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Report of the

SYMPOSIUM ON IMPACTS OF FISHING ON THE ENVIRONMENT
ICES-FAO Working Group on Fishing Technology and Fish Behaviour

Bangkok, Thailand, 6–10 May 2013

Cover photographs: Courtesy of (from top left clockwise): Dan Watson, Yoshiki Matsushita, Petri Suuronen, Philip Walsh.

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PREPARATION OF THIS DOCUMENT

This document is the final report of the Symposium on Impacts of Fishing on the Environment arranged by the ICES-FAO Working Group on Fishing Technology and Fish Behaviour (WGFTFB) and held from 6 to 10 May 2013 in Bangkok, Thailand. The document was prepared by Mr Steve Eayrs (Gulf of Maine Research Institute, Maine, USA) and Mr Petri Suuronen (Fishing Operations and Technology Branch, FAO). The text presented in Appendix 3 of this report summarizes the presentations of the workshop and has been reproduced as submitted. The text has attempted to faithfully capture the issues raised by each presenter. The editors apologize for any misrepresentation that may have arisen in their summation.

This Symposium was the first collaborative working group meeting hosted by FAO, and the first to be hosted outside of traditional ICES countries. The preparation, coordination, and planning of this Symposium was extraordinary. The efforts of SEAFDEC staff, especially Bundit Chokesanguan, deserve special acknowledgment. We also want to acknowledge the efforts of the WGFTFB Co-Chairman, Michael Pol (Massachusetts Division of Marine Fisheries, USA) for his contribution to the planning, coordination, and execution of the Symposium. We are very grateful to Mike Breen (Institute of Marine Research, Norway) for his thorough review of the LIGHT session. Finally, we would like to acknowledge the vision of individuals from ICES and FAO in joining forces to form the ICES-FAO Fishing Technology and Fish Behavior Working Group.

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ABSTRACT

This report summarizes the symposium "Impacts of Fishing on the Environment", which was part of the annual meeting of the joint ICES-FAO Working Group on Fishing Technology and Fish Behaviour (WGFTFB). The symposium comprised three one-day sessions: (i) low-impact and fuel-efficient fishing gear (LIFE); use of artificial light as a stimulus on fish behaviour in fish capture (LIGHT); and (iii) selectivity of trawls in multispecies/crustacean fisheries (SHRIMP). This report also summarizes presentations from the open session of the annual meeting, while details on the remaining sessions are provided in the WGFTFB meeting report produced by ICES.

The ICES-FAO WGFTFB annual meeting was held in Bangkok, Thailand, on 6–10 May 2013, the first time it had been hosted by FAO and held outside the ICES region. More than 130 fishing technologists, scientists and others representing 25 countries attended this meeting.

The LIFE session featured presentations on the performance of modified fishing gear, based on at-sea research or computer simulation. Overall, around the world, considerable research is focusing on LIFE fishing, which includes advances in fish and shrimp trawl fisheries, beam and pulse trawl fisheries for demersal finfish, tuna longline fisheries, pot fisheries for cod, and set net and boat seine fisheries for small pelagics. However, several presentations highlighted the lack of gear uptake by fishers, often despite clear environmental and economic benefits.

Many presentations in the LIGHT session described the benefits (e.g. reduced energy consumption) and application of LED lighting. It appears that LED lighting is increasingly replacing other light sources. The presentations were dominated by research from Asia, where light fishing is an important method. Other presentations focused on techniques to evaluate the visual ability of fish, squid and other animals, and how to use this knowledge to manipulate fish behaviour and increase catch rates.

The SHRIMP session included presentations on improving selectivity and reducing bycatch in a variety of fisheries. A main theme was the ongoing challenge of reducing bycatch, including the development of effective turtle excluder devices and bycatch reduction devices (BRDs), and their poor uptake and compliance by some fishers. Another theme was the importance of underwater video cameras to observe trawl performance, BRDs and response to trawl stimuli.

The symposium provided an opportunity for fishing technologists and others from ICES member countries to exchange knowledge and ideas with contemporaries from around the world, especially Asia. The main global theme to emerge was that of poor uptake and compliance of new fishing gear by fishers. The rationale for this behaviour by fishers is complex, and often inconsistent among fisheries and individual fishers. This issue remains a major challenge to sustainable fisheries development, and it is clear that much work remains in this area in many fisheries.

