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Evaluation of "Hoppers" for reduction of bycatch mortality in the Queensland East Coast Prawn Trawl Fishery

FRDC 2001/098

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Cover Image: Qld East Coast Commercial Prawn Trawlers anchored in Torres Strait during the 2002 Tiger Prawn season. [Photo: Quinton Dell, QDPI Northern Fisheries Centre]

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INTRODUCTION AND RESEARCH OVERVIEW

2001 / 098 Evaluation of "Hoppers" for reduction of bycatch mortality in the Queensland East Coast Prawn Trawl Fishery

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1. OBJECTIVES

- To evaluate the comparative survival* of trawl bycatch between boats fitted with Hoppers and those without in the Queensland East Coast Trawl Fishery.
- To evaluate the 2-hour and 4-hour survival* of bycatch subsamples taken from Hoppers fitted to trawlers in Queensland East Coast Trawl Fishery.
- To evaluate the effectiveness of the prototype non-mechanised Hopper currently being developed for the Queensland East Coast inshore Banana prawn fishery (carried out in association with SeaNet).

* Survival throughout this report is discussed in terms of "potential survival". This term is used to indicate trends in short-term survival, given that this was an initial pilot study.

2. NON-TECHNICAL SUMMARY

Project Outcomes

This preliminary research into Hoppers used in the Queensland prawn trawl fishery has established that:

- Improvement in bycatch survival is achievable through the use of alternative catch processing devices (Hoppers); short-term survival is doubled compared to tray sorting.
- Hoppers contribute to the survival of greater numbers and diversity of bycatch species from trawl operations
- Improvement in trawl practices and Hopper operation will benefit both bycatch survival and quality of the processed product
- Multiple devices, methods and practices can be used together as a suite of tools to manage bycatch issues and contribute to long term sustainability goals

The average bycatch survival from Hopper systems was found to be 16.09% based on numbers surviving, compared to 8.46% from standard Non-Hopper (sorting tray) vessels. The range of survival was from a low of 4.61% from Hopper vessels compared to 1.22% from Non-Hopper vessel, to a high of 37.41% from Hoppers compared to the highest survival from a standard vessel of 17.05% (see Table 5). The number of species and weights of animals surviving were significantly higher from Hopper vessels, as was the diversity of species surviving. The survival rates presented do not account for all species however, due to difficulties in assessing particular animals: ie, large sharks and rays (rarely seen) and crabs. Crabs were usually alive and would kill other bycatch species, seriously affecting the results so had to be discarded when caught.

The relatively short duration of the current survival study meant that results were really indications for "potential survival"; longer survival trials would be required to fully assess survival rates.

Other significant factors found to influence bycatch survival were the trawl duration and depth. The set-up of the Hopper and the way it was operated were also identified as playing a crucial role in bycatch survival. Encouragement of better operation of Hoppers by fishers was addressed in this study by the compilation of a "Recommended Practices for Hopper Operation" multimedia CD. This was compiled as a first draft of recommended practices, as part of the extension of the project’s results.

Numerous fish-kill incidents have arisen from trawler discards along the northern beaches of the Cairns region, Far North Queensland. This prompted an industry representative body ECOFISH to initiate discussion amongst local trawl operators for methods to address the issue of "dead fish washing-up on high-profile tourist beaches", particularly during seasonal Banana prawn trawling.

A Small Vessel Hopper designed by a local fisher to address the Banana prawn trawl bycatch problem was investigated for potential use aboard the smaller prawn trawl vessel fleet throughout Queensland waters. The design can be modified to suit different back-deck layouts of small boats and is cheap to build and repair, resulting in a cost effective lightweight device that runs off an existing deck-hose.

Initial trials suggest good potential for discard survival, given the correct trawl procedures. Footage of the trials was compiled into a multimedia CD to demonstrate the concept to fishers. Those fishers observing the Development Trials of the “Small Boat” Hopper CD or the actual Hopper prototype have immediately identified with the benefits to their fishing operations.

3. KEYWORDS

Hopper, bycatch, survival, prawn trawl, Torres Strait, mortality, recommended practices

4. BACKGROUND

The Queensland East Coast Trawl Fishery Management Plan was completed and introduced on 21st December 2000. The plan sets performance criteria for a 40% reduction in bycatch and a 25% reduction in damage to benthos. Furthermore Ecologically Sustainable Development (ESD) is a requirement in Queensland, under both the 1994 Fisheries Act and under Schedule 4 of the new Commonwealth Wildlife Protection Act (Import & Export).

Environment Australia, as the administrator of the Commonwealth Act, sets criteria on the sustainability of (1) target species, (2) retained bycatch (by-product), and (3) discarded bycatch species from trawl fisheries; a key factor of which is the total mortality on these species caused by the fishing operation. That is, there is a requirement not simply for a reduction in the quantity but a reduction in the mortality of bycatch species taken while trawling.

The FRDC Research and Development Plan 2000, identifies sustainable levels of fisheries productivity as a major challenge. The Bureau of Rural Science (BRS) produced a set of ESD certification proforma which are being trialed under the SCFA-FRDC "Ecologically Sustainable Development (Case Studies)" project. The first case study was the Queensland Trawl fishery held on the 28th June 2000. The Queensland East Coast Trawl Fishery was of particular interest as this fishery operates to a large extent within the Great Barrier Reef World Heritage Area (GBR WHA). Hence there is a critical need to quantify and manage risk to the ecological sustainability of its fishing grounds. The fishery is currently worth A$140 million in gross value of product, but also has a profound economic downstream effect on local fishing communities and support infrastructure along the 2000 km coastline.

"Hoppers" are innovative product-quality and cost-efficiency devices that are being progressively introduced into the South Australian, Western Australian and NORMAC Prawn Trawl Fisheries, and have been fitted by a small percentage of trawlers on the Queensland East Coast (Figures 1 and 2). Investment in these devices is purely a commercial decision as they reduce cost in sorting and processing the prawn catch, and increase the price obtained for a higher quality product. As an indication of their commercial acceptance, Hoppers are recommended in the 1997 QCFO (QSIA) sponsored ISO Best Practice manual for catching and processing of wild-caught prawns (Anon 1997).

Figure 1: The catch is emptied into a Hopper full of flow-through seawater and then transferred via conveyors for processing with minimal physical handling.

Figure 2: Catch is removed from the Hopper via elevator conveyors onto a sorting conveyor.

Anecdotal reports suggest that Hoppers not only enhance product quality but also increase the survival of bycatch species that are caught. This is because the catch is emptied into a tank of fresh seawater (a Hopper) rather than onto a dry sorting-tray where the catch stays exposed until being processed manually. Allowing the prawns to "rest" in a Hopper, after the stress of capture, returns their colour and ensures that the product is fresh as possible when transferred to the snap freezer. An elevator conveyor belt system is used to mechanise and simplify sorting of the catch. Commercial product and bycatch is lifted from the Hopper and transferred onto a moving conveyor belt where prawns are removed (Figure 2). The prawns are sent down a chute for further processing and bycatch is allowed to continue on the belt over the side of the vessel via a discard chute.

In contrast to a traditional sorting-tray, the bycatch on Hopper vessels spends a minimum of time out of water and is discarded over the side in a sluice of seawater. The system ensures that bycatch is discarded automatically at the time of sorting, rather than being left till after all the commercially important species have collected, which can take over 30 mins.

Theoretically this system should result in lower mortality of bycatch prior to discarding. Therefore a Hopper can represent a win-win investment for trawler operators. They are both a good business strategy, by lowering costs and improving product quality/price, and show environmental responsibility by lowering the impact on the ecosystem in line with ESD requirements.

It should be stressed that the progressive adoption of Hoppers is part of a commercial evolution within the various prawn trawl fisheries around Australia and is currently being driven by economic considerations. This research will provide industry with an evaluation of Hoppers as a tool to help achieve ESD requirements. It is part of an ongoing commitment by Queensland Department of Primary Industries Agency Food & Fibre Science (QDPI AFFS), Fisheries and Aquaculture to empower the industry to meet present and future challenges by providing it with better information about the sustainability of its resource, and providing tools to help the industry make informed strategic decisions.

5. NEED

The Queensland East Coast Trawl Fishery Management Plan has set performance criteria for a 40% reduction in bycatch and a 25% reduction in damage to benthos. Need for this research has arisen specifically through this initiative and in combination with the Environment Australia criteria for sustainability of target species, retained by-product and discarded bycatch species from trawl fisheries. The FRDC is currently funding QDPI research to describe and quantify trawl bycatch in Queensland and the preliminary effects of bycatch reduction devices (BRDs) on bycatch (FRDC # 2000/170).

Hoppers are product-quality and cost-efficiency enhancement devices that are being progressively introduced throughout Australian trawl fisheries. Anecdotal reports suggest that these devices could also assist the survival of bycatch species that are caught by the trawl net because the catch is emptied into a Hopper of fresh seawater rather than onto a dry sorting-tray.

There is a need to pro-actively evaluate and document the effect of Hoppers on survival of discarded bycatch to ensure that the Queensland Prawn Trawl fleet gains maximum recognition for the "environmental credits" accrued as Hoppers are progressively introduced. This would provide an added bonus to a process already underway as a commercial evolution in trawl fisheries around Australia. Such information could also act as an environmental incentive, apart from the product quality and cost consideration, for trawl operators to fit Hoppers.

Smaller inshore boats involved in the Queensland East Coast banana fishery have considerable community pressure for inshore closures to cover local and tourist destination beaches. This has occurred as a result of discarded bycatch washing up after trawling operations. An appropriately sized non-mechanised Hopper designed for smaller vessel operations is currently under development to address this issue. The Hopper will need to be independently evaluated to ensure that the community is satisfied they will reduce bycatch mortality.

6. ACKNOWLEDGEMENTS

Without industry support and participation this project would not have been possible. The following companies are thanked and acknowledged for providing vessels for this project (Companies listed in alphabetical order):

Lee Fishing Pty Ltd
Moreton Bay Seafood Pty Ltd
Palin Fisheries (S.E.A Cairns) Pty Ltd
San Antone Fishing Company Pty /Ltd.

The hospitality and cooperation from Owners, Skippers and Crew of the following vessels is greatly appreciated (Vessels listed in alphabetical order):

FV 'Amanda Jane'
FV 'Aquarius 6'
FV 'Cape Bedford'
FV 'K-Maree II'
FV 'Shomac'
FV 'Somatina'
FV 'Torakina'
FV 'Valkyrie Voyager'

Endeavour Shipping Company Pty Ltd is acknowledged for assistance in storage and transport of project equipment. Bevis and Trish Dicker (Captain Tom Barge) in particular are thanked for assisting with equipment between field trips and transport from Yorke Island to the participating fishing vessels.

Andrew Redfearn was responsible for the innovative Small Boat Hopper concept, construction and undertaking of sea trials. Trials were conducted on numerous vessels of which we thank for their participation, with particular acknowledgement to Trevor Perkis on FV Trevanna and the crew from FV Lin-G.

Russel Holt, Marine Engineer, is thanked for his input and development of the back deck working procedures document leading to the concept of the Hopper recommended practices CD.

Lastly, we wish to thank Mark Tonks (QDPI Southern Fisheries Centre) and Claire Van Der Geest (QDPI Northern Fisheries Centre) for their assistance with bycatch species identification. Advice and assistance with project operations by numerous QDPI Northern Fisheries staff is also sincerely appreciated.

