulations pertaining to TEDs and minimum mesh size (Ferreira and Soomai, 2013). Many organizations representing fishermen do not participate in fishery management, and they are reluctant to address common difficulties and challenges (Soma, 2003).

Outreach and extension

Outreach and extension efforts are being made to inform fishers, boat owners and others about the need to reduce bycatch, as well as the design and performance of TEDs and BRDs as part of the FAO REBYC-II LAC project, either through the active participation of these individuals or by their learning of project outcomes. While the innate suspicion of fishers towards government officials (FAO, 2015) has possibly hampered earlier efforts to share information and encourage collaboration, efforts to communicate and share project results with fishers and others continue.

UNITED STATES OF AMERICA (THE)





3.18 UNITED STATES OF AMERICA (THE)

The United States of America has a very long and active history developing bycatch reduction devices in the Gulf of Mexico and South Atlantic shrimp fisheries, initially with a focus on reducing the mortality of sea turtles. Significant achievements have been made, particularly in terms of the development of effective TEDs and associated regulations. However, the incidental capture and mortality of red snapper (*Lutjanus campechanus*) remains a highly contentious issue in these fisheries, and there are concerns over the capture of other fish bycatch.

There are approximately 1 500 federally permitted shrimp trawlers in the Gulf of Mexico (Scott-Denton *et al*., 2012; Soldevilla *et al*., 2016) and approximately 500 in the South Atlantic (Scott-Denton *et al*., 2012). In 2010, shrimp landings amounted to approximately 80 000 tonnes; they were primarily made up of brown shrimp (*Farfantepenaeus aztecus*), white shrimp (*Litopenaeus setiferus*), and pink shrimp (*Farfantepenaeus duorarum*) (Scott-Denton *et al*., 2012). Shrimp accounts for less than 30 percent of total catch weight across both of the South Atlantic and the Gulf of Mexico. The bycatch is typically dominated by finfish, including commercially and recreationally important species (Hataway, Foster and Saxon, 2017). Information describing these fisheries, including bycatch issues, historical shrimp landings, and management and enforcement issues, is provided in Gillett (2008), Helies and Jamison (2009), and Gallaway, Gazey and Cole (2017).

TEDs

Efforts to avoid the capture and mortality of sea turtles in shrimp trawls date back to the late 1970s (Seidel, 1997; Watson, 1988), in response to the listing of all sea turtle species in United States of America waters as either threatened or endangered (Watson, 2000). Initially, these efforts included lacing large-mesh panels over the trawl mouth to prevent the entry of sea turtles. These panels reduced sea turtle capture by around 80 percent and were accompanied by shrimp losses of up to 30 percent (NOAA, 2017). In the 1980s, the NMFS TED was developed, consisting of a box-shaped frame with a grid of parallel bars to guide sea turtles towards a hinged escape flap (Watson, 1988). The frame was constructed of galvanized pipe and measured 91 cm long, 114 cm wide and 76 cm high. It was placed immediately ahead of the codend, and the parallel bars were spaced 7.5 cm apart to guide sea turtles towards the escape opening in the TED. The escape flap measured 76 cm by 76 cm. Originally, this device was used as a bottom-opening TED (Jenkins, 2012), and despite excluding up to 89 percent of sea turtles with minimal shrimp loss, it was cumbersome and heavy. Diver observations also indicated that sea turtles were having difficulty escaping past the escape flap (Watson, 1988; NOAA, 2017). This TED was then tested with a top-opening door, and sea turtle exclusion rates increased to around 97 percent. A funnel of net was installed ahead of the grid to guide the catch to the centre of the codend, and this improved the shrimp catch by 7 percent compared to an unmodified trawl.

In 1987, the use of TEDs became a mandatory requirement in the offshore shrimp fishery, accompanied by regulations designed to ensure that 97 percent of all sea turtles entering a shrimp trawl escape unharmed, with a 90 percent confidence interval (Hataway, Foster and Saxon, 2017). This was accompanied by a suite of design and rigging regulations, including a maximum bar spacing of 10.2 cm. Around this time fishers and net makers started developing their own TED designs, including the Georgia Jumper, Anthony Weedless and Super Shooter TED. A history of this development is described in Watson (2000), Jenkins, (2012), NOAA (2017), and Hataway, Foster and Saxon (2017).

In the inshore shrimp fishery, the use of TEDs became a mandatory requirement in 1992 (Hataway, Foster, and Saxon, 2017). Additional changes in TED design were then introduced in the late 1990s following concerns over the impact of shrimp trawling on leatherback turtles (*Dermochelys coriacea*). These changes include the use of large escape openings and double-cover escape openings. In 2010, the impact of grids with a bar spacing of 5.1 cm was evaluated and found to reduce the capture of sharks and rays by around 80 percent, as well as by 31 percent for croaker (*Micropogonias undulates*) (Hataway, Foster and Saxon, 2017). The associated shrimp catch was reduced by almost 10 percent. In recent years efforts have been made to evaluate TEDs in skimmer trawls and fish trawls, as well as the efficacy of a suite of modifications on shrimp and bycatch including various grid angles, orientation, curved bars and overlap of cover flaps (Gearhart *et al*., 2015).