CONTENTS

ABBREVIATIONS AND ACRONYMS

ADCP	acoustic doppler current profiler
BED	bycatch excluder device
BRD	bycatch reduction device
CEFAS	Centre for Environment, Fisheries and Aquaculture Science
CPUE	catch per unit effort
CSIRO	Commonwealth Scientific and Industrial Research Organisation
EAF	ecosystem approach to fishing
EBM	ecosystem based management
ECG	electrocardiogram
EMG	electromyogram
ERG	electroretinogram
FCAP	Faithlie Cod Avoidance Panel
FE	fisheye
FFG	Flip Flap Grid trawl
GEF	Global Environment Facility
GHG	greenhouse gas
HL	halogen lamp
ICES	International Council for the Exploration of the Sea
IL	incandescent lamp
IMARES	Institute for Marine Resources and Ecosystem Studies
IMR	Institute of Marine Research
JTED	juvenile and trash excluder device
LED	light-emitting diode
LIFE	Low-impact and fuel efficient fishing gear (symposium session)
LIGHT	Use of artificial light as a stimulus on fish behaviour in fish capture (symposium session)
LNG	liquefied natural gas
MC	meshes in circumference
MCS	management control systems
MHL	metal halide lamp
NFRDI	National Fisheries Research and Development Institute
NPF	Northern Prawn Fishery
OWAS	Ovako Working Posture Analysis System
PFD	photon flux density
SEAFDEC	Southeast Asian Fisheries Development Center
SHRIMP	Selectivity of trawls in multispecies/crustacean fisheries (symposium session)
SS	Super Shooter
SMW	square-mesh window
TDR	temperature-depth recorder
TED	turtle excluder device
TUMST	Tokyo University of Marine Science and Technology
UFL	underwater fishing lamps
UMass	University of Massachusetts Dartmouth
UNEP	United Nations Environment Programme
UV	ultraviolet
WGFTFB	Working Group on Fishing Technology and Fish Behaviour

1. INTRODUCTION

1. On 6–10 May 2013, FAO hosted the annual meeting of the ICES–FAO Working Group on Fishing Technology and Fish Behaviour (WGFTFB) at the Southeast Asian Fisheries Development Center (SEAFDEC) Training Department near Bangkok, Thailand. This meeting included a three-day symposium on impacts of fishing on the environment. Topics included low-impact fuel-efficient fishing, fishing with artificial light, and the selectivity of trawls in shrimp and multispecies trawl fisheries. More than 130 fishing technologists, scientists and others representing 25 countries attended the meeting.

2. The ICES–FAO Working Group on Fishing Technology and Fish Behaviour was established in 2002. Prior to this time, the working group was comprised primarily of individuals from the member countries of the ICES (International Council for the Exploration of the Sea) in Europe and North America and was known as the ICES Working Group on Fishing Technology and Fish Behaviour. However, after many years of close collaboration between ICES and FAO on a variety of activities and issues, the forging of a new, combined working group with a global mandate was viewed as an important development and extension of this relationship. A primary objective of this joint working group is to foster dialogue and collaboration between member countries to address all aspects of fishing technology and fish capture and to contribute to the sustainable exploitation of global fisheries resources.

3. In 2011, ICES and FAO further defined the purpose of collaboration at the WGFTFB, with the subsequent outcome that FAO would co-chair the annual meeting and host the meeting every third year at a location chosen by FAO. The meeting held at the SEAFDEC Training Department on 6–10 May 2013 was the first meeting hosted by FAO under this new arrangement.

4. SEAFDEC is an autonomous intergovernmental organization that was established in 1967 with a mandate to develop and rationally utilize fisheries resources in the region and to contribute to economic development and food security. It is comprised of multiple departments with the Secretariat and Training Department located in Thailand, the Aquaculture Department located in the Philippines, and both the Marine Fisheries Department and Marine Fishery Resources Development and Management Department located in Malaysia. A close working relationship exists between SEAFDEC and FAO, and for many years they have participated in a variety of collaborative activities including the prominent global shrimp bycatch reduction project of the United Nations Environment Programme (UNEP) / Global Environment Facility (GEF) in 2002–08.

5. The overarching goal and objectives of the 2013 WGFTFB meeting were to:

- (i) Provide a forum for global synthesis of the scientific knowledge of fishing technology and its effective use.
- (ii) Evaluate the role and potential for capture technologies and practices to reduce fishing impacts on the environment and energy use.
- (iii) Review and discuss advances in technology and analytical methods used to study these effects.
- (iv) Provide a forum for discussion on how perceptions and decisions of fishers and resource managers affect the success of achieving sustainable use and successful management of fishery resources.
- (v) Foster new partnerships between scientists and technologists from developed and developing economies to minimize the impact of fishing in the environment.