7. PROJECT STAFF

Dr Neil Gribble (QDPI Northern Fisheries Centre)

Position: Principal Fisheries Biologist

Project Role: Principal Investigator / Senior Project Biologist

Key Responsibilities: Project leader, support project organisation and methodology, presentation of results at industry meetings and workshops, Final Report Co-Author and Editor.

Mr Quinton Dell (QDPI Northern Fisheries Centre)

Position: Fisheries Biologist

Project Role: Co-Investigator / Project Biologist

Key Responsibilities: Organisation and conduct of at sea survival experiments, data management and analysis, production of recommended practices CD for industry, Milestone Report, Final Report Primary Author.

Mr Denis Ballam (SeaNet)

Position: SeaNet Extension Officer

Project Role: Co-Investigator

Key Responsibilities: Industry liaison, initial sea trials of 'Small Boat Hopper', production of recommended practices CD for industry, Final Report Co-Author.

Mr Scott Foster (QDPI Farming Systems Institute)

Position: Biometrician

Project Role: Statistical advice and statistical analysis

Key Responsibilities: Organisation of statistical results, Co-Author analysis section.

BYCATCH SURVIVAL AND HOPPER EVALUATION

8. HOPPER APPLICATION

The use of Hoppers focuses on a different approach to trawl bycatch issues and ecological sustainability; that is to improve bycatch survival post-capture. This is in contrast to the development of specific devices to minimise the initial capture of bycatch in trawl nets, which has been a strong research focal point to date (eg; Mounsey et.al. 1995, Brewer et.al. 1998).

Hoppers may be considered as one of many tools in a collective approach to address bycatch concerns. They are not devices designed specifically with bycatch issues in mind, they have arisen from industry innovation to benefit catch quality and assist catch processing. Due to their mode of operation they are potentially beneficial to reducing bycatch mortality.

The overall concept is to use a complementary approach utilising purpose specific solutions, such as TED's and BRD's, in conjunction with alternative devices or processes, such as Hoppers. This provides an innovative and synergistic suite of methods for management and industry to address the principles of Ecologically Sustainable Development.

Hopper use in the Queensland East Coast is presently restricted to a limited number of vessels. The gradual uptake of Hoppers as a new processing method is largely attributable to initial cost and installation expenses. Fishers also like to investigate how new devices or technologies perform before changing operational procedures, modifying back-deck layouts, or investing in expensive capital. As more industry members trial a concept or technology, the knowledge base and acceptance of the innovation gains momentum.

Researching environmental benefits of such devices assists uptake of new methods by providing information that aids industry and management in working toward sustainable fishing practices. Other financial incentives such as development grants or concessions are beneficial to the uptake of new technologies where large costs are involved for operators.

9. OBJECTIVES ADDRESSED

- Evaluate the comparative survival[*] of trawl bycatch between boats fitted with Hoppers and those without in the Queensland East Coast Trawl Fishery

- Evaluate the 2-hour and 4-hour survival of bycatch subsamples taken from Hoppers fitted to trawlers in Queensland East Coast Trawl Fishery

Note. Survival throughout this report is discussed in terms of "potential survival". This term is used to indicate trends in survival given that this is an initial pilot study.

Objective three, "effectiveness of a prototype non-mechanised Hopper", will be dealt with in a separate section (14) on "ALTERNATIVE HOPPER DESIGN FOR SMALLER VESSEL OPERATIONS".

10. METHODS

10.1 Area Of Operation

The Queensland East Coast Prawn Trawl Fishery was targeted as the main area of operation for the project. Due to vessel availability, the Hopper / Non-Hopper comparisons and survival experiments were conducted in the Torres Strait Prawn Trawl Fishery (Figure 3). All vessels operating in the Torres Strait fishery are Queensland East Coast commercial fishing vessels.

Trawls were sampled aboard vessels operating normally in the Torres Strait Prawn Trawl Fishery during April, May and June 2002 (Figure 4). Three Hopper vessels and three Non-Hopper vessels had sufficient data from survival studies to be used for comparison. Eight vessels (four Hopper and four Non-Hopper) were observed for catch processing comparisons.

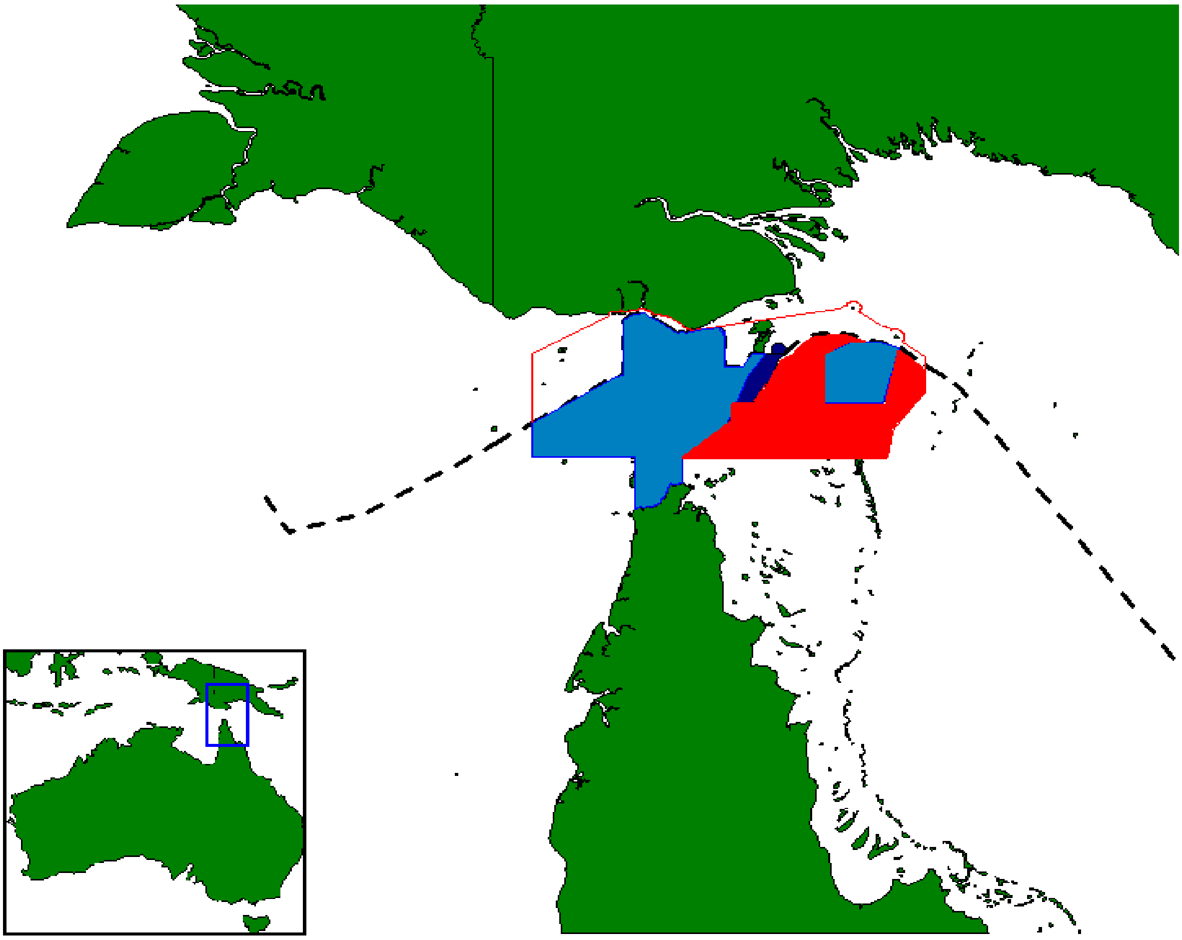

Figure 3: The Torres Strait Prawn Trawl Fishery (Red). Light Blue designates the permanent closures, mainly west of Warrior Reef, Dark blue designates the seasonal closure east of Warrior Reef. The red line defines the Torres Strait protection zone and the black dashed line defines the jurisdiction between Australia and Papua New Guinea (Source: Taranto and Long 1996).

Figure 4: Sample locations within the Torres Strait Prawn Trawl Fishery. Each point (orange) designates the starting location of trawls sampled or recorded for processing times. (Source of underlying map: Taranto and Long 1996)

For prawn stock assessment purposes the Torres Strait Prawn Trawl Fishery is divided into a Northern and Southern component. This division occurs at ten degrees latitude and is based on Tiger and Endeavour prawn distribution. To consider some form of spatial influence the Northern and Southern definition was applied to the dataset.

10.2 Experimental Design

10.2.1 ONBOARD SAMPLING

Two trawls per night were sampled for use in the survival experiments. Records were kept of the trawl duration and processing time-line of these and all other trawls throughout the night. Trawl qualifiers were used to maintain consistency in the sampling operation:

- No rough weather trawls were sampled.
- Trawls were not sampled where gear breakdown, obstructions, etc, influenced "normal" catch processing or landing of the catch.
- "Average" size catches were sampled. Very large and small catch bags were avoided.

Samples were obtained for each experimental tank during the catch processing phase. The trawl catch underwent all winch-up, bag spill and sorting procedures before a sample was acquired. Samples were gathered at the stage when bycatch exited the vessel via the discards chute using a purpose built scoop net (Figure 5). This allowed a bycatch sample to be obtained that was representative of normal processing procedures before ordinarily being returned to sea.

Figure 5: Samples obtained in the discards chute using a (trawl cod-end) net scoop.

A total 5 kilogram bycatch “subsample” was obtained for each experimental tank. That total sample consisted of bycatch that was sampled equally at three different stages throughout the trawl processing period (near-beginning, middle and near-end).

Heales *et*. *al* (*In press*) note that species bias can occur as a result of subsampling from Hopper catch processing systems. Unfortunately, for survival assessment the catch has to pass into and through the Hoppers as per normal processing operations. Heales *et*. *al* (*In press*) note that numbers of individual species are strongly skewed towards either the first or last catch groups exiting the Hopper. In addition to this, many survivors tend to exit the Hopper first and many deceased individuals tend to exit last (pers obs.).

To alleviate species and survivor/non-survivor bias, sampling was undertaken after an initial flush of catch, with the last sample obtained before the very final group of “floaters”. The same process was undertaken for collection of subsamples from Non-Hopper vessels to avoid bias.

10.2.2 SAMPLE PROCESSING

All species in the samples for each experimental tank were recorded, allowing a measure of the diversity of species sampled, surviving and not surviving. The next process was to separate individuals based on three definitions of condition:

- Alive: Limited visual injuries or markings, animal swimming in a normal manner. Some minor scale loss allowed but very limited. Resting within the water column or bottom surface was acceptable (normal behaviour for some species).
- Alive-Injured[*]: An individual may have more noticeable scale loss, mild lacerations or markings, or damaged fins. Swimming ability must not be dysfunctional, resting within the water column or bottom surface acceptable.
- Dead / Critically Injured: Deceased or individuals exhibiting substantial injuries or unusual behaviour indicating major traumatic injury. For example, Swim bladders protruding from the mouth, dysfunctional swimming behaviour, impalement on other objects or animals etc.

All deceased individuals were removed and set aside for identification (Figure 6). Alive and Alive-Injured individuals were left in the experimental tanks for the 2hr and 4hr survival studies. At completion of those times the same separation of individuals based on physical condition occurred as before.