BRDs

BRDs have been required in these fisheries since 1997 (Parsons and Foster, 2015) although concerns over the impact of shrimp trawling on fish bycatch, and particularly species of commercial and recreational importance, dates back to at least the 1970s (Seidel, 1997). The bycatch is discarded as this is required by regulations and it has no commercial value. Considerable efforts have been made to reduce fish bycatch, including evaluation of over 150 different bycatch reduction devices (Scott-Denton *et al*., 2012).

The BRDs certified for use in the Federal waters of the Gulf of Mexico and the South Atlantic shrimp fisheries include the composite panel, extended funnel, Fisheye, Jones-Davis BRD and the modified Jones-Davis BRD (Scott-Denton *et al.,* 2012; NOAA, 2019c). The composite panel consists of two vertical panels that taper inward, guiding catch towards the centre of the codend (NOAA, 2008a). These panels create regions of low, turbulent flow that allows fish to escape through a triangular escape opening on either side of the codend. Each panel is constructed from two overlapping sheets of netting. The interior panel is constructed from diamond mesh netting to reduce water flow, while the outer panel is constructed from square-mesh netting to provide support and prevent the panels from billowing outward, thereby closing access to the escape openings. This device is similar to the Radial Escape Section described in Eayrs (2012) and usually located immediately behind a TED, although it can be used in the absence of a TED.

The extended funnel design consists of a panel of large square mesh extending radially around the circumference of the codend (NOAA, 2008b). These meshes are held open by a semi-rigid hoop. A funnel of small-mesh netting guides fish and other animals past the square meshes. It also creates a region of slow, turbulent flow to allow fish to escape through the square mesh. A part of the funnel extends vertically to help create an area of low water flow. This device is also usually located immediately behind a TED. Construction details, images and instructions for the composite panel, extended funnel and the modified Jones-Davis BRD are available in NOAA (2008c).

TABLE 17
Estimated finfish reduction and shrimp loss (mean and range) for NOAA Fisheries approved BRDs by weight

BRD Type	Reduction in total finfish bycatch (percent)	Shrimp loss (percent)
Fisheye < 9′ from tie-off	37.0 (30.6–43.3)	10.4 (6.2–14.6)
Jones Davis	58.0 (53.0–63.0)	4.0 (0.0–9.0)
Modified Jones Davis	33.1 (30.3–36.0)	3.2 (1.4–4.9)
Composite panel with square-mesh panel	49.9 (44.1–55.6)	1.0 (-7.0–9.0)[1]
Composite panel with cone	51.3 (45.0–57.7)	8.2 (3.3–13.1)

[1]*Negative value represents a gain*
Source: Scott-Denton *et al.* (2012) via NOAA Fisheries Service, Pascagoula.

The Jones-Davis BRD is similar to the extended funnel in some respects, with a funnel of netting guiding the catch into the centre of the codend and producing regions of slow, turbulent flow. However, in contrast to the extended funnel, the escape openings of the Jones-Davis BRD are rectangular-shaped and are located on the sides of the codend. A total of four openings are available: two on either side of the codend, in addition to a semi-rigid wire hoop that is used to hold open the codend meshes. A cone fish stimulator is located behind the funnel to stimulate fish to turn and swim forward towards the escape openings.

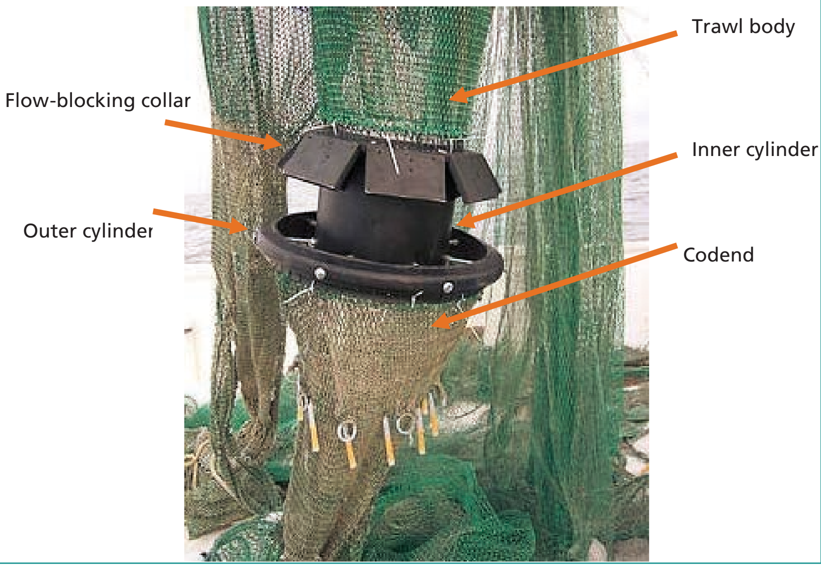
The modified Jones-Davis BRD replaces the netting funnel with two panels of netting, each attached to the codend in such a way as to guide the catch into the centre of the codend and produce regions of slow, turbulent flow.