6. The WGFTFB meeting included the three-day symposium “Impacts of Fishing on the Environment”, plus an open session of presentations covering a variety of topics related to the working

group, ICES topic group break-out sessions and summary reports, country reports and a general business session. The symposium consisted of the following sessions:

- Low-impact and fuel-efficient fishing gear (LIFE).
- Use of artificial light as a stimulus on fish behaviour in fish capture (LIGHT).
- Selectivity of trawls in multispecies/crustacean fisheries (SHRIMP).

7. Presentations from the symposium and the open session are provided in Appendix 3, while details of the ICES topic groups, country reports, and general business can be found in the 2013 ICES Working Group report.

2. SUMMARY OF SYMPOSIUM

Effects of fishing on the environment

Day 1: Low-impact and fuel-efficient fishing gear (LIFE)

8. The primary focus of this session was:

- cost-effective next-generation fishing technologies;
- modification/replacement of high-impact and fuel-hungry fishing techniques and practices;
- energy-efficient fishing vessel design;
- barriers for adoption of LIFE fishing practices;
- policy and socio-economic aspects;
- research directions.

9. The LIFE session was convened by Thomas Catchpole (Centre for Environment, Fisheries and Aquaculture Science [CEFAS], the United Kingdom of Great Britain and Northern Ireland), Yoshiki Matsushita (Nagasaki University, Japan) and Bob van Marlen (Institute for Marine Resources and Ecosystem Studies [IMARES], the Netherlands).

10. The session comprised 15 presentations from 11 countries. The keynote presentation, presented by John Willy Valdemarsen (Institute of Marine Research [IMR], Norway) and Petri Suuronen (FAO), was titled "Low Impact and Fuel Efficient (LIFE) fishing: challenges, opportunities, and some technical solutions".

11. The scope of presentations in this session was broad and varied, and clearly indicated that a significant body of research and development is being dedicated to LIFE fishing around the world, including major advances across a variety of fishing gear types, including fish and shrimp trawls, beam and pulse trawls, tuna longlines, cod pots, set nets and boat seines.

12. Most of the research presented in this session involved fishing gear modification and the collection of data at sea. However, one presenter spoke of the value of computer simulation as a cost-effective alternative. Another presenter spoke of advances in diesel electric technology that could be utilized in large fishing boats as a more efficient option that also produces significantly lower carbon emissions, while another described the benefits and outcomes of vessel energy audits. Two presenters spoke of advances in set net gear in Thailand and of the benefits that such gear brings to coastal communities, while several others spoke of the effect of large-mesh panels and semi-pelagic doors to reduce fuel consumption.

13. In at least four presentations in this session, the problem of poor uptake of research outcomes by fishers was discussed. This problem was a central theme to two presentations, where gear uptake was classed as poor despite clearly identified and articulated benefits that could be realized from this uptake, extensive outreach efforts, as well as financial subsidy to fishers. One presenter made a case for a return to first principles by accepting a need to better understand the motivation of fishers to change and how such change can be permanent. Another suggested that by applying recognized principles of change management it might be possible to guide fishers through the process of change so that they are better prepared to adopt LIFE fishing practices.

14. During the discussion period of this session, several other key points were made regarding LIFE fishing:

- There is no simple solution to increasing interest and uptake of new fishing gear by fishers, as it often depends on the fishery and individual circumstances.
- Consideration should be given to incentivizing the participation of fishers and the development of incentive frameworks.
- Fishers must make efforts to find solutions to problems facing their fishery.
- Consideration should be given to how motivation and incentives (economic, regulatory, peer pressure, societal expectations, public perception, markets, etc.) can drive uptake and change by fishers.
- The WGFTFB should consider its role (if any) in regard to the consideration of appropriate motives and incentives.

Day 2: Use of artificial light as a stimulus on fish behaviour in fish capture (LIGHT)

15. The primary focus of this session was:

- physics and measurement of artificial light in water;
- design and engineering of artificial lights;
- promotion of energy efficient light sources;
- biology of vision in fish;
- behavioural responses of fish to artificial light;
- application of artificial light in fisheries; and
- novel and innovative approaches.