*In the data analysis for survivors the Alive-Injured category individuals were presumed to die and not included in the survivors category. This was done so as to err on a more conservative survival estimate given that the longest experimental duration to monitor survival was 4hrs.

Figure 6: Deceased individuals for each tank were removed. Those individuals surviving were left in the tanks for the respective 2 and 4-hour survival experiments.

10.2.3 EXPERIMENTAL TANK DESIGN

Large plastic "Nally Bins" were converted to experimental tanks via addition of a stand pipe, removable lid and controllable water inlet (Figure 7). Dark grey Nally Bins were used to minimise light refraction and reduce stress. At stand pipe drainage level, the tanks each held 60 litres of flow-through seawater.

Figure 7: Flow-through tanks used for onboard survival experiments. Each tank had an individual feed line and control tap to regulate water flow rate.

Fresh seawater was pumped into each tank via a manifold that linked to one of the boat's deck hoses (Figure 8).

Figure 8: The yellow pipe is the seawater manifold that connects to one of the spare deck hoses and feeds into each experimental tank individually.

Each inlet into an experimental tank had a tap to regulate flow. The flow rate was set between two and three litres per minute to allow sufficient fresh seawater and dissolved oxygen. This flow rate allowed for one hundred percent exchange per twenty to thirty minutes without causing unsettling currents.

10.3 Statistical Analysis

10.3.1 TREATMENTS AND TERMS

Treatments:

- Vessel (Hopper and Non-Hopper). Treatment is at the fishing vessel level.
- Experimental Duration (2hr and 4hr survival experiment tanks). Treatment is at the experimental tank level.

Note. No tests were carried out on the variation between the three different stages throughout the trawl processing period (near-beginning, middle and near-end) making up a subsample. The subsample was assumed to be well mixed.

Terms:

- Initial Sample – the total sample obtained for each tank, post trawl and processing, before any division of deceased and living animals.
- Initial Survivors – those animals surviving immediately post trawl and trawl processing that were left in the tanks for survival experiments.
- Final Survivors – those animals surviving after the 2hr and 4hr Experimental Durations.
- Trawl Duration – amount of time that the trawl gear is towed underwater (from the moment the Otter Boards enter the water to the moment Otter boards are winched up and secure).
- Shot Time – when a trawl was undertaken.

10.3.1 DERIVED VARIABLES

The measured and observed variables during at-sea operations aboard the commercial trawlers are utilised in the descriptive summary results. Further variables were derived for statistical testing, these variables were:

North / South: A classification variable to qualify broad spatial separation.
Total Survival (%): For each experimental tank the total percent survival (irrespective of species) was calculated and analysed. The numerator was 100x the number of fish surviving (Final Survivors) per tank and the denominator was the total number of individuals gathered in the 'Initial Sample' per tank (irrespective of alive or dead status).
Treatment Survival (%): For each experimental tank the percent survival (irrespective of species) was calculated and analysed. Here the numerator is 100x the number of fish surviving (Final Survivors) per tank and the denominator was the number of alive individuals entering each experimental tank (Initial Survivors).
Total Weight Survival (%): As for Total Survival (%) but for weights.
Treatment Weight Survival (%): As for Treatment Survival (%) but for weights.
Initial Sample Diversity: Shannon's Diversity Indexes (Zar 1974) were calculated for the total sample (dead and living) obtained post trawl processing.
Initial Survivor Diversity: Shannon's Diversity Indexes were calculated for those alive in the Initial Sample to enter the experimental tanks (Initial Survivors).
Final Survivor Diversity: Shannon's Diversity Indexes were calculated for those alive at the completion of the survival experiments (Final Survivors)

The following variables were derived to examine change in diversity within the sampling and survival experiment stages:

Initial Sample-Initial Survival: Change in diversity from the Initial Sample obtained to the Initial Survivors to left in the survival study experimental tanks
Initial Survival-Final Survival: Change in diversity from Initial Survivors to those surviving at completion of the survival experiments (Final Survivors).

All covariates were centred (variate mean subtracted from each observation) before being utilized in the hierarchical model. Log transformations (Log[x+1]) were performed where there appeared to be any relationship between the mean and the variance of the outcome variable.

10.3.3 THE HIERARCHICAL MODEL

The structure of the sampling program was hierarchical, as trawl vessels were utilised, the trawls within a night on a vessel were sampled and the experimental tanks were utilised as a result of sampling a trawl.

The treatment of 'Vessel' (Hopper or Non-Hopper) is assigned at the commercial trawler level. The 'Experimental Duration' treatment and interaction are assigned at the experimental tank level. These distinctions are made at different levels because it directly influences the magnitude of residual error used in the statistical testing. It also affects the confidence of the test by assigning the correct residual degrees of freedom.

A Hierarchical Linear Model was fitted using mixed models estimated by REML (Residual Maximum Likelihood), (Patterson and Thompson 1971). REML was chosen over a sum of squares model (ANOVA) as it allowed greater flexibility in fitting covariates. REML also provides variance parameter estimates, which are unbiased as opposed to maximum likelihood.

Once the model was fitted to the data, covariates could be fitted to explain excess variation. The use of REML allows introduction of models with a semi-parametric functional form, namely as a smoothing spline. If the smooth does not explain the data as well as a straight line function then it was removed and the straight line used instead. It is assumed that the covariate has the same effect irrespective of treatment.

11. RESULTS

There were 60 trawls with sufficient data for Hopper and Non-Hopper vessel comparison. These trawls were spread over 3 Hopper vessels and 3 Non-Hopper vessels, where 10 survival experiments were conducted on each vessel.

11.1 Species Survival Profile

A total of 151 species from 53 families were sampled during the survival studies in Torres Strait (Refer to Appendix A). A typical bycatch sample contained many species with a great variation in the numbers of individuals. Those species occurring commonly (greater than 70%) were represented by 15 species from 12 families (Table 1).

Table 1: Species occurring more than seventy percent of the time during trawl sampling.

Species	Family	Occurrences	# Individuals	% Occurrence
Apogon ellioti	APOGONIDAE	215	1435	89.6
Engyprosopon grandisquama	BOTHIDAE	191	975	79.6
Callionymus belcheri	CALLIONYMIDAE	233	3288	97.1
Paramonacanthus japonicus	MONACANTHIDAE	212	858	88.3
Nemipterus peronii	NEMIPTERIDAE	175	640	72.9
Scolopsis taeniopterus	NEMIPTERIDAE	210	1156	87.5
Inegocia japonica	PLATYCEPHALIDAE	194	496	80.8
Onigocia macrolepis	PLATYCEPHALIDAE	225	1350	93.8
Priacanthus tayenus	PRIACANTHIDAE	176	576	73.3
Scyllarus demani	SCYLLARIDAE	217	1100	90.4
Saurida undosquamis	SYNODONTIDAE	233	3099	97.1
Lagocephalus sceleratus	TETRAODONTIDAE	192	676	80.0
Metapenaeopsis palmensis	PENAEIDAE	226	7284	94.2
Trachypenaeus curvirostris	PENAEIDAE	221	6589	92.1
Cuttle/Octopus	SEPIIDAE	168	413	70.1

During the survival studies 88 species from 38 families survived Hopper vessel processing, as to 53 species from 29 families surviving Non-Hopper vessel processing (Table 2). The summary results are based on simple survival occurrence data only. The actual number of some surviving species may be as low as one individual. All species are listed for the benefit of future studies as an initial investigation of species potentially surviving Hopper systems (Table 2).

A total of 58 species from 29 families were never found to survive. These species could have died either during the trawl, the catch processing or during the survival experiments (Table 3).

Table 2: Species comparison list for the total number of 'Final Survivors' between Hopper and Non-Hopper vessels during sampling in the Torres Strait prawn trawl fishery.

Hopper Vessel Species	#	Non-Hopper Species	#	Family
Antennarius hispidus	1			ANTENNARIIDAE
		Tathicarpus butleri	2	ANTENNARIIDAE
Adventor elongatus	2	*Adventor elongatus*	4	APLOACTINIDAE
Apogon brevicaudatus	1			APOGONIDAE
Apogon ellioti	5	*Apogon ellioti*	1	APOGONIDAE
Apogon hartzfeldi	8			APOGONIDAE
Apogon poecilopterus	1			APOGONIDAE
Apogon quadrifasciatus	2			APOGONIDAE
Engyprosopon grandisquama	4			BOTHIDAE
Pseudorhombus diplospilus	2	*Pseudorhombus diplospilus*	1	BOTHIDAE
Pseudorhombus elevatus	2			BOTHIDAE
Pterocaesio diagramma	1			CAESIONIDAE
Callionymus belcheri	18	*Callionymus belcheri*	3	CALLIONYMIDAE
Callionymus grossi	2			CALLIONYMIDAE
Synchiropus rameus	3	*Synchiropus rameus*	1	CALLIONYMIDAE
Alepes sp	4			CARANGIDAE
Carangoides fulvoguttatus	2			CARANGIDAE
Carangoides talamparoides	2			CARANGIDAE
Caranx bucculentus	16	*Caranx bucculentus*	5	CARANGIDAE
Decapterus macrosoma	24	*Decapterus macrosoma*	2	CARANGIDAE
Gnathanodon speciosus	1	*Gnathanodon speciosus*	2	CARANGIDAE
Selar crumenophthalmus	4			CARANGIDAE
Selaroides leptolepis	149	*Selaroides leptolepis*	14	CARANGIDAE
Seriolina nigrofasciata	1			CARANGIDAE
		Carangoides humerosus	1	CARANGIDAE
Dactyloptena papilio	5			DACTYLOPTERIDAE
Cyclichthys jaculiferus	6	*Cyclichthys jaculiferus*	2	DIODONTIDAE
Drepane punctata	1			EPHIPPIDIDAE
Glaucosoma magnificum	10	*Glaucosoma magnificum*	2	GLAUCOSOMATIDAE
Yongeichthys nebulosus	84	*Yongeichthys nebulosus*	100	GOBIIDAE
Diagramma pictum	4			HAEMULIDAE
Pomadasys maculatum	1			HAEMULIDAE
Choerodon cephalotes	125	*Choerodon cephalotes*	7	LABRIDAE
Choerodon monostigma	37	*Choerodon monostigma*	1	LABRIDAE
Choerodon sp.2	40			LABRIDAE
Lethrinus laticaudis	32	*Lethrinus laticaudis*	3	LETHRINIDAE
Lethrinus lentjan	1	*Lethrinus lentjan*	3	LETHRINIDAE
Lethrinus nebulosus	1	*Lethrinus nebulosus*	6	LETHRINIDAE
Lutjanus sebae	2	*Lutjanus sebae*	5	LUTJANIDAE
Lutjanus vitta	1	*Lutjanus vitta*	1	LUTJANIDAE
		Lutjanus russelli	1	LUTJANIDAE
Monacanthus chinensis	3	*Monacanthus chinensis*	3	MONACANTHIDAE
Paramonacanthus japonicus	103	*Paramonacanthus japonicus*	17	MONACANTHIDAE
Paramonacanthus otisensis	8			MONACANTHIDAE
Pseudomonacanthus elongatus	21	*Pseudomonacanthus elongatus*	2	MONACANTHIDAE
		Paramonacanthus filicauda	1	MONACANTHIDAE

Table 2 [*Continued*]: Species comparison list for the total number of 'Final Survivors' between Hopper and Non-Hopper vessels during sampling in the Torres Strait prawn trawl fishery.