The most commonly used device in this fishery is the Fisheye, primarily because it is perceived to be simpler to install and operate compared to other devices (Helies and Jamison, 2009; Graham and Reisinger, 2014). The Fisheye features a rigid frame attached to the top of the codend (Eayrs, 2007). The frame includes an elliptical escape opening that allows fish to escape while shrimp passively enter the codend.

All certified BRDs have demonstrated an ability to reduce fish bycatch by more than 30 percent, although shrimp loss of up to 10 percent has also been documented (Table 17). However, the projected reduction in annual revenues when using a BRD is often less than 3 percent, depending upon the ability of the fisher and fishing conditions (Federal Register, 2016b). A thorough review of bycatch reduction efforts in these waters is found in Scott-Denton *et al.* (2012) and (Gallaway, Gazey and Cole, 2017).

A relatively new development is the Nested Cylinder bycatch reduction device (Plate 23). It features a circular flow-blocking collar made of aluminium, and an inner and outer cylinder (Parsons and Foster, 2015). The inner and outer cylinders are bolted together, the codend is attached to the bottom of the outer cylinder, and the trawl net is attached to the top of the inner cylinder. The escape opening of this BRD extends around the circumference of the inner

PLATE 23
The Nested cylinder device



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cylinder. An adjustable canvas sock, attached to the bottom of the inner cylinder, guides catch past the escape opening. Meanwhile, the flow-blocking collar is attached to the inner cylinder and creates water turbulence as the trawl is towed through the water. This turbulence results in eddies and regions of relatively low water flow, which fish actively seek. With this BRD, the areas of low water flow are adjacent to the escape opening, thus reducing the effort required for small fish to escape the trawl. Trials with this device in 2007 resulted in a 32 percent reduction in bycatch and a 15 percent loss of shrimp. The red snapper catch was reduced by 27 percent. When the length of the sock was increased, bycatch reduction fell but shrimp retention increased.

Regulations

The United States of America is one of few countries with very detailed and prescriptive regulations for both TEDs and BRDs. A testing protocol related to the certification of TEDs is described in the Federal Register (1990b) and is sometimes known as the small-turtle testing programme (Jenkins, 2012; Gearhart *et al*., 2015). This programme involves the release of small, live turtles immediately ahead of an approaching trawl fitted with the TED. During the test, the towing speed is fixed at 1.25 ms^{-1} and each turtle has 5 minutes to escape. At least 25 turtles are used in the test, although it may be terminated prior to the release of all turtles if the TED is not performing as anticipated. Scuba divers are used to release, monitor and recapture the turtles, and the results are compared against a control TED tested under the same conditions, with the same year class of turtles (Jenkins, 2012; Gearhart *et al*., 2015). The performance of the TED is compared against a control TED and a statistical test is employed, which compares the proportion of turtles excluded by both TEDs (Federal Register, 1990b).

In the early 2000s, new TED regulations were introduced to ensure large leatherback turtles could escape capture, including modifications to the escape cover or flap (Jenkins, 2012); in 2016, over 90 percent of the fleet were compliant with TED regulations (Gearhart *et al*., 2015). Details of all TED regulations requirements, including regulations to protect leatherback turtles, can be found in NOAA (2019d) and Eayrs (2007). An example of TED testing is reported in Gearhart *et al*. (2015).

Since 1997, BRDs have been required in the Federal waters of the South Atlantic, since 1998 in the western Gulf of Mexico, and since 2004 in the eastern Gulf of Mexico (Federal Register, 2016b). Specifications for the five currently certified BRDs are described in Federal Register (2016b). To achieve certification, a BRD must reduce the weight of fish bycatch by at least 30 percent compared to an unmodified trawl (control) under controlled testing conditions (NOAA, 2016; Helies and Jamison, 2009). The unmodified trawl includes a certified TED. This reduction must be achieved in at least 50 percent of the test hauls and accompanied by a bycatch reduction of less than 25 percent in no more than 10 percent of the test hauls. The minimum sample size is 30 hauls, and a paired t-test is used to evaluate bycatch reduction performance (NOAA, 2016). Provisional certification of a BRD can be granted if the device achieves a 25 percent reduction in bycatch (Parsons and Foster, 2015; NOAA, 2016). Provisional certification is effective for two years from the date of publication in the Federal Register (Parsons and Foster, 2015). The NOAA bycatch reduction testing manual is available in NOAA (2016).

Outreach and extension

The United States of America has a long history of providing outreach and extension material to fishers and others, including information brochures, videos, industry workshops and demonstrations. As early as the 1970s the NOAA National Marine Fisheries Service (NMFS) Pascagoula Laboratories in Mississippi were working with fishers as part of their comprehensive TED testing and evaluation programme (Seidel, 1997). Many early TEDs were designed by fishers, netmakers and others, and then

tested under rigorous, controlled testing conditions using a standardized testing protocol. In the early 1990s efforts to reduce fish bycatch commenced in earnest, and this also included working closely with the fishing industry, notably taking into account design and operational considerations as well as performance evaluation (Seidel, 1997; Watson, 2000). According to Davis (2016), strong participation by fishers has been instrumental to the success of the TED programme.