16. The LIGHT session was convened by Mike Breen (IMR, Norway), Heui-Chun An (National Fisheries Research and Development Institute [NFRDI], the Republic of Korea), and Professor I. Zhou (Shanghai Ocean University, China).

17. The session comprised 16 presentations by presenters from 8 countries, and most presentations focused on research conducted in Asia, and in particular in Japan and the Republic of Korea. The keynote presentation, titled "Fish behaviour and visual physiology in the capture process of light fishing", was presented by Professor Takafumi Arimoto (Tokyo University of Marine Science and Technology [TUMST], Japan).

18. A clear message from several presenters was that the most significant technological advance in light fisheries in recent years is the adoption of light-emitting diode (LED) lights in favour of incandescent, halogen, and metal halide illumination. This technology is similarly effective compared with many of the older sources of illumination with the added benefit of requiring considerably less energy; hence, fuel consumption and greenhouse gas (GHG) emissions are significantly reduced.

19. Many presenters focused on the use and development of artificial light in squid jigging operations. Other fishing methods discussed included purse seine, angling, lift nets including the Bagan, large-scale fish traps (set nets), and fish pots. Several presenters covered the physics, properties and characteristics of light (including tools to measure light and clarification of the myriad of metrics and units used in light measurement). Other presenters described the importance of understanding fish vision, its influence on fish response to visual stimuli, and research methods and techniques to investigate fish vision and function, such as visual acuity, maximum sighting distance, and spectral sensitivity. One presenter spoke of the development and engineering of LED lights, while another spoke of harvesting renewable energy sources from the fishing process and ocean environment itself using innovative technologies and techniques to develop self-powered underwater lights. Several presenters spoke of measurement of the underwater light field and the behaviour of squid and fish in

response to artificial illumination either onboard the fishing vessel or underwater. One spoke of the importance of polarized light to some fish and invertebrates, particularly in prey detection. The benefits of LED lights compared with other sources of illumination was covered by several presenters, including their effect on catch rates and fuel consumption, as well as the relative performance of LED lights of different colours.

20. During the discussion, several key points were made regarding LIFE fishing:

- Why light fisheries are so popular in the East and less so in the West is not precisely clear, but it is probably linked to abundance and schooling behaviour.
- Knowledge of why fish are positively phototactic is not well understood and remains an area of ongoing research.
- Light fisheries are often less harmful to the environment, and overfishing is seemingly less of an issue than in fisheries using other gear.
- In some fisheries, light can create conflict between fisheries or fishers and is difficult to regulate.

Day 3: Selectivity of trawls in multispecies/crustaceans fisheries (SHRIMP)

21. The primary focus of this session was:

- species and size selectivity – new technologies and approaches;
- future of bycatch reduction in multispecies trawl fisheries;
- alternative fishing practices for tropical shrimp trawl fisheries;
- balanced harvest vs selective fishing;
- social and market implications.

22. The SHRIMP session was convened by Professor Pingguo He (University of Massachusetts Dartmouth [UMass], the United States of America) and Bundit Chokesanguan (SEAFDEC).

23. The session comprised 13 presentations, representing research efforts from 11 countries. The keynote presentation, provided by David Brewer (Commonwealth Scientific and Industrial Research Organisation [CSRIO], Australia), was titled “Understanding and managing impact on bycatch in Australia’s Northern Prawn Fishery”.

24. Many presenters focused on challenges associated with the development, testing, uptake, and regulatory compliance of turtle excluder devices (TEDs) and bycatch reduction devices (BRDs). Several presenters reported high shrimp discard ratios and the ongoing practice of landing significant numbers of undersized fish for commercial purposes. Another issue raised was the loss of shrimp and other commercial species from using TEDs and BRDs. This loss was often described as the result of poor compliance with effective regulations and poor motivation by fishers to optimize performance, despite the associated risk of catch loss. In other instances, catch loss was reportedly due to poor TED or BRD design, or clogging of the TED by sawfish, tree limbs, and other debris. Overall, it seems that significant additional efforts are required in many fisheries to optimize the performance of these devices and overturn negative attitudes of fishers.

25. One presenter described efforts to deal with bycatch by turning it into fishmeal using onboard fish meat and bone separators and the daily production that could be produced per hour. Another presenter focused on the use of semi-pelagic doors and floating bridles to reduce herding behaviour and capture of demersal bycatch species and the benefits such gear can bring in terms of reduced sea-bed impact and fuel consumption. This presenter also included details about the performance of a topless trawl to retain shrimp and allow the escape of bycatch, while another focused on codend modification and the impact this had on the minimum landing size of shrimp.