Hopper Vessel Species	#	Non-Hopper Species	#	Family
Parupeneus pleurospilus	1			MULLIDAE
Upeneus asymmetricus	2			MULLIDAE
Upeneus luzonius	9			MULLIDAE
Upeneus moluccensis	5			MULLIDAE
Upeneus sp	5			MULLIDAE
Upeneus sundaicus	2			MULLIDAE
Nemipterus furcosus	19	*Nemipterus furcosus*	4	NEMIPTERIDAE
Nemipterus hexodon	6	*Nemipterus hexodon*	1	NEMIPTERIDAE
Nemipterus mesiprion	1			NEMIPTERIDAE
Nemipterus peronii	3			NEMIPTERIDAE
Pentapodus porosus	68	*Pentapodus porosus*	6	NEMIPTERIDAE
Scolopsis taeniopterus	123	*Scolopsis taeniopterus*	33	NEMIPTERIDAE
		Nemipterus nematopus	1	NEMIPTERIDAE
Rhynchostracion nasus	7	*Rhynchostracion nasus*	15	OSTRACIIDAE
Pegasus volitans	57	*Pegasus volitans*	241	PEGASIDAE
Parapercis nebulosa	20			PINGUIPEDIDAE
Cymbacephalus nematophthalmus	11	*Cymbacephalus nematophthalmus*	13	PLATYCEPHALIDAE
Inegocia japonica	27	*Inegocia japonica*	8	PLATYCEPHALIDAE
Onigocia macrolepis	89	*Onigocia macrolepis*	9	PLATYCEPHALIDAE
Suggrundus macracanthus	1			PLATYCEPHALIDAE
Samaris cristatus	1			PLEURONECTIDAE
Euristhmus nudiceps	1			PLOTOSIDAE
Plotosus lineatus	1	*Plotosus lineatus*	61	PLOTOSIDAE
Pristotis jerdoni	24	*Pristotis jerdoni*	4	POMACENTRIDAE
Priacanthus tayenus	13	*Priacanthus tayenus*	7	PRIACANTHIDAE
Psettodes erumei	5	*Psettodes erumei*	4	PSETTODIDAE
Apistus carinatus	1			SCORPAENIDAE
Minous trachycephalus	3	*Minous trachycephalus*	2	SCORPAENIDAE
Paracentropogon longispinis	323	*Paracentropogon longispinis*	66	SCORPAENIDAE
Epinephelus sexfasciatus	29	*Epinephelus sexfasciatus*	17	SERRANIDAE
Siganus canaliculatus	8			SIGANIDAE
Zebrias craticula	1			SOLEIDAE
Saurida micropectoralis	1			SYNODONTIDAE
Saurida tumbil	4			SYNODONTIDAE
Synodus hoshinonis	1			SYNODONTIDAE
Synodus sageneus	7	*Synodus sageneus*	1	SYNODONTIDAE
Arothron manillensis	1			TETRAODONTIDAE
Lagocephalus sceleratus	16			TETRAODONTIDAE
Torquigener pallimaculatus	99	*Torquigener pallimaculatus*	5	TETRAODONTIDAE
Metapenaeopsis palmensis	748	*Metapenaeopsis palmensis*	174	PENAEIDAE
Trachypenaeus curvirostris	161	*Trachypenaeus curvirostris*	34	PENAEIDAE
Scyllarus demani	302	*Scyllarus demani*	776	SCYLLARIDAE
Thenus indicus	70	*Thenus indicus*	88	SCYLLARIDAE
Thenus orientalis	28	*Thenus orientalis*	25	SCYLLARIDAE
Erugosquilla woodmasoni	10	*Erugosquilla woodmasoni*	34	SQUILLIDAE
stomat1	37	stomat1	45	-STOMATOPODA-
stomat2	12	stomat2	19	-STOMATOPODA-

Table 3: Species never surviving overall (trawl, catch processing or survival experiments).

Species	Family	# Occurrences	# Individuals
Apogon carinatus	APOGONIDAE	2	2
Apogon nigripinnis	APOGONIDAE	4	4
Apogon septemstriatus	APOGONIDAE	56	104
Arius thalassinus	ARIIDAE	1	1
Grammatobothus polyophthalmus	BOTHIDAE	128	238
Psettina gigantea	BOTHIDAE	48	72
Pseudorhombus argus	BOTHIDAE	38	55
Pseudorhombus jenynsii	BOTHIDAE	4	4
Pseudorhombus spinosus	BOTHIDAE	163	355
Dactylopus dactylopus	CALLIONYMIDAE	22	33
Absalom radiatus	CARANGIDAE	1	1
Carangoides hedlandensis	CARANGIDAE	1	1
Decapterus russellii	CARANGIDAE	1	1
Megalaspis cordyla	CARANGIDAE	4	5
Selar boops	CARANGIDAE	11	14
Ulua aurochs	CARANGIDAE	25	47
Centriscus scutatus	CENTRISCIDAE	2	2
Chaetodontoplus duboulayi	CHAETODONTIDAE	2	2
Parachaetodon ocellatus	CHAETODONTIDAE	17	20
Amblygaster sirm	CLUPEIDAE	8	25
Herklotsichthys lippa	CLUPEIDAE	7	8
Sardinella gibbosa	CLUPEIDAE	1	1
Cynoglossus macrophthalmus	CYNOGLOSSIDAE	48	56
Fistularia petimba	FISTULARIIDAE	72	128
Gerres filamentosus	GERREIDAE	39	48
Gerres subfasciatus	GERREIDAE	1	1
Pentaprion longimanus	GERREIDAE	26	70
Gazza minuta	LEIOGNATHIDAE	2	2
Leiognathus bindus	LEIOGNATHIDAE	6	14
Leiognathus decorus	LEIOGNATHIDAE	12	21
Leiognathus fasciatus	LEIOGNATHIDAE	3	4
Leiognathus leuciscus	LEIOGNATHIDAE	57	122
Leiognathus moretoniensis	LEIOGNATHIDAE	2	2
Leiognathus sp	LEIOGNATHIDAE	72	158
Lutjanus carponotatus	LUTJANIDAE	1	1
Lutjanus malabaricus	LUTJANIDAE	2	2
Anacanthus barbatus	MONACANTHIDAE	3	3
Upeneus tragula	MULLIDAE	2	2
Nemipterus marginatus	NEMIPTERIDAE	9	27
Sirembo imberbis	OPHIDIIDAE	3	3
Elates ransonnetii	PLATYCEPHALIDAE	16	17
Rachycentron canadus	RACHYCENTRIDAE	1	1
Rastrelliger kanagurta	SCOMBRIDAE	5	6
Pterois russelli	SCORPAENIDAE	15	16
Siganus fuscescens	SIGANIDAE	1	1
Sillago maculata	SILLAGINIDAE	5	6
Sillago sihama	SILLAGINIDAE	41	117
Zebrias quagga	SOLEIDAE	2	2
Saurida sp.2	SYNODONTIDAE	50	146
Saurida undosquamis	SYNODONTIDAE	233	3099
Trachinocephalus myops	SYNODONTIDAE	9	12
Anchisomus multistriatus	TETRAODONTIDAE	1	1
Lagocephalus lunaris	TETRAODONTIDAE	1	2
Tetrosomus gibbosus	TETRAODONTIDAE	5	7
Trixiphichthys weberi	TRIACANTHIDAE	5	5
Lepidotrigla argus	TRIGLIDAE	20	45
Cuttle/Octopus	SEPIIDAE	168	413
stomat4	-STOMATOPODA-	2	2

11.2 Trawl Processing Comparisons

A total of 160 trawls were observed for processing time comparisons during operations in Torres Strait where trawl duration was greater than 2hrs 30min and less than 3hrs 40 min (80 Hopper vessel trawls, 80 Non-Hopper vessel trawls). Catch processing time aboard each vessel was measured from the moment codends were winched clear of the water ready for unload, to the moment the last of the catch was sorted from the tray or Hopper.

There was a thirty nine percent reduction in mean catch processing time on Hopper vessels in comparison to Non-Hopper vessels. The mean catch processing time aboard Hopper vessels was twenty six minutes (Table 4).

Table 4: Catch processing time comparisons between Hopper and Non-Hopper vessels

Vessel Type	Stage	Average	Min	Max	STD Dev
Hopper:	Catch Processing	0:26	0:14	0:54	0:08
	Trawl Duration	2:57	2:30	3:31	0:11
Non-Hopper:	Catch Processing	0:43	0:19	1:13	0:10
	Trawl Duration	2:56	2:35	3:38	0:12

11.3 Hierarchical Model application: Survival Percentages

11.3.1 TOTAL SURVIVAL

Comparisons were made on the survival percentage (irrespective of species) across Hopper and Non-Hopper vessels. Survival was based on the number of organisms alive after the survival experiments (Final Survivors) as to the number of organisms obtained in the Initial Sample for each experimental tank.

Comparisons based on total survival indicated:

- There was a significant Hopper effect ($p = 0.011$) on survival but no effect of Experimental Duration nor was an interaction term significant.
- The Hopper and Non-Hopper mean survival rates, at the average Trawl Depth and Trawl Duration, were 16.09% and 8.46% respectfully (Table 5), that is Hopper survival rate was approximately double that of Non-hopper with trawl depth and duration being equal.

- There was a significant relationship between Trawl Depth and survival outcome as well as Trawl Duration and survival outcome.
- Every 10 metre increase in trawl depth decreased the percentage surviving by 3.79% (0.379% per metre)
- Every half hour increment in trawl duration decreased the percentage surviving by 1.45% (0.0484% per minute. NB: Based on a trawl duration range of 2hrs to 4 hrs)

Table 5: Percentage survival comparison based on numbers (irrespective of species). Survival rates calculated at the average trawl depth and duration

Vessel Type	Average	Min	Max	STD Dev
Hopper:	16.09	4.61	37.41	6.41
Non-Hopper:	8.46	1.22	17.05	3.52

11.3.2 TREATMENT SURVIVAL VIA 'DEATHS' ANALYSIS

The proportion of animals dying during the survival experiments was analysed for the treatment effects of Experimental Duration and Vessel (Log transformation on deaths as Log[%Deaths+1]). There was a significant interaction ($p = 0.002$) between the treatments of Experimental Duration and Vessel (Table 6).

Table 6: A two-way comparison table where significant interactions have occurred between treatments, on the Log transformed scale, calculated at the average trawl time. The values are relative to each other, the higher the value the greater the proportion of deaths.

	Non-Hopper	Hopper
2 Hours	1.661	2.395
4 Hours	1.100	2.575

Comparisons on the proportion of deaths between and across Vessel and Experimental Duration treatments (Table 6) indicate that:

- Hopper vessels had a greater proportion of Initial Survivors dying during the process of the survival experiments.

- For Hopper vessels the proportion of deaths was related to Experimental Duration, with more deaths occurring in the 4-hour treatment.

11.3.3 TOTAL WEIGHT SURVIVAL

Comparisons were made on the percentages of survivor weights (irrespective of species) across Hopper and Non-Hopper vessels. Survival was calculated on the basis of total weight of organisms alive after the survival experiments (Final Survivors) as to the weight of initially surviving organisms, post catch processing, that were left in survival tanks for the 2 and 4-hour experiments (Initial Survivors). (Log transformation on the percentage weight survival as Log[%Wt+1]).