Over the years, NOAA has continued to lead the way in TED and BRD outreach and extension. This includes a dedicated website on sea turtle protection,[8] which provides useful information such as a history of TEDs in the region, TED design and installation instructions, TED regulations and guidelines). A second NOAA website provides information related to using BRDs in the region including BRD design, construction, installation instructions and BRD testing protocols[9] Additional efforts include technical memoranda, port workshops, meetings and presentations. NOAA also issues annual calls for industry participation in TED and BRD testing and certification, including an invitation for fishers to test their own TED or BRD under controlled conditions at sea.

8 The website can be found at (https://sero.nmfs.noaa.gov/protected_resources/sea_turtle_protection_and_shrimp_fisheries/index.html)

9 Website can be found at www.fisheries.noaa.gov/southeast/bycatch/bycatch-reduction-devices-gulf-mexico-and-south-atlantic

VENEZUELA (BOLIVARIAN REPUBLIC OF)

3.19 VENEZUELA (BOLIVARIAN REPUBLIC OF)

In 2008, the industrial trawl fishery was banned from all Venezuelan waters (Tagliafico *et al*., 2016), although anecdotal reports suggest that some shrimp trawling continues with non-industrial vessels. Prior to this, shrimp trawling was a traditionally important fishing activity involving approximately 450 trawlers fishing for shrimp, fish and molluscs night and day (Alio, Marcano and Altuve, 1995). Shrimp trawling was introduced on an exploratory basis in the 1940s (Marcano *et al*., 2001) and was well established by the 1960s (Mendoza, 2015) or 1970s (Ferreira and Soomai, 2001). In 1991, shrimp landings had reached an estimated at 7 000 tonnes (Alio, Marcano, and Altuve, 1995). By 2007, these landings had reached 12 400 tonnes, and bycatch was over 100 000 tonnes (Alio *et al.*, 2009; Davis *et al*., 2009).

The shrimp catch was dominated by white shrimp (*Litopenaeus schmitti*) and brown shrimp (*F. subtilis*), and to a lesser extent by pink shrimp (*Farfantepenaeus brasiliensis* and *F. notialis*) and Titi (*Xiphopenaeus kroyeri*) (Alio, 2001; Alio *et al.*, 2009). Shrimp made up around 11 percent of total catch weight, and 20–30 percent of bycatch consisted of commercially valuable species (Alio, Marcano and Trujilio, 1995; Davis *et al*., 2009). The bycatch included croakers (*Macrodon ancylodon*, *Micropogonias furnieri*, and *Cynoscion virescens*) and catfish (*Arius parkeri* and *Cathorops spixii*) (Alio, 2001). The bycatch discard rate was around 60 percent (Kelleher, 2005; Mendoza, 2015), and mainly composed of juvenile fish, including commercially important species (Alio, Marcano and Trujilio, 1995).

TEDs

Limited evidence of TED research prior to the trawl ban has been found. However, between 1994 and 2000 around 120 fishing trips were completed using a Super Shooter (Alio, Marcano and Altuve, 2010). This TED measured 167 cm by 114 cm, and no sea turtles were caught. The catch of commercially important fish increased by 23 percent following efforts to increase bar spacing from 10 cm to 14 cm (Hernandez, 2002). Prior to the introduction of TEDs, the mortality of sea turtles from trawling was estimated at 63 individuals per year, and the estimated rate of turtle capture for each trawler was one turtle per 930 hours of trawling (Alio, Marcano and Altuve, 2010).

BRDs

Consideration of trawl modifications to reduce bycatch date back to at least the 1980s; the modifications included the installation of escape panels in the upper panel of the trawl extension, footrope modification, and use of the Suripera (Alio, Marcano and Trujilio, 1995; Hermes, 2009). These modifications reduced bycatch by 40 percent and the shrimp catch by 25 percent. In a subsequent study, the performance of three escape panels was tested. The first involved the installation of a square-mesh panel in the codend, measuring 42 bar lengths long and 31 bar lengths wide. The netting substituted by the square-mesh panel was cut on three sides and then pushed down to form a guiding panel ahead of the escape panel. In this way the catch approaching the

escape panels was guided toward the lower panel of the trawl; this served to reduce the loss of shrimp and commercial fish. The second escape panel was constructed from green netting with a bar length of 59 mm. This panel measured 35 bar lengths long and 28 bar lengths wide. The third panel consisted of 10 parallel lengths of rope. Based on the results of eight research cruises, and comparing catches between a control and modified trawl, non-commercial bycatch was reduced by up to 49 percent. Shrimp catch was highly variable, ranging from a 50 percent loss to a 70 percent increase. Subsequent testing of the first escape panel reported an average bycatch reduction of 45 percent (Pomares *et al*., 1998). Testing in 2007 included a Fisheye and the Suripera, which in some instances reduced bycatch by 62 percent, with little or no shrimp loss (Alio *et al.*, 2009).