26. The value of underwater video cameras to observe crab behaviour in response to an approaching trawl was described by one presenter, with a view to using this information to consider modifications to ground gear to reduce crab contact, damage, and mortality. Several other presenters focused on improving the selectivity of trawls for Norway lobster, while another focused on the benefits of being able to land both shrimp and Atlantic cod at the same time using a dual codend trawl.

27. Efforts by SEAFDEC to introduce the juvenile and trash excluder device (JTED) into shrimp fisheries in the region were presented, as was an outline of a new project focusing on mitigating bycatch in fisheries in the region, including the adoption of best fishing practices and the use of landed catch. This is a regional project funded by GEF and participating countries.

28. During the discussion session, the issue of blocked or clogged grids was raised, and options for overcoming this issue were discussed. This problem often affects the level of enthusiasm among fishers to use these devices because of associated shrimp loss. Ways to reduce this issue include the use of a well-designed and maintained grid operated at the correct angle. The use of a large grid was suggested in order to increase the filtering area and increase the likelihood that shrimp could pass around the blockage and through the grid into the codend. A large grid also comes with a large escape opening so that large animals can quickly pass unimpeded through the opening, and the distortion of the codend by a large grid helps to ensure the escape cover is held over the escape opening by water pressure. Ensuring that the escape cover can be readily pushed aside by escaping large animals and then readily returned to place (by water pressure) is also important. Despite these options, the challenge of convincing fishers to use grids, let alone large ones, is difficult given their concerns for shrimp loss and grid impact on the fishing operation.

29. A concern was raised regarding the notion that a successful TED or BRD trial in one location or fishery could be quickly replicated in another. This is not always the case, and time and patience are required to tune and optimize these devices, which may take several weeks or longer.

30. The option of utilizing bycatch was seen as a somewhat attractive option that could provide additional income to fishers. However, concerns were raised regarding the sustainability of this activity, and this option should not be seen as a quick response to initial issues and concerns with TEDS or BRDs. Alternative tools to managing bycatch should also be considered, such as incentives to fishers in regions where a lack of capacity prevents enforcement of legislation. The possibility of involving producers and suppliers in producing incentives was discussed.

31. The issue of "balanced" fishing was also raised. This proposed practice uses fishing gear or modifies fishing operations so that species of all sizes are retained and utilized rather than discarded dead or dying. It was argued that balanced fishing was more in keeping with the ecosystem approach to fisheries (EAF) rather that the use of fishing gear that selects for a limited number of species. The role of the WGFTFB in this issue was debated, but there was no clear agreement on the next steps.

Open session

32. The open session included six presentations representing research efforts from six countries.

33. The first presenter described the efforts to understand size selectivity in diamond-mesh codends and impacts of fish morphology. Codend-mesh geometry was measured in five locations in a flume tank over three simulated catch weights. Morphological data, based on the cross-section of cod was used to calculate L50 values at these and other selected locations along the codend, and a curve representing L50 values over a range of catch weights was compared against data collected in the field. While the calculated data poorly fitted the fieldwork data, a key implication of this work was that catch weight has significant implications for size selectivity, particularly when catches are low.

34. The second presenter explained efforts to use underwater video cameras to evaluate qualitatively fish behaviour during the capture process, and in response to TEDs and BRDs. The benefits of this footage were described, including observation and understanding of trawl performance, observation of TED and BRD performance, sources of blockage and catch loss, and demonstration that trawl gear does not capture all animals in its path.

35. The next presenter described a collaborative effort to test fish pots to capture Patagonian toothfish and avoid the problem of depredation by killer whales in toothfish longline operations. The pots successfully caught toothfish, but also caught substantial numbers of crabs. Importantly, there was no depredation by killer whales associated with using this gear.

36. The fourth presenter described efforts to evaluate the physiological condition of fish over a range of towing speeds. This evaluation involved electrocardiograms and electromyograms of jack mackerel to evaluate change in heart rate and muscle power output over a range of swimming speeds. The peak swimming performance of jack mackerel was found to be about 5.0 fish lengths per second and its maximum sustained swimming speed was 4.0 fish lengths per second. Recovery time was 300 minutes.