Comparisons based on total survival weight analysis indicated:

- There was a significant Hopper effect ($p = 0.034$) on survival but no effect of Experimental Duration nor interaction.
- There was a significant relationship between Trawl Depth and survival outcome by weight.
- Every 10 metre increase in trawl depth decreased the percentage weight surviving by 0.265% (0.0265% per metre)
- The Hopper and Non-Hopper mean weight survival, at the average Trawl Depth and Trawl Duration, were 2.397 % and 2.072% respectfully.

11.3.4 PERCENTAGE WEIGHT SURVIVAL VIA 'DEATHS' ANALYSIS

The weight of animals dying during the survival experiments was analysed for the treatment effects of Experimental Duration and Vessel (Log transformation on deaths as Log[%Death Weight+1]).

- There was a significant interaction ($p = 0.009$) between the treatments of Experimental Duration and Vessel (Table 7).
- There was a significant relationship with Shot Time, which may also indicate an interaction between survival and different species assemblages occurring at different trawl times.

Table 7: A two-way comparison table where significant interactions have occurred between treatments, on the Log transformed scale of weight data, calculated at the average trawl time. The values are relative to each other, the higher the value the greater the proportion of deaths.

	Non Hopper	**Hopper**
2 Hours	2.014	2.891
4 Hours	1.383	3.035

Comparisons on the deaths by weight between and across Vessel and Experimental Duration treatments (Table 7) indicate that:

- Hopper vessels had a greater proportion by weight of Initial Survivors dying during the process of the survival experiments.
- For Hopper vessels the deaths by weight was related to Experimental Duration, with more deaths occurring in the 4-hour treatment.

This result is in part due to there being a larger proportion of survivors in Hopper subsamples to begin with, then attrition reducing the number at a slightly higher rate than for Non-hopper subsamples. The final result after four hours is still a higher survival rate for Hoppers than for Non-hoppers.

11.4 Hierarchical Model application: Diversity Indexes

11.4.1 INITIAL SAMPLE DIVERSITY

Tests between treatments and across trawls for species diversity were undertaken on the whole samples (Initial Sample) obtained for the survival studies before segregation into categories (Initial Dead, Initial Survivors, Final Survivors).

There were no significant differences between treatments during any particular sample. Thus samples obtained for survival experiments were not significantly different for the treatments on all vessels.

11.4.2 INITIAL SURVIVOR DIVERSITY

Diversity Indexes were statistically analysed for initial surviving species, post processing, that were used in the survival experiments (Initial Survivors).

- There was a Hopper Vessel main effect ($p < 0.001$) and an Experimental Duration main effect ($p = 0.005$) but no interaction between.
- The mean Diversity Indexes for the Hopper and Non-Hopper Vessels were 0.996 and 0.625 respectively.
- The mean Diversity Indexes for the 2-hour Experimental Duration and 4-hour Experimental Duration were 0.831 and 0.79 respectively.

The Hopper vessels had a greater diversity of species alive that survived the processing phase and were then placed into the experimental tanks for the survival study. Interestingly the 2-hour Experimental Duration tanks had slightly greater diversity, statistically significant, than the 4-hour Experimental Duration tanks for the initial survivors used in the survival studies.

11.4.3 DIVERSITY CHANGE FROM INITIAL SAMPLE TO INITIAL SURVIVORS

A test was undertaken on the change in diversity that occurred between the Initial Sample and what survived the trawl processing to become Initial Survivors used in the survival experiments.

- The mean difference in Diversity Index from the Initial Sample and the Initial Survivors for the Hopper Vessels was 0.216.

- The mean difference in Diversity Index from the Initial Sample and the Initial Survivors for the Non-Hopper Vessels was 0.6412.

11.4.4 FINAL SURVIVOR DIVERSITY

Statistical analysis on Diversity Indexes of species alive at completion of the survival experiments indicated:

- There was a Hopper Vessel main effect ($p < 0.001$) and an Experimental Duration main effect ($p = 0.031$) but no interaction between
- The mean Diversity Indexes for the Hopper and Non-Hopper Vessels were 0.838 and 0.564 respectively
- The mean Diversity Indexes for the 2-hour Experimental Duration and 4-hour Experimental Duration were 0.716 and 0.686 respectively.

The Hopper vessels had a greater diversity of Final Survivors from both Experimental Duration treatments than the Non-Hopper vessels. The 2-hour Experimental Duration tanks had greater diversity in Final Survivors than the 4-hour Experimental Duration tanks.

11.4.5 DIVERSITY CHANGE FROM INITIAL TO FINAL SURVIVORS

A test was undertaken on the change in diversity occurring between the Initial Survivors used in the survival experiments and the Final Survivors at the completion of the survival experiments.

- There was a significant interaction between Hopper Vessel and Experimental Duration ($p=0.016$).

This indicates that the effect of the Hoppers was related to the time individuals spent in the survival tanks (Experimental Duration).

12. DISCUSSION

12.1 Potential Bycatch Survival

The mean bycatch survival from Hopper systems was found to be 16.09% based on numbers surviving compared to 8.46% for Non-hopper systems (Table 5). The numbers and weights of animals surviving were significantly higher from Hopper vessels and the diversity of species surviving was also significantly higher from Hoppers.

This research is based mainly on teleost species and does not account for any crabs (mainly portunids), elasmobranches, echinoderms or bivalves. These animals were eliminated from the survival study either due to difficulty in ascertaining live status or their detrimental influence on other species in an experimental tank; i.e. increase in secondary mortality.

While teleosts in Torres Strait make up a majority of bycatch from most trawls by weight (Harris and Poiner 1990), substantial *numbers* of Portunidae are evident in most trawls (pers obs.), while Hill and Wassenberg (1990) found non commercial crustaceans making up 18% of the catch *by weight* in Torres Strait. Crabs from prawn trawl operations have been reported to survive and suffer lower levels of mortality from trawling then teleosts (Hill and Wassenberg 1990).

Survival studies for small sharks and rays from Australian prawn trawls are not well covered but echinoderm and bivalve species have been reported to reach the seabed alive following trawl processing (Wassenberg and Hill 1990). Therefore Hopper survival rates in our study are likely to be underestimated when considering the combination of all non-teleost species known to survive and those species with high survival potential.

While the mortality and diversity loss was higher in Non-Hopper vessel systems, there were substantially less species and numbers of individuals surviving to begin with compared to Hopper vessels. A profile of "hardy species" can be gained from the Non-Hopper survivors. These species can endure physical and stressful conditions and because of this are likely to benefit further from a Hopper environment.

12.2 Factors Influencing Survival

The condition of individuals entering the experimental tanks is a key aspect for survival results. Hoppers should deliver animals in a healthier condition than normal sorting trays but a suite of external factors can influence survival, especially when Hoppers aren't operated optimally. This study was based on Hoppers that were set up and run both well and badly.

Improvement in the operation of Hoppers by fishers will have a substantial positive influence on both the quality of commercial product and bycatch survival.

In developing a catch mortality model for commercial fishing, Chopin et al. (1996) attempted to account for many aspects of fishing induced mortality. They noted that the sum of all fishing induced mortalities include deaths occurring as a result of capture or indirectly due to contact with fishing gear influences. Those fishing capture mortalities are also related to fishing method and trawl ground dynamics. Olla et al. (1997) found that simulated longer trawl durations (2 and 4 hours) on two trawl fish species produced greater increases in mortality, and in the 4-hour case, an increase in factors potentially adversely affecting post trawl survival.

From statistical assessment on percentage survival there were significant relationships found between both trawl depth and trawl duration on the survivor outcome (Hopper and Non-Hopper trawls). Likewise for percentage weight survival, a significant relationship between trawl depth and survivor outcome was evident.

Processing on Hopper vessels produced a significantly greater number and diversity of individuals alive from a sample to conduct the survival studies on. The higher rate of deaths during Hopper survival studies appeared to indicate a possible influence of a "tank effect" on survival. The influence of the survival tanks was assumed to be negligible but may have contributed to lower survival estimates. Almost certainly a higher proportion of fragile species or the more hardy individuals of such species would survive through a Hopper as stressed "Alive-Injured", although this may not have been easily detected visually.

Samples from Non-Hopper vessels tended to be mainly deceased individuals, few ‘Alive’ individuals and few cases of ‘Alive-Injured’. Hoppers on the other hand delivered a broader suite and greater number of Alive and Alive-Injured individuals. The ‘Initial Survivors’ taken immediately from the Hopper sorting conveyor yielded an assortment of animals with varying degrees of injury.

Deaths during Hopper survival experiments (losses in numbers and diversity of species) are likely to be attributable to a host of factors impacting on the bycatch leading up to processing and discard back to sea. Chopin et al. (1996) identify that recent research in fishing mortality show mortalities, (a) vary by gear type and species, (b) may be immediate or delayed and, (c) may be due to injuries or stressors associated with capture-escape trauma.

The possible effect of delayed mortality appeared to be evident in the statistical comparisons in terms of numbers and diversity of survivors between experimental duration treatments. More animals died during the 4-hour treatment than the 2-hour treatment. Survival studies by Wassenberg and Hill (1993) on "pre-Hopper" vessels indicated that survival rates were reduced in longer survival experiments. The extent of injury in a sorting tray system is likely to be greater following catch spill, exposure and physical handling. Delayed mortality effects are still likely to occur after Hopper processing but the degree of that affect is yet to be investigated.

12.3 The Benefits of Efficient Trawl Processing

Wassenberg and Hill (1989) note that while species specific, the time spent on deck exposed to air is a critical factor governing bycatch survival. Hoppers have two key operational advantages that address such factors and assist survival. Firstly, the catch is spilt immediately into fresh seawater. In a Hopper the catch is suspended in water and lifted out by conveyor. It undergoes minimal exposure to air and physical handling compared to Non-Hopper vessels where shovelling and greater application of hand-held shorting bats is required.

The second advantage is that more of the back deck processing has become automated, requiring less physical effort. More time is free to concentrate on sorting the conveyor delivered catch as quickly as possible. Catch processing here is referred to the time taken to sort all of the catch. Catch processing on Hopper vessels was substantially quicker allowing the grading, boxing and storage of commercial product in freezers to occur earlier.

The result is that bycatch spends less time onboard and is returned to sea in the shortest possible turn-around time, while commercial product is processed and frozen in less time enhancing product quality.

13. CONCLUSION

Hoppers can contribute significantly to improving short-term bycatch survival. They produce less mortality due to their mode of operation, and enable the discard of bycatch back to sea in the shortest turn-around time. A greater number and diversity of animals appeared to survive (over the observation period in the current study), while Hoppers have obvious processing efficiency and catch quality benefits for operators.

Trawl duration and depth, and optimisation of Hopper practice are important considerations influencing bycatch survival. Improvements in trawl practice and the operation of Hoppers have been shown to benefit the survival rate.

Published literature, together with the attrition with time in number and diversity observed in this study, indicates that longer-term trend and impacts may be involved; such as delayed mortality or a variable ability to recover from degrees of injury. Follow-up, longer duration research from this initial pilot study would be highly advantageous.

ALTERNATIVE HOPPER DESIGN FOR SMALLER VESSEL OPERATIONS

14. OVERVIEW

14.1 Small Vessel Hopper Development

Numerous fish-kill incidents have arisen from trawler discards along the northern beaches of the Cairns region, Far North Queensland. This prompted an industry representative body (ECO-FISH) to initiate discussion amongst local trawl operators for methods to address dead fish washing up on the beaches, particularly during intense trawling periods concentrating on good banana prawn (*Fenneropenaeus merguiensis*) catches.