Regulations

Prior to the trawl ban, the Venezuelan fleet traditionally used 50 mm mesh in the body of the trawl and 35 mm in the codend (Alio, Marcano and Altuve, 1995; Pomares *et al*., 1998; Pomares *et al*., 1998). This fleet had been using approved TEDs since 1993 to avoid the United States of America embargo (Pomares *et al*., 1998), although significant losses of shrimp and valuable fish were reported (FAO, 2000). This was a significant inducement not to use TEDs, particularly offshore when the likelihood of detection by enforcement was more limited (Alio *et al*., 2010). Regulations relating to BRDs included a mandate for a Fisheye with an elliptical escape opening measuring 220 mm wide and 135 mm high located in the top panel of the codend (Pomares *et al*., 1998).

Outreach and extension

Outreach and extension efforts prior to the trawl ban, which may have aimed to inform fishers, boat owners and others about reducing bycatch and the design and performance of TEDs and BRDs, are unknown.

3.20 VIET NAM

Bottom trawling for shrimp and fish is a dominant fishing practice in Viet Nam, with approximately 21 000 boats engaged in the activity, accounting for around 20 percent of total boat numbers and 40 percent of total landings (Thanh and Phu, 2004). The shrimp catch is dominated by giant tiger shrimp (*Penaeus monodon*), Greasyback shrimp (*Metapenaeus ensis*), and pink shrimp (*M. affinis*) (Eayrs, Hai and Ley, 2007); it typically accounts for around 40 percent of total catch weight but 70 percent of total catch value (FAO, 2013b). By comparison, trash fish typically accounts for around 40 percent of catch weight, but only around 8 percent of its value. Concern over the impact of bottom trawl fishing on trash fish has been a key reason for Vietnamese interest in bycatch reduction.

TEDs

Limited evidence has been found of TED research in Viet Nam. In the early 2000s some effort was apparently made to test TEDs fitted to shrimp trawls (Thanh and Phu, 2004) but no details describing the success or otherwise of these tests have been found. No evidence could be found suggesting recent efforts to test TEDs in this fishery.

BRDs

In the early 2000s, research with JTEDs and square mesh windows commenced in the Tonkin Gulf (Thanh and Phu, 2004). At least five types of JTED were tested, with bar spacing measuring 12 mm, 20 mm, 25 mm, 30 mm and 40 mm. Each rectangular frame of the JTED measured 500 mm by 800 mm. Two different-sized square-mesh windows were tested measuring 1.2 m by 0.8 m and 2.0 m by 0.8 m. Each square-mesh window was tested with a bar length measuring 20 mm, 25 mm, 30 mm, 35 mm and 40 mm. The performance of each device was evaluated using a covered codend and towing for one hour.

From smallest to largest bar spacing, the JTED reduced the total retained catch (shrimp and other valuable species) by 28 percent, 20 percent, 24 percent, 47 percent and 45 percent respectively. The smaller square-mesh window reduced total retained catch by 17 percent, 19 percent, 21 percent, 29 percent and 33 percent respectively, from smallest to largest bar length, and the larger square-mesh window reduced total retained catch by 34 percent, 48 percent, 46 percent, 51 percent, and 64 percent respectively. Neither the effect of these devices on the shrimp catch nor the total number of tows was recorded.

The Research Institute for Marine Fisheries (RIMF) and SEAFDEC also tested the JTED in 2001 and 2005, conducting field tests and demonstrations of TED performance as well as providing information on rigging and operating the device (Chokesanguan *et al*., 2010). Three rectangular rigid sorting grids were tested with a bar spacing of 20 mm, 30 mm and 40 mm (Chokesanguan, 2004). A cover net surrounding the JTED and codend was used to retain escaped fish to demonstrate the performance of the JTED, and the catch was sampled from 21 hauls of 1 hour each (7 hauls per JTED).

From smallest to largest bar spacing, the escape rate of trash fish, was 28 percent, 15 percent and 12 percent respectively. The escape rate of pelagic fish was 22 percent, 25 percent and 40 percent respectively, while the escape rate of demersal fish was 17 percent, 10 percent and 14 percent respectively. The impact on the shrimp catch was not described.

The JTED was also tested off the Vietnamese coast in the Gulf of Thailand in 2003, which also included a survey of Vietnamese fishers. A total of 65 fishers responded, which found that trash fish makes up just over 50 percent of the total catch landed by small trawlers (< 15 hp) but only around 5 percent for the largest trawlers (45–60 hp) (Eayrs and Nguyen, 2004). The retention of trash fish was favoured by all fishers in the small trawler category but none in the largest trawler category. In decreasing order of preference, responses from all fishers indicated their expectations for a BRD were: no loss of commercial catch, cheap construction and maintenance costs, ease of handling, and reduced catch sorting time.

The JTED was first tested in a flume tank to evaluate changes in water velocity and direction in and around the device as it is towed through the water (Eayrs, Hai and Ley, 2007). This was followed by at-sea testing with a codend cover placed around the escape opening to retain catch that escaped. After completion of 15 hauls of 3 hours each, the JTED was found to reduce the shrimp catch by 8 percent, trash fish by 73 percent, and the catch of valuable fish by 16 percent – although most of the valuable fish and shrimp that escaped were smaller than the minimum legal landing size. The estimated loss of revenue using the JTED was 9 percent, although yield-per-recruit analysis indicated that this loss could quickly be offset by not catching fish less than the minimum legal landing size.