37. The next presenter described the results of a codend selectivity study. Four different codends were tested in a covered codend experiment, and the selectivity of five common fish species and two species of shrimp was described. One of the codends was a newly developed hand-woven design, which has become increasingly popular with fishers. An evaluation of the impact of each codend on the income of fishers was also presented and, because several codends reduced income, their uptake by fishers has met resistance.

38. The final presenter explained efforts to develop and test a rope separator trawl to reduce catches of cod while retaining haddock. Following model testing in a flume tank, sea trials with a full-sized separator trawl showed promise with significant reductions in cod, flounders and skates compared with a control trawl. The impact of this trawl on catches of haddock was difficult to evaluate owing to low and variable catch rates at the time of the tests, although catch rates were only slightly less with the experimental trawl.

APPENDIX 1

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APPENDIX 2

Agenda and timetable

6 May 2013 (Monday)

08:00 – 09:00	Registration
09:00 – 09:30	Welcome and General Introduction of the Meeting. **Bundit Chokesanguan** Speech & Opening from Secretary-General of SEAFDEC. **Chumnarn Pongsri** Speech & Opening from FAO. Mr Vili Fuavao **(on behalf of Mr Hiroyuki Konuma)** Greetings, Introductions, and Transition to LIFE Session. **Michael Pol and Petri Suuronen**
"LIFE" Mini-Symposium	
Opening Addresses, Welcome and Meeting Housekeeping	
09:30 – 09:45	Introduction, Welcome. **Thomas Catchpole**
09:45 – 10:15	Keynote – "Low-Impact and Fuel-Efficient (LIFE) Fishing Challenges, Opportunities and Some Technical Solutions." **John Willy Valdemarsen and Petri Suuronen**
10:15 – 10:40	***Body and Mind Break (Coffee and Tea)***
Mobile Gear Fishing	
10:40 – 11:00	Propulsion System Optimizations for Fuel Saving in Trawlers. **Emilio Notti and Antonello Sala**
11:00 – 11:20	A Comparison of the Fishing Gear Efficiency on the Trawl with Knotted and Knot-less Net Webbings. **Shigeru Fuwa, Saeko Kude, Keigo Ebata, and Hiroyasu Mizoguchi**
11:20 – 11:40	The Development of Pulse Trawling in the Netherlands. **Bob van Marlen**
11:40 – 12:00	Reduction of Hydrodynamic Force Acting on Bottom Trawl Net. **Keigo Ebata and Shinpei Teraji**
12:00 – 13:00	***Lunch***
13:00 – 13:20	Using Best Available Technology Drastically Improve Fuel Efficiency in Trawl Fisheries. **Ulrik J Hansen, Johan W Nielsen, and Jacob L Rønfeldt**
13:20 – 13:40	CIFT's Initiatives Towards Development of Green Fishing Systems for Indian Waters. **Leela Edwin, and T.K. Srinivasa Gopal**
Stationary Gear Fishing	
13:40 – 14:00	A Comparison of Two Catch Rate Calculation Methods: Application to a Longline Tuna Fishery. **Liming Song, Weiyun Xu, Daomei Cao, and Jie Li**
14:00 – 14:20	Comparative Baited Pots Trials to Harvest Northern Stone Crab (*Lithodes maja*) and White Hake (*Urophycis tenuis*). **Philip Walsh, and Rennie Sullivan**
14:20 – 14:50	***Body and Mind Break (Coffee and Tea)***
14:50 – 15:10	Operation System Analysis of Set Net in Rayong Thailand from the View Point of Cost-profit Simulation with Fuel Consumption Assessment. **T. Arimoto, T. Kudoh, Y. Takashima, K. Ebata, A. Boutson, A. Munprasit, T. Amornpiyakurit, N. Manajit, W. Yingyuad, Yap Minlee, and S. Ishikawa**

15:10 – 15:30	Seasonal Variation in Fishing Operations and Fuel Consumption of Small Scale Fisheries in Rayong, Thailand. **Keigo Ebata, Anukorn Boutson, Isara Chanrachkit, Nakaret Yasook, Tanut Srikum, Takafumi Arimoto, Takatsugu Kudoh, Minlee Yap, and Satoshi Ishikawa**
Tools for LIFE fishing	
15:30 – 15:50	Energy Saving Fishing Gears Design Using a Numerical Simulation. **Chun-Woo Lee and Jihoon Lee**
15:50 – 16:10	GEARNET: A Bottom-up Approach to Gear Testing and Uptake. **Michael Pol, Steve Eayrs, and Pingguo He**
16:10 – 16:30	Developing Fishing Gear to Reduce Environmental Impact and Increase the Profitability of Fishermen in the New England Groundfish fishery: So Why are They so Reluctant to Use This New Gear? **Steve Eayrs and Christopher Glass**
16:30 – 17:10	Discussion, Conclusions & Recommendations and Closing
17:30 – 20:00	***Welcoming Reception***