A local fisher became interested in developing a smaller and cost effective version of Hoppers used in the Northern Prawn Fishery and Queensland East Coast / Torres Strait Prawn Trawl Fisheries. The concept was based on developing a device that would keep the bycatch alive during onboard processing operations. The sorting process worked around the continuous flushing of live bycatch back into the sea from the device (Small Vessel Hopper). The primary objective was to reduce the amount of dead fish floating onto beaches, with the added advantage of an improvement in prawn catch quality as per the larger scale Hopper concept.

Although other similar small Hopper ideas are starting to be developed at present, the initial investigations here are based on a self-financed prototype designed and developed by Mr Andrew Redfearn. The Hopper observed for this project has evolved over a period of two years via trials and modifications of three prototypes.

14.2 Design and Operation

Operation of the Small Vessel Hopper is based on utilising animal behaviour to achieve bycatch discard in a device designed to be free from mechanised conveyor systems.

The Hopper is designed so that water flow, light control and high density of individuals cue the mainly fish bycatch to swim out of the Hopper tank and down the discard chute; ie to "auto-discard". The device consists of an onboard rectangular tank, filled with fresh seawater sourced from a deck hose. The water is pumped to create a flow away from the overflow point ie a current that primarily circulates water away from the outlet but with a small amount that overflows down the discards chute. Fish tend to orient into the prevailing water flow so point towards the outlet until they hit the overflow vortex then are carried down the shute. Finally a mesh floor is raised by hydraulic water rams to crowd the swimming bycatch toward the water outflow that overflows via the discards chute.

When a lid is placed to cover the top of the Hopper, the only light penetrating the darkness is directly from the slot at the discards chute. Water flow in the Hopper orientates bycatch to face the light; they react to the light by swimming toward it. The result is that bycatch exit the Hopper following the watercourse down the discards chute. In contrast prawns tend to go to the bottom of the tank gripping the mesh and avoid the light, creating a useful stratification in the catch/by-catch mix.

The process can be repeated a number of times once sorting has started, or the catch can be left in the tank in the event of any onboard problems. When the mesh floor reaches sorting height the water flow can be turned off or slowed down and the catch sorted as usual. Any product that does flow out can be retrieved from the discards chute, which is altered to allow product sorting.

15. OBJECTIVES ADDRESSED

- To evaluate the effectiveness of the prototype non-mechanised Hopper currently being developed for the Queensland East Coast inshore banana prawn fishery (carried out in association with SeaNet)

16. METHODS

The prototypes were transported on barge supply vessels (Mother-ships) throughout Queensland east coast and Torres Strait waters. Sea trials were undertaken aboard volunteer vessels in trawl fisheries throughout Queensland.

Sea trials in commercial fishing grounds throughout Queensland were observed and filmed in order to archive prototype performance and design. The trials and video footage served to provide a snapshot of the Hopper's potential and allow evaluation of the prototype.

Further evaluation of the Small Vessel Hopper via survival study experiments would have been advantageous. However, vessel availability and timing of the commercial fishing seasons did not allow a sufficient window to undertake additional survival experiments.

17. RESULTS

File video footage was compiled by SeaNet into an informative multimedia CD for fishers explaining Small Vessel Hopper potential and operation (Please refer to Appendix C: Development Trials of the "Small Boat" Hopper. Open the "Small Vessel Hopper" file on the accompanying CD).

Onboard observations during trial runs of the Hopper prototype suggest positive survivor potential of bycatch exiting the device. Bycatch survival is a factor of trawl depth and trawl duration (refer to Chapter 2 Results). Inshore prawn trawl operations are generally short (20 to 90 minutes) and occur in predominately shallow waters (typically less than 10m).

Results from sea trails of the Small Vessel Hopper indicate:

- There is a prototype cost effective model suited particularly to the needs of small commercial Queensland east coast trawl vessels.
- A successful adaptation of the initial Hopper concept has been accomplished, using animal behaviour and basic machinery.
- There has been ongoing refinement and development of a fourth prototype in preparation for production of the final model.
- Sea trial observations and video footage suggest potential effectiveness in improving bycatch survival, although quantitative analysis awaits testing the final model.
- The advantages evident in the larger automated commercial Hoppers, such as catch processing efficiency, are also evident for operators using the Small Vessel Hopper.

18. DISCUSSION

Bycatch survival is a factor of the depth trawled and duration of the trawl shot, amongst other factors. Fortunately most small trawler operators work in shallow waters and use short trawls to target prawn species. Given these conditions, the Small Vessel Hopper device appears to be a very suitable solution to maximise the survivability of trawl discards.

The design is cheap to build and runs completely off the existing deck-hose that is available on most small trawlers. It is made from fibreglass and plywood and can be easily repaired. The result is a lightweight cost effective device that can be adapted to suit most back-deck layouts.

There has been considerable interest from Moreton Bay trawl fishers in the Small Vessel Hopper as their boat size is restricted to less than 14 metres. There have also been expressions of interest from New South Wales estuary trawl fishers, as new management plans require discard survival to be maximised.

From a Queensland perspective, the major aim of the Small Vessel Hopper is to provide a cost effective means to allow small east coast trawlers to reach the 40% reduction in bycatch mortality levels called for in the East Coast Trawl Management Plan. The Hopper can contribute to achieving this goal, given the nature of shallow banana prawn fishing operations and the short trawl times.

Benefits to fishers will be in the form of improved product quality, as the prawns are kept alive during catch processing. The sorting process should be shortened considerably as most bycatch is flushed/swims overboard instead of having to be physically managed and discarded. Crew safety is also enhanced, as there is less interaction with the discards while processing.

19. CONCLUSION

The Small Vessel Hopper design can be modified to suit different back-deck layouts. It is cheap to build and repair, resulting in a cost effective lightweight device that runs off an existing deck-hose.

Initial trials suggest good potential for discard survival, given that bycatch friendly trawl procedures are used. Fishers observing the SeaNet Development Trials of the "Small Boat" Hopper CD or the actual Hopper prototype have immediately identified with the potential benefits to their fishing operations.

RECOMMENDED PRACTICES FOR HOPPER OPERATION

20. PURPOSE

Hopper use aboard vessels in the Queensland East Coast Prawn Trawl Fishery was limited at the time of this study. There is however increasing interest for Hopper application in Queensland.

New equipment or procedures aboard commercial fishing vessels usually undergo some form of review of back deck procedures by operators to maintain an efficient routine. This period is when the opportunity arises to investigate some methods of operation and review processes and protocols for operation. For industry, this practice is typically centred on maximising the quality of product, for example, the ISO Beat Practice manual for catching and processing of wild-caught prawns (Anon 1997).

Considering the potential benefits of Hoppers for bycatch survival, the opportunity is there to formulate a set of recommendations that will benefit both catch quality and bycatch. A simple effective means to communicate recommended procedures is thus extremely beneficial to developing a culture of new practices that assist bycatch survival.

21. DEVELOPMENT

Russel Holt (Marine Engineer) and Denis Ballam (SeaNet) compiled an early document that was to form the basis of the 'Recommended Practices for Hopper Operation' concept. The draft document outlined summary recommendations during back deck operations concerning a particular brand of Hopper, (FISHQUIP).

Fieldwork operations during this pilot study were filmed to provide footage and images for presentation, extension documents and archive Hopper operations. Each field trip was also filmed for useful scenes that could be compiled into a summary video presentation. The production of a "Recommended practices" CD was not part of the project's original objectives but is an added extension of the project's results.

22. RECOMMENDED PRACTICES CD FOR INDUSTRY

The video footage produced for the recommended practices was compiled in the format of a video "avi" file for distribution on CD (Please refer to Appendix B: Recommended Practices for Hopper Operation. Open the 'Hopper Best Practices' file on the accompanying CD).

The format of a CD was chosen because it could be produced and distributed easily to industry. Computers are nearly universal on modern commercial fishing vessels for navigation via GPS. The CD format was also effective medium to target fishers as it can be viewed by the Microsoft Windows Media Player, which is common to the Windows operating system on Personnel Computers. The CD is deliberately identified as "shareware" to encourage distribution of information.

BENEFITS

Large scale Hoppers (larger "offshore" prawn trawlers)

From a Queensland perspective, the major aim was to evaluate a cost effective means for east coast trawlers to reach the 40% reduction in bycatch mortality levels, called for in the East Coast Trawl Management Plan. Our short duration survival experiments indicate that Hoppers represent an effective component in a suite of measures and strategies for the reduction in bycatch mortality. Therefore the ultimate benefit to the industry may be to allow the continuation of a trawl fishery within the GBR World Heritage Area.

Direct economic benefits to fishers from Hoppers will be through improved product quality, as the prawns are kept alive and fresh during catch processing. The sorting process should be shortened and made more cost efficient by mechanisation. Crew safety will also be enhanced, as there is less interaction with the hazardous discards while processing.

Small Scale Hoppers (inshore "small boat" trawlers)

Again from a Queensland perspective the major issue for inshore trawlers is "dead fish washed up on the beach", particularly when these are major tourist beaches. The small scale Hopper has potential in reduction of the mortality of discarded bycatch, given the shallow water fishing operations, the relatively short trawl times, and therefore the maximum chance for survival through a Hopper system. The benefits are similar to the large scale Hopper in improving product quality, economic efficiency, and work safety. The real benefit may be in the reduction of community protest for closure of inshore trawl grounds.

On a wider ecological scale, the high levels of bycatch mortality involved in trawling are unacceptable as a sustainability issue and in some quarters as a simple ethical issue. The benefit of wide spread use of Hoppers is a real reduction in that mortality and, in concert with BRD's, TED's and shorter trawl duration, represent best practice for both product quality and environmental impact. These best practice procedures demonstrate a clear commitment to ecological responsibility under State and Commonwealth legislation and to international agreements.

FURTHER DEVELOPMENT

23. HOPPER EVALUATION AND BYCATCH SURVIVAL

Phase two of the Hopper and bycatch survival evaluation is under consideration for funding in a national approach to Hopper research across several Australian states. Further development is discussed with reference to the organisation for potential future study planned in this area of research.

The time frame available for this pilot study meant that short survival experiments were conducted in order to undertake a sufficient number of experiments. There have been several longer-term studies conducted over a number of days, observing the survival of trawl bycatch (eg; Soldal and Engås 1997). Wassenburg and Hill (1993) found that four days was an optimal duration for survival studies from trials on trawl bycatch from Moreton Bay.

Survival studies over at least four days would allow assessment of "Alive-Injured" animals and testing of the influence of factors such as stress-induced muscle breakdown, scale loss, infection from trawl injuries and the impact of stress following trawl capture and catch processing.

24. SMALL VESSEL HOPPERS

Significant interest from commercial fishers in Moreton Bay and estuary fishers in NSW has been expressed in the Small Vessel Hopper design, while the device would also be beneficial to Beam Trawl fishers in southeast Queensland.

Due to delays in development of the final prototype, sea trials involving survival experiments on bycatch were not undertaken for the Small Vessel Hopper in this project.

Further development in assessing the benefit of the Small Vessel Hopper would be highly desirable for east coast trawlers considering the number of small vessels throughout Queensland waters. Design refinement of the prototype is currently underway and survival studies have been planned and budgeted for in the national Hopper Phase II project proposal.