Recent efforts to reduce bycatch include testing two square-mesh codends: one with a bar length of 12.5 mm and the other of 15 mm (Phu, Hung and Hung, 2016). A small-mesh covered codend was used to surround each square-mesh codend and retain animals that escaped internal. The catch was sampled from a total of 16 hauls of 2 hours each. The escape rate of shrimp and fish bycatch from the 12.5 mm codend was 51 percent and 42 percent respectively; from the 15 mm codend it was 67 percent and 55 percent respectively. A significant proportion of escaped shrimp and fish were less than the minimum landing size.

Regulations

Regulations are in place to prohibit fishers from landing certain species at certain times of the year, and they must also comply with minimum mesh regulations (Ministry of Fisheries, 2006). This includes a 20 mm minimum mesh size for small shrimp trawlers (less than 33.5 kW), 30 mm for medium-sized boats (33.5–112 kW), and 40 mm for larger boats. Violation of these regulations is widespread (Long and Thong, 2008; Nguyen, 2011). Moreover, there is no legal framework that supports the management of trawling (FAO, 2013b), there are no regulations requiring the use of TEDs (Davis, 2016), and so the trawl catch is essentially unmanaged (Davis *et al*., 2009).

Outreach and extension

The Research Institute for Marine Fisheries (RIMF) and SEAFDEC hosted JTED testing and training programmes in 2001 and 2005, which included field tests and demonstrations of TED performance, as well as the provision of rigging and operational information (Chokesanguan *et al*., 2010). This work was part of the FAO REBYC-II CTI project. These programmes included workshops with fishers and local authorities describing the rigging, operation, performance and benefits of the JTED. This was accompanied by field testing on a local trawler with fishers and other individuals onboard to observe testing, often for only one or two days. The voluntary uptake of the JTED or other BRD by Vietnamese fishers is unknown, despite these efforts.

OTHER COUNTRIES

There appear to be a number of countries that have made limited or no effort to reduce bycatch through gear modification, or where information is either scant or unknown (Table 13). Brief reviews of shrimp-trawl fisheries, bycatch issues, regulation and surveillance for many African countries including Angola, Guinea, Guinea-Bissau, Kenya, Mauritania, Morocco, Mozambique, Namibia, Senegal, South Africa, Tunisia and the United Republic of Tanzania are available in FAO (2018). Additional information is provided in Fennessy, Mwatha and Thiele (2004), although both sources lack detail regarding bycatch reduction, possibly because so little has been done to reduce bycatch through gear modification in these countries. TEDs are apparently used in Kenya and Mozambique, although compliance with regulations is low due to gear blockage, damage and shrimp loss (FAO, 2020b). Cameroon was a participant in the REBYC project (Hermes, 2009) although its recent progress is unknown. Nigeria appears to be at the forefront of African bycatch reduction and is currently recognized by the United States of America as using approved TEDs (Federal Register, 2016a).

In Southeast Asia, many countries have conducted limited testing of TEDs and/or BRDs, although information is also limited and lacking in detail. Many countries participated in the REBYC and REBYC-CTI projects, including Indonesia, Malaysia (REBYC only), Philippines (the), Thailand and Viet Nam (see country reports). Brunei Darussalam, Cambodia and Myanmar also participated in REBYC-I, yet apart from a summary of JTED testing conducted under limited testing conditions, as provided by SEAFDEC and the host fishing departments (see Chokesanguan *et al*., 2010), it is not known whether subsequent or additional efforts have been made to reduce bycatch in these countries. Based on the available literature, it seems there has been little recent progress.

In the Near East, progress towards bycatch reduction has also been limited. Bahrain has conducted limited testing of BRDs, although information describing recent efforts to reduce bycatch are scant. In Saudi Arabia the fishery no longer exists. Iran (Islamic Republic of) and Kuwait (see country reports) appear to have made the greatest progress, having tested multiple devices over a relatively long period of time.