7 May 2013 (Tuesday)

“LIGHT” Mini-Symposium

Introduction	
09:00 – 09:20	An Introduction to Light and its Measurement When Investigating Fish Behaviour. **Mike Breen**
09:20 – 09:50	Keynote – "Fish Behaviour and Visual Physiology in Capture Process of Light Fishing". **T. Arimoto**
Physics & Engineering	
09:50 – 10:10	Marine Optics - Essential Elements for Fishing Technology and Fish Behaviour. **Yoshiki Matsushita**
10:10 – 10:30	Review of Technological Design: LED Packaging and Lighting. **Ja Soon Jang**
10:30 – 11:00	***Body and Mind Break (Coffee and Tea)***
11:00 – 11:20	Research on Artificial Light Sources for Light Fishing. **Heui Chun An**
11:20 – 11:40	Light Output Arrangement in Light Fishing through the Use of Simulation Model of Underwater Illuminance Distribution. **Sugeng Wisudo**
11:40 – 12:00	Novel Power Supply Technologies for Artificial Lights on Fishing Gears / Energy Harvesting in the Trawling Environment. **Dan Watson**
12:00 – 13:00	***Lunch***
Biology & Behaviour	
13:00 – 13:20	The Biology of Underwater Vision. **Ronald Kröger**
13:20 – 13:40	Polarization Vision in the Sea. **Amit Lerner**
13:40 – 14:00	Development of the Evaluation Method on the Effect of Artificial Fishing Light. **Kazuhiko Anraku**
14:00 – 14:20	Visual Threshold of Rockfish (*Sebastes inermis*) Response to Different Wavelength of LED Lamp. **Hyeon-Ok Shin**
14:20 – 14:50	***Body and Mind Break (Coffee and Tea)***
14:50 – 15:10	Attracting Effects on Swimming Behaviour Patterns of the Chub Mackerel (*Scomber japonicus*) and Common Squid (*Todarodes pacificus*) by LED Luring Lamp. **Kyounghoon Lee**
Light Fishing	
15:10 – 15:30	Progress of Fish Luring Lamps for Squids Jigging in China. **Weiguo Qian**
15:30 – 15:50	Fishing Efficiency of LED Fishing Lamp for Squid Jigging and Hair Tail Angling in Korean Waters. Young-Il An
15:50 – 16:10	Application of the Low-power Underwater Light to a Large Scale Fish-trap Fishery. **Daisaku Masuda**
16:10 – 16:30	Modifying Baited Cod Pots to Capture Flatfish Species while Excluding Snow Crab. **Andrew Murphy**
16:30 – 17:30	Discussion, Conclusions & Recommendations