25. RECOMMENDED PRACTICES FOR HOPPER OPERATION

Improvement in the operation of Hoppers by fishers will have a substantial positive influence on bycatch survival and the quality of commercial product. The first version of a 'Recommended Practices for Hopper Operation' has been produced to provide information to Queensland fishers. Further development of a best practice information series would be beneficial to specific regional/state fisheries and at the national level. Integration of that information into a format such as the ISO best practice manual (Anon 1997) would also be highly beneficial.

PLANNED OUTCOMES

Outcome: Better information base for Prawn Trawl Fishery and fishery managers on the effectiveness of Hoppers in regard to sustainability of resource. The results of the evaluation have been presented at the:

1. National Workshop on bycatch reduction for industry and management organised by QFS Trawl Manager. (22/23 April 2002)
2. ECOFISH briefing (Marine Industry cluster Group) (2 May 2002). This forum was championing gear changes for the inshore trawl fishery, which have since been adopted by QFS for the Cairns region.
3. National Workshop on Hoppers organised through Ocean Watch (10 September 2002)
4. Presentation of results to Queensland Trawl Mac Scientific Advisory Committee (2003)

NOTE. The Cairns region inshore trawl fishery, through ECOFISH, is currently applying for international Marine Stewardship Certification. The Packard Foundation has funded the preliminary assessment/audit. The principals of the current FRDC funded project, particularly Denis Bellum of SEANET, were instrumental in initiating the application, obtaining the funding, and providing advice to the assessment team. In this case output from the DPI/industry evaluation of Hoppers has been the demonstration of a proactive commitment to ecological responsibility.

Outcome: Strategic tool (ESD evaluation of Hoppers) to help with informed strategic decisions. The project has produced three instructional videos and recorded these on CD format for distribution to the industry and managers, via the SEANET extension program:

1. Hoppers: a method for reducing trawl bycath mortality.
2. Hopper Best Practices
3. Small Vessel Hopper (Winners are grinners).

Outcome: Evaluate pro-active and innovative solutions to environmental problems. The project has dealt with this output by fostering the development and initial evaluation the small vessel Hopper, aimed at reducing bycatch mortality in the highly controversial inshore and river trawl fishery. The outcome has been the production of a prototype and a raised awareness of this option for the Qld and NSW (Clarence River) fishers concerned.

We have also extended our evaluation into the use of Hoppers in the trawl whiting fishery (see appendix D). Again this is a pro-active solution to bycatch survival, in a fish rather than prawn trawl fishery.

OVERALL CONCLUSIONS

- Hoppers can contribute significantly to improving short-term bycatch survival. They produce less mortality due to their mode of operation, and enable the discard of bycatch back to sea in the shortest turn-around time. A greater number and diversity of animals appeared to survive (over the observation period in the current study), while Hoppers have obvious processing efficiency and catch quality benefits for industry operators.

- Trawl duration and depth, and optimisation of Hopper practice are important considerations influencing bycatch survival. Improvements in trawl practice and the operation of Hoppers have been shown to benefit the survival rate.

- Published literature, together with the attrition and decrease in diversity with time observed in this study, indicates that longer-term trend and impacts may be involved; such as delayed mortality or the variable ability to recover from degrees of injury. Follow up, longer duration research from this initial pilot study would be highly advantageous.

- The Small Vessel Hopper design can be modified to suit different back-deck layouts. It is cheap to build and repair, resulting in a cost effective lightweight device that runs off an existing deck-hose.

- Initial trials of the Small Vessel Hopper suggest good potential for discard survival, given that bycatch friendly trawl procedures are used. Fishers observing the CD of Development Trials of the "Small Boat" Hopper or the actual Hopper prototype have immediately identified with the potential benefits to their fishing operations.

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INTELLECTUAL PROPERTY

No commercial intellectual property arose from this work.

APPENDICES

APPENDIX A: Torres Strait Species List

Appendix Table 1: Total species list of organisms sampled in the Torres Straight prawn trawl fishery

Species	Family	# Occurrences	# Individuals
Antennarius hispidus	ANTENNARIIDAE	1	1
Tathicarpus butleri	ANTENNARIIDAE	7	9
Adventor elongatus	APLOACTINIDAE	26	31
Apogon brevicaudatus	APOGONIDAE	58	95
Apogon carinatus	APOGONIDAE	2	2
Apogon ellioti	APOGONIDAE	215	1435
Apogon hartzfeldi	APOGONIDAE	43	172
Apogon nigripinnis	APOGONIDAE	4	4
Apogon poecilopterus	APOGONIDAE	136	462
Apogon quadrifasciatus	APOGONIDAE	44	58
Apogon septemstriatus	APOGONIDAE	56	104
Arius thalassinus	ARIIDAE	1	1
Engyprosopon grandisquama	BOTHIDAE	191	975
Grammatobothus polyophthalmus	BOTHIDAE	128	238
Psettina gigantea	BOTHIDAE	48	72
Pseudorhombus argus	BOTHIDAE	38	55
Pseudorhombus diplospilus	BOTHIDAE	62	72
Pseudorhombus elevatus	BOTHIDAE	105	216
Pseudorhombus jenynsii	BOTHIDAE	4	4
Pseudorhombus spinosus	BOTHIDAE	163	355
Pterocaesio diagramma	CAESIONIDAE	2	15
Callionymus belcheri	CALLIONYMIDAE	233	3288
Callionymus grossi	CALLIONYMIDAE	159	480
Dactylopus dactylopus	CALLIONYMIDAE	22	33
Synchiropus rameus	CALLIONYMIDAE	31	40
Absalom radiatus	CARANGIDAE	1	1
Alepes sp	CARANGIDAE	10	12
Carangoides fulvoguttatus	CARANGIDAE	7	8
Carangoides hedlandensis	CARANGIDAE	1	1
Carangoides humerosus	CARANGIDAE	22	37
Carangoides talamparoides	CARANGIDAE	39	77
Caranx bucculentus	CARANGIDAE	18	30
Decapterus macrosoma	CARANGIDAE	54	210
Decapterus russellii	CARANGIDAE	1	1
Gnathanodon speciosus	CARANGIDAE	6	8
Megalaspis cordyla	CARANGIDAE	4	5
Selar boops	CARANGIDAE	11	14
Selar crumenophthalmus	CARANGIDAE	8	9
Selaroides leptolepis	CARANGIDAE	158	787
Seriolina nigrofasciata	CARANGIDAE	5	5
Ulua aurochs	CARANGIDAE	25	47
Centriscus scutatus	CENTRISCIDAE	2	2
Chaetodontoplus duboulayi	CHAETODONTIDAE	2	2
Parachaetodon ocellatus	CHAETODONTIDAE	17	20
Amblygaster sirm	CLUPEIDAE	8	25
Herklotsichthys lippa	CLUPEIDAE	7	8

APPENDIX A: Torres Strait Species List

Appendix Table 1 [*Continued*]: Total species list of organisms sampled in the Torres Straight prawn trawl fishery

Species	Family	# Occurrences	# Individuals
Sardinella gibbosa	CLUPEIDAE	1	1
Cynoglossus macrophthalmus	CYNOGLOSSIDAE	48	56
Dactyloptena papilio	DACTYLOPTERIDAE	109	180
Cyclichthys jaculiferus	DIODONTIDAE	15	16
Drepane punctata	EPHIPPIDIDAE	1	1
Fistularia petimba	FISTULARIIDAE	72	128
Gerres filamentosus	GERREIDAE	39	48
Gerres subfasciatus	GERREIDAE	1	1
Pentaprion longimanus	GERREIDAE	26	70
Glaucosoma magnificum	GLAUCOSOMATIDAE	25	33
Yongeichthys nebulosus	GOBIIDAE	112	248
Diagramma pictum	HAEMULIDAE	9	10
Pomadasys maculatum	HAEMULIDAE	1	1
Choerodon cephalotes	LABRIDAE	138	294
Choerodon monostigma	LABRIDAE	98	172
Choerodon sp.2	LABRIDAE	140	331
Gazza minuta	LEIOGNATHIDAE	2	2
Leiognathus bindus	LEIOGNATHIDAE	6	14
Leiognathus decorus	LEIOGNATHIDAE	12	21
Leiognathus fasciatus	LEIOGNATHIDAE	3	4
Leiognathus leuciscus	LEIOGNATHIDAE	57	122
Leiognathus moretoniensis	LEIOGNATHIDAE	2	2
Leiognathus sp	LEIOGNATHIDAE	72	158
Lethrinus laticaudis	LETHRINIDAE	47	114
Lethrinus lentjan	LETHRINIDAE	4	5
Lethrinus nebulosus	LETHRINIDAE	14	27
Lutjanus carponotatus	LUTJANIDAE	1	1
Lutjanus malabaricus	LUTJANIDAE	2	2
Lutjanus russelli	LUTJANIDAE	2	3
Lutjanus sebae	LUTJANIDAE	16	17
Lutjanus vitta	LUTJANIDAE	15	18
Anacanthus barbatus	MONACANTHIDAE	3	3
Monacanthus chinensis	MONACANTHIDAE	29	35
Paramonacanthus filicauda	MONACANTHIDAE	4	4
Paramonacanthus japonicus	MONACANTHIDAE	212	858
Paramonacanthus otisensis	MONACANTHIDAE	12	14
Pseudomonacanthus elongatus	MONACANTHIDAE	143	314
Parupeneus pleurospilus	MULLIDAE	13	16
Upeneus asymmetricus	MULLIDAE	102	285
Upeneus luzonius	MULLIDAE	50	127
Upeneus moluccensis	MULLIDAE	31	45
Upeneus sp	MULLIDAE	29	146
Upeneus sundaicus	MULLIDAE	7	8
Upeneus tragula	MULLIDAE	2	2
Nemipterus furcosus	NEMIPTERIDAE	165	958
Nemipterus hexodon	NEMIPTERIDAE	110	292

APPENDIX A: Torres Strait Species List

Appendix Table 1 [*Continued*]: Total species list of organisms sampled in the Torres Straight prawn trawl fishery