TABLE 18
Progress toward bycatch reduction

Country	Comments
Bangladesh	In 2004, the industrial trawl shrimp catch was 3 000 tonnes and the artisanal catch was approximately 15 000 tonnes per annum (Ahmad, 2005). TEDs are required by law, although the shrimp fishery is characterized by a weak regulatory framework and law enforcement capability (Davis, 2016). The use of TEDs in this fishery is deemed to be minimal (Davis, 2016), and discard rates are an estimated 80 percent (Kelleher, 2005). The codend mesh size on most shrimp trawlers is 45 mm (Khan, 2018). A review of the shrimp fishery is provided in Khan (2018).
Bahrain	The shrimp fishery captures around 300 turtles every year (Abdulqader, 2010). This country has conducted some experiments with BRDs (TED and square-mesh windows), particularly during the REBYC project (Hermes, 2009). There are no specific regulations for bycatch reduction, aside from legislation associated with a closed season. There are no known efforts to use a TED or other conservation measure to protect sea turtles. A new national bycatch reduction plan was drafted and awaits funding (Hermes, 2009).
Cambodia	Few known measures to manage or reduce bycatch have been attempted (Kelleher, 2005). Several BRDs were tested in 2004 in collaboration with SEAFDEC, including the rectangular window, semi-curved window with 10 mm bar spacing, and the semi-curved rigid sorting grid with 10 mm and 20 mm bar spacing (Chokesanguan *et al*., 2010). The 10 mm sorting grid had the lowest escape rate of commercial catch.
Cameroon	A review of the shrimp fishery is provided in Njock (2001). Marine fisheries management policy is weak, stakeholder conflict is high, and compliance with regulations is low. Vessels catching shrimp use mesh sizes as small as 10 mm. Shrimp production is less than 1 000 tonnes per annum and a significant proportion of fish bycatch is retained for sale. Bycatch includes Scianidae, Cynoglossidae, Arisu spp., Polynemidae, Haemulidae and Clupeidae (Njifonjou, 2008). Discards include hairtails (16 percent), crabs (13 percent), and juveniles of many species (42 percent). A comparison using a quad-rig trawl system (n = 21 two-hour hauls) compared catches between a codend with a TED, a T90 codend, and a codend with a square-mesh window, and found the shrimp catch (kg) was reduced by 25 percent, increased by 20 percent, and did not change respectively, compared to a standard (unmodified) trawl. Fish of commercial value increased by approximately 8 percent for all modified codends and trash fish was reduced by 13 percent, 32 percent and 13 percent respectively. The REBYC project enabled the country to test several TEDs and other BRDs (Hermes, 2009). The results of this testing led to the drafting of a new fisheries law, of which government approval is still pending for which will make the use of BRDs mandatory.
Cuba	A shrimp trawl with Fisheye BRD was tested in collaboration with Mexico. Plans included mandating the use of this device (Hermes, 2009).
Madagascar	A thorough review of the shrimp fishery, including management and enforcement issues, historical landings and bycatch issues is provided in Gillett (2008). In 2009, shrimp catches fell by 50 percent compared to mean catches between 1995–2003 (Chaboud and Vendeville, 2011). This helped promote changes in fishery management and bycatch reduction, including increasing the codend mesh size from 40 mm to 50 mm, reducing trawl size and night trawling, and extending closed seasons. TEDs and BRDs were mandated in 2003. Approximately half the catch is retained, comprised of shrimp and valuable fish, while the remainder is discarded.
Myanmar	Several BRDs were tested in 2004–5 in collaboration with SEAFDEC, including the rectangular window, semi-curved window with 10 mm bar spacing, and the semi-curved rigid sorting grid with 10 mm, 20 mm, and 30 mm bar spacing (Chokesanguan *et al*., 2010). Total catch was reduced by about 38 percent by the sorting grid. Escape of small fish was estimated at 10 percent, 25 percent, and 50 percent for the 10 mm, 20 mm, and 30 mm bar spacing grids respectively. Both windows reduced small fish catch by around 25 percent.
Pakistan	The shrimp trawl fleet numbers around 2 500 trawlers and comprises almost 20 percent of the entire fishing fleet in Pakistan (Khan and Nawaz, 2015). Annual shrimp landings are around 25 000 tonnes (FAO, 2009) and bycatch levels are high (Khan and Nawaz, 2015). Trawl mesh size is 50 mm and codend mesh size is 25 mm. Killing sea turtles is considered a bad omen and therefore efforts are taken to release them alive (Khan and Nawaz, 2015). Turtle capture is extremely rare; in one government survey over 76 days no turtles were captured, and other multi-year surveys have reported similar outcomes. Efforts to introduce approved TEDs and comply with the United States of America embargo were introduced in 2000, however effective regulations have still not been introduced, primarily because shrimp fishers are not convinced that shrimp trawling results in turtle entanglement and mortality. Pakistan is approved to export shrimp to the United States of America (Federal Register, 2016a), possibly because trawl duration is typically less than one hour and captured turtles are released alive (Khan and Nawaz, 2015).
Papua New Guinea	The shrimp trawl fleet in the Gulf of Papua Prawn Fishery numbers 15 steel trawlers (FAO & SEAFDEC, 2013). The catch is dominated by banana prawns (*Penaeus merguiensis*, *P. indicus*), tiger prawns (*P. monodon*, *P. semisulcatus*, and *P. esculentus*), and endeavor prawns (*Metapenaeus demani*, and *M. ensis*). Bycatch issues include large volumes of small fish, including trash fish. The use of TEDs and BRDs has been legislated, but poorly implemented. Mesh size cannot be larger than 50 mm in the trawl body and codend.
Saudi Arabia	The industrial shrimp trawl fleet consists of seven boats (Abdulqader *et al*., 2017) and is responsible for less than 1 percent of landings (Directorate of Fisheries, 2010). Over 2 000 artisanal boats use a variety of fishing gears, including shrimp trawls, gillnets, traps and longlines. The shrimp trawl fishery, which also includes almost half of the artisanal fleet, was responsible for the capture of 770 turtles over an 18-month period, equivalent to almost 90 percent of turtle captures from all fisheries combined (Abdulqader *et al*., 2017). Despite a recommendation to prioritize turtle protection, no known efforts to use a TED or other sea turtle conservation measure has been introduced. An annual closed season for shrimp fishing (FAO, 2003a) was the only known measure contributing to bycatch reduction.
Senegal	In the deepwater shrimp trawl fishery, bycatch and discards may comprise up to 75 percent of total catch (FAO, 2020). Several bycatch reduction devices, including a modified Nordmore grid, were tested in 2015 under commercial conditions (Thiam *et al*., 2018). Three different grid spacings were tested (24 mm, 28 mm, and 30 mm) to optimize bycatch reduction and minimize shrimp loss. The sea trials indicated that the Nordmore grid with 30 mm bar spacing effectively released large-sized bycatch, including rays and sharks. Shrimp loss varied between 3 and 20 percent with an average loss of 8 percent. Catches of small fish and juvenile fish were considered too high.
Sri Lanka	Shrimp trawling is illegal although still practised (Jones *et al*., 2018). Target species include *Metapenaeus dobsoni*, *Penaeus indicus*, *P. merguiensis*, *P. monodon*, and *P. semisulcatus*. Shrimp accounts for over 60 percent of the total catch (Jayawardane, McLusky and Tytler, 2004). Significant volumes of bycatch are also caught, some of which is discarded.
Tunisia	Management measures in the shrimp fishery include a 40 mm minimum mesh size, a minimum landing size for many species, a minimum trawling depth of 50 m, fishing time restrictions, and no-fishing zones (Hermes, 2009). Small fish bycatch may not exceed 20 percent of the total catch, otherwise trawling ceases.