8 May 2013 (Wednesday)
"SHRIMP" Mini-Symposium

09:00 – 09:20	Introduction, Welcome. **Pingguo He and Bundit Chokesanguan**
09:20 – 10:05	Keynote- Understanding and Managing Impacts on Bycatch in Australia's Northern Prawn Fishery. **David Brewer, S. Griffiths, S. Zhou, S. Eayrs, I. Stobutzkic, R. Bustamante, and C. Dichmont**
Chair: Pingguo He (USA)	
10:05 – 10:30	Incorporating Human Dimension in the Bycatch Management of Shrimp/Bottom Trawl Fisheries. **Petri Suuronen and Daniela Kalikoski**
10:30 – 11:00	***Body and Mind Break (Coffee and Tea)***
11:00 – 11:20	Research on Bycatch of Shrimp Trawl Fishery in Arafuru Sea: Volume, Reduction Devices, and Utilization of Discarded Bycatch. **Ari Purbayanto, Ronny I. Wahyu, and Joko Santoso**
11:20 – 11:40	Selectivity of Five Different Codend Designs to Improve Size Selectivity for Deep Water Rose Shrimp (*Parapenaeus longirostris*) in the Aegean Sea. **Adna Tokaç, Hüseyin Özbilgin and Hakan Kaykaç**
11:40 – 12:00	Discard Ratios of Fish and Shrimp Trawls in the North Eastern Mediterranean. **Gökhan Gökçe, Ahmet Eryaşar, Yeliz Özbilgin, Adem Bozaoğlu, Ebrucan Kalecik and Hüseyin Özbilgin**
12:00 – 13:00	***Lunch***
Chair: Bundit Chokesanguan (SEAFDEC)	
13:00 – 13:20	A Decade of Systematic Research to Minimize Discards in Northern Shrimp Trawls. **Pingguo He**
13:20 – 13:40	When Shrimp Trawling Collides with Crab Fisheries: A Case Study from Newfoundland, Canada. **Truong Nguyen, Paul Winger, George Legge, Earl Dawe, and Darrell Mullowney**
13:40 – 14:00	Trawling for Shrimps and Simultaneously Retaining Cod. **Eduardo Gramaldo, Jørgen Vollstad, and Roger B. Larsen**
14:00 – 14:20	The Promotion of Responsible Trawl Fishing Practices in Southeast Asia through the Introduction of Juvenile and Trash Excluder Devices (JTEDs). **Bundit Chokesanguan and Suppachai Ananpongsuk**
14:20 – 14:50	***Body and Mind Break (Coffee and Tea)***
14:50 – 15:10	Netting Grids in *Nephrops* Trawls to Reduce the Capture of Cod in the North Sea. **F.G. O'Neill, R.J. Kynoch, J. Drewery, A. Edridge, and J. Mair**
15:10 – 15:30	Development of Sorting Grids for Norway Lobster Fisheries. **Niels Madsen, Rikke Frandsen, Jordan Feekings, and Ludvig A. Krag**
15:30 – 15:50	REBYC-II CTI - Trawl Fisheries Management in Southeast Asia and Coral Triangle Region. **Petri Suuronen and Isara Chanrachkij**
15:50 – 16:10	Introducing a RIHN Project (Coastal Area Capability Enhancement in Southeast Asia). **Minlee Yap**
16:10 – 17:20	Discussion, Conclusions & Recommendations
17:20 – 17:30	***Closing***
17:30 – 20:00	***Social Event***

9 May 2013 (Thursday)

FTFB Open Session	
09:00 – 09:30	Housekeeping Issues, Welcome, Agenda Review
09:30 – 09:50	Understanding the Size Selectivity in Diamond Mesh Codends Based on Flume Tank Experiments and Fish Morphology: Effect of Catch Size and Fish Escape Behaviour. **Junita Karlsen**
09:50 – 10:10	Observation of Fish Behaviour During Demersal Trawling Operations in The North Eastern Mediterranean. **Yeliz Özbilgin**

10:10 – 10:30	Can we save toothfish, killer whales and fishermen together? **Gerard Bavouzet, Fabien Morandeau, Sonia Mehault, and Jean Roullot**
10:30 – 11:00	***Body and Mind Break (Coffee and Tea)***
11:00 – 11:20	Swimming Performance of Fish in Capture Process Simulation Examined by EMG / ECG Monitoring and Muscle Twitch Experiment. **Mochammad Riyanto and Takafumi Arimoto**
11:20 – 11:40	Improvement of Size Selectivity and Short term Commercial Loss in the Eastern Mediterranean Demersal Trawl Fishery. **Hüseyin Özbilgin**
11:40 – 12:00	Test of the Rope Separator Haddock Trawl on Georges Bank. **Chris Rillahan**
12:00 – 13:00	***Lunch***
13:00 – 13:20	FTFB Topic Group Introductions. **Topic Group Convenors**
13:20 – 15:00	Topic Group Meetings. 3 Separate Meetings; Agenda at Discretion of Conveners
15:00 – 15:30	***Body and Mind Break (Coffee and Tea)***
15:30 – 17:00	Topic Group Meetings ***(Continue)***
17:00 – 17:10	***Closing***
10 May 2013 (Friday)	
FTFB	
09:00 – 09:30	ICES Stuff and Summary of National Reports. **Michael Pol**
09:30 – 10:00	ToR A CATCH CONTROL: Report, Conclusions & Recommendations. **Convenors**
10:00 – 10:30	ToR B LIGHT: Report, Conclusions & Recommendations. **Convenors**
10:30 – 11:00	***Body and Mind Break (Coffee and Tea)***
11:00 – 11:45	ToR C GEAR: Report, Conclusions & Recommendations. **Convenors**
11:45 – 12:00	ToRs for 2014. (Including Joint Session, and Appointment of Joint Session Chair)
12:00 – 13:00	