Species	Family	# Occurrences	# Individuals
Nemipterus marginatus	NEMIPTERIDAE	9	27
Nemipterus mesiprion	NEMIPTERIDAE	41	110
Nemipterus nematopus	NEMIPTERIDAE	13	39
Nemipterus peronii	NEMIPTERIDAE	175	640
Pentapodus porosus	NEMIPTERIDAE	77	239
Scolopsis taeniopterus	NEMIPTERIDAE	210	1156
Sirembo imberbis	OPHIDIIDAE	3	3
Rhynchostracion nasus	OSTRACIIDAE	94	182
Pegasus volitans	PEGASIDAE	107	426
Parapercis nebulosa	PINGUIPEDIDAE	70	113
Cymbacephalus nematophthalmus	PLATYCEPHALIDAE	32	35
Elates ransonnetii	PLATYCEPHALIDAE	16	17
Inegocia japonica	PLATYCEPHALIDAE	194	496
Onigocia macrolepis	PLATYCEPHALIDAE	225	1350
Suggrundus macracanthus	PLATYCEPHALIDAE	35	65
Samaris cristatus	PLEURONECTIDAE	37	55
Euristhmus nudiceps	PLOTOSIDAE	120	245
Plotosus lineatus	PLOTOSIDAE	36	156
Pristotis jerdoni	POMACENTRIDAE	79	161
Priacanthus tayenus	PRIACANTHIDAE	176	576
Psettodes erumei	PSETTODIDAE	31	37
Rachycentron canadus	RACHYCENTRIDAE	1	1
Rastrelliger kanagurta	SCOMBRIDAE	5	6
Apistus carinatus	SCORPAENIDAE	93	203
Minous trachycephalus	SCORPAENIDAE	74	95
Paracentropogon longispinis	SCORPAENIDAE	79	477
Pterois russelli	SCORPAENIDAE	15	16
Epinephelus sexfasciatus	SERRANIDAE	59	78
Siganus canaliculatus	SIGANIDAE	68	98
Siganus fuscescens	SIGANIDAE	1	1
Sillago maculata	SILLAGINIDAE	5	6
Sillago sihama	SILLAGINIDAE	41	117
Zebrias craticula	SOLEIDAE	9	10
Zebrias quagga	SOLEIDAE	2	2
Saurida micropectoralis	SYNODONTIDAE	1	1
Saurida sp.2	SYNODONTIDAE	50	146
Saurida tumbil	SYNODONTIDAE	162	417
Saurida undosquamis	SYNODONTIDAE	233	3099
Synodus hoshinonis	SYNODONTIDAE	13	26
Synodus sageneus	SYNODONTIDAE	97	163
Trachinocephalus myops	SYNODONTIDAE	9	12
Anchisomus multistriatus	TETRAODONTIDAE	1	1
Arothron manillensis	TETRAODONTIDAE	2	2
Lagocephalus lunaris	TETRAODONTIDAE	1	2
Lagocephalus sceleratus	TETRAODONTIDAE	192	676
Tetrosomus gibbosus	TETRAODONTIDAE	5	7

APPENDIX A: Torres Strait Species List

Appendix Table 1 [*Continued*]: Total species list of organisms sampled in the Torres Straight prawn trawl fishery

Species	Family	# Occurrences	# Individuals
Torquigener pallimaculatus	TETRAODONTIDAE	150	433
Trixiphichthys weberi	TRIACANTHIDAE	5	5
Lepidotrigla argus	TRIGLIDAE	20	45
Metapenaeopsis palmensis	PENAEIDAE	226	7284
Trachypenaeus curvirostris	PENAEIDAE	221	6589
Scyllarus demani	SCYLLARIDAE	217	1100
Thenus indicus	SCYLLARIDAE	97	166
Thenus orientalis	SCYLLARIDAE	39	55
Cuttle/Octopus	SEPIIDAE	168	413
Erugosquilla woodmasoni	SQUILLIDAE	24	62
stomat1	-Stomatopoda-	79	120
stomat2	-Stomatopoda-	42	49
stomat4	-Stomatopoda-	2	2

APPENDIX B:

Recommended Practices for Hopper Operation
(‘Hopper Best Practices’ File on the accompanying CD)

APPENDIX C:

Development Trials of the “Small Boat” Hopper
(‘Small Vessel Hopper’ File on the accompanying CD)

APPENDIX D: Hopper use in the Queensland Whiting Fishery

Introduction

The Whiting trawl fishery (*Sillago robusta*) off the Queensland South East coast is made up of less than ten vessels. The majority of vessels in the fleet have Hoppers, fitted by industry to assist catch processing. The Hoppers are of the same design and operation as used in the Queensland prawn trawl fishery.

Hoppers may be beneficial in trawl fisheries other than prawn trawl with regard to bycatch processing, and bycatch survival. Investigating their use in an alternative fish trawl scenario contributes to a better understanding of Hopper operation, the factors influencing survival, and the impact of Hoppers in different trawl fisheries.

Objective

- Evaluate potential bycatch survival and Hopper performance in a fish trawl environment (multi-disciplinary approach).

Methods

Sampling methods are as per section 10.2 (Bycatch Survival and Hopper Evaluation). Survival studies and sampling were carried out in the South East Queensland Whiting Trawl Fishery, off Fraser Island between 25 22.95 latitude 153 19.34 longitude, and 25 46.71 latitude 153 9.38 longitude. Only one vessel was available for survival studies due to extreme weather conditions at the time available for opportunistic *ad hoc* sampling/observing.

Results

Trawl duration in the Whiting trawl fishery is extremely variable. The minimum trawl duration sampled was 1 hour 16 minutes and the maximum 2 hours 23 minutes (mean trawl time 2 hours 22 minutes). Trawls can range greatly from 15 minutes to 4 hours.

The catch volume is typically large and captured in a single towed trawl net. The resultant catch processing time is a factor of large catches of the target species and other byproduct species that are utilised as part of the commercial catch. The average catch processing time was 52 minutes.

A total of 63 species from 35 families were sampled during 14 trawls on a Hopper vessel for survival studies. Of these, 37 species from 24 families were found to survive. These summary results are based on simple survival occurrence data only. The actual number of some surviving species may be as low as one individual (Appendix Table 2).

Appendix Table 2 (*Following Page*): Total species list of organisms sampled in the Whiting trawl fishery. Species surviving the 2 and 4-hour experiments are bolded blue.

Discussion

Trawl duration in the Whiting fishery is extremely variable due to schooling behaviour of the target and byproduct species. Fishers search for "marks" on the echo sounder as an indicator for schools of fish. Once a mark is found they repeatedly target that mark and then winch up. These are typically very short trawls where the catch is almost completely target species alone.

Longer "search" style trawls contain greater ratios of non target species but many of these species are used as commercial byproduct (members from Nemipteridae, Mullidae and Clupeidae). Short trawls for marks are at highly irregular times, possibly more at the beginning of the season. Trawls sampled here were chosen on the basis of what was an average style of trawl at that time.

Hoppers appeared to be beneficial to bycatch survival but only to those species that exited the Hopper early. Large catch bags limit survival due to crushing factors and the amount of processing time to deal with a large catch volume. Representative sampling from the Hopper was far more difficult due to the size of catch and amount of time taken to empty the Hopper.

Conclusion

Bycatch survival is dependant on fishery specific modes of operation such as trawl duration, style and type of fishing gear. These factors influence density of the catch, both in the codend and Hopper, and processing time.

Trawl fisheries, other than prawn trawl, can benefit from Hoppers even if a relatively smaller suite of species survives. Processing advantages are still a highlight for fishers.

Species	Family	Number of Occurrences	Total Number	Survivor Occurrences	Total Survivors
Apogon ellioti	APOGONIDAE	3	3		
Apogon nigripinnis	APOGONIDAE	13	18		
Apogon quadrifasciatus	APOGONIDAE	7	9		
Arnoglossus waitei	BOTHIDAE	1	1		
Engyprosopon grandisquama	**BOTHIDAE**	54	928	**7**	**9**
Grammatobothus polyophthalmus	**BOTHIDAE**	10	16	**1**	**1**
Pseudorhombus argus	**BOTHIDAE**	21	38	**6**	**7**
Pseudorhombus elevatus	**BOTHIDAE**	10	13	**1**	**1**
Pseudorhombus spinosus	**BOTHIDAE**	7	7	**3**	**3**
Callionymus japonicus	**CALLIONYMIDAE**	20	57	**1**	**1**
Callionymus moretonensis	**CALLIONYMIDAE**	31	101	**10**	**15**
Synchiropus rameus	**CALLIONYMIDAE**	5	6	**2**	**2**
Alepes sp	CARANGIDAE	7	10		
Carangoides chrysophrys	**CARANGIDAE**	1	1	**1**	**1**
Carangoides ferdau	CARANGIDAE	2	2		
Carangoides fulvoguttatus	CARANGIDAE	1	1		
Carangoides humerosus	CARANGIDAE	1	1		
Parastromateus niger	CARANGIDAE	6	6		
Ulua aurochs	**CARANGIDAE**	5	7	**1**	**1**
Etrumeus teres	CLUPEIDAE	10	80		
Cynoglossus macrophthalmus	**CYNOGLOSSIDAE**	44	165	**13**	**14**
Dactyloptena papilio	DACTYLOPTERIDAE	8	9		
Fistularia petimba	FISTULARIIDAE	1	1		
Gerres filamentosus	GERREIDAE	3	3		
Diagramma pictum	**HAEMULIDAE**	2	4	**2**	**2**
Pomadasys argenteus	**HAEMULIDAE**	1	1	**1**	**1**
Choerodon cephalotes	**LABRIDAE**	1	1	**1**	**1**
Leiognathus moretoniensis	LEIOGNATHIDAE	3	4		
Paramonacanthus filicauda	MONACANTHIDAE	2	2		
Paramonacanthus japonicus	**MONACANTHIDAE**	5	5	**2**	**2**
Pseudomonacanthus elongatus	MONACANTHIDAE	2	3		
Nemipterus theodorei	**NEMIPTERIDAE**	55	1151	**17**	**21**
Rhynchostracion nasus	OSTRACIIDAE	1	1		
Parapercis nebulosa	**PINGUIPEDIDAE**	45	114	**25**	**35**
Ambiserrula jugosa	**PLATYCEPHALIDAE**	46	422	**38**	**105**
Inegocia japonica	**PLATYCEPHALIDAE**	6	18	**5**	**8**
Platycephalus endrachtensis	**PLATYCEPHALIDAE**	17	24	**7**	**7**
Platycephalus longispinis	**PLATYCEPHALIDAE**	36	174	**12**	**19**
Euristhmus nudiceps	PLOTOSIDAE	3	3		
Plotosus lineatus	**PLOTOSIDAE**	8	12	**2**	**2**
Pristotis jerdoni	**POMACENTRIDAE**	6	14	**2**	**2**
Priacanthus macracanthus	**PRIACANTHIDAE**	18	28	**2**	**2**
Apistus carinatus	**SCORPAENIDAE**	16	54	**2**	**2**
Inimicus sinensis	**SCORPAENIDAE**	1	1	**1**	**1**
Minous trachycephalus	SCORPAENIDAE	2	3		
Pterois russelli	SCORPAENIDAE	8	9		
Sillago robusta	**SILLAGINIDAE**	47	1173	**1**	**1**
Zebrias quagga	**SOLEIDAE**	1	1	**1**	**1**
Saurida sp.2	SYNODONTIDAE	24	70		
Saurida undosquamis	SYNODONTIDAE	51	602		
Trachinocephalus myops	**SYNODONTIDAE**	24	37	**8**	**11**
Pelates sexlineatus	**TERAPONIDAE**	11	135	**5**	**22**
Tetrosomus gibbosus	**TETRAODONTIDAE**	3	3	**1**	**1**
Torquigener pallimaculatus	**TETRAODONTIDAE**	41	160	**24**	**39**
Trixiphichthys weberi	TRIACANTHIDAE	2	2		
Lepidotrigla argus	**TRIGLIDAE**	50	1878	**14**	**21**
Diodon holacanthus	TRIODONTIDAE	1	1		
Uranoscopus cognatus	URANOSCOPIDAE	1	1		
Metapenaeopsis palmensis	**PENAEIDAE**	14	48	**4**	**5**
Thenus orientalis	**SCYLLARIDAE**	3	5	**2**	**2**
Cuttle/Octopus	SEPIIDAE	23	46		
Erugosquilla woodmasoni	**SQUILLIDAE**	2	2	**2**	**2**
Belosquilla laevius	**SQUILLOIDEA**	6	6	**4**	**4**