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Glossary

Bycatch
Part of the catch that the fisher did not intend or want to retain, in addition to the target species. Bycatch 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. 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.

Bycatch reduction device (BRD)
Any modification to a 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.

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.

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 fishermen.

Discard
Part of the catch that is released or returned to the sea, either dead or alive, whether or not such fish are brought fully onboard a fishing boat.

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

Extension
The act of providing a service to one or more individuals, such as assistance or the sharing of information, to achieve an improved outcome. Has a similar meaning to outreach.

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.

Monitoring, control and surveillance (MCS)

A term that refers to a range of specific fishery management measures and their compliance by fishers. *Monitoring* is the requirement for continuous measurement of fishing activity: for example, fishing effort, gear type, catch landings, bycatch, and habitat impact. *Control* refers to the regulatory conditions (if any) under which fishery resources are exploited, including limits on fishing effort, bycatch, discarding, and habitat impact. *Surveillance* refers to the type and degree of observations required to ensure fishing activity is compliant with regulatory controls. This includes the use of fishery patrols, logbook entries by captains or skippers, independent fishery observers, or onboard electronic monitoring using cameras.

Net bias

The ability of a net to fish differently and retain a different catch composition compared to 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.

Outreach

Reaching out to one or more individuals to provide a service, such as assistance or the sharing of information. Has a similar meaning to extension.

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 gear

A fishing gear allowing fishermen to capture the target species with minimal or no bycatch.

Selectivity

This term is often used generically to refer to the ability of fishing gear to capture certain sizes and species of fish, or other animals, with minimal or no bycatch. In more precise terms, selectivity is a measurement of the selection process, which is the relative likelihood of shrimp and fish of different sizes and species being retained by the gear if there were equal numbers of each in the population (Wileman, Ferro, Fonteyne and Millar, 1996). The selectivity of a shrimp trawl can be influenced by the timing and location of the fishing operation, as well as the size, design, rigging and operation of the fishing gear. Sometimes onboard processing and handling practices may influence the size of kept individuals – e.g. retention of largest shrimp when a deckload of fish and shrimp is sorted by hand.

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, and relatively small fishing boats (if any). The boats make short fishing trips, close to the shore, and the catch is 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 fishermen rather than being bought by a middle-(wo)man 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 fishermen in a particular fishery.

TED
TED is an acronym for turtle exclusion device, but sometimes means a trawl efficiency device. A TED is a type of BRD. It usually refers to an inclined grid or netting panel that prevents the passage of large animals such as sea turtles –but also 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 pass through the grid can avoid capture by voluntarily swimming through the escape opening.

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

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

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

This technical report describes advances and best practices in bycatch reduction in tropical shrimp-trawl fisheries in over 30 countries. Efforts by researchers, fishers and others to reduce bycatch in tropical shrimp-trawl fisheries around the world have escalated in recent decades. Collectively, achievements in bycatch reduction have been significant, but the report reviews areas and issues that remain challenging in the quest to manage bycatch and discards appropriately. The report was prepared as part of the GEF/FAO Project on the Sustainable Management of Bycatch the Bottom Trawl Fisheries of Latin America and the Caribbean (REBYC-II LAC), a five-year initiative involving six countries and regional organizations to improve the management of bycatch, support the sustainable development of shrimp-trawl fisheries, and support the coastal fishers and communities that depend on them.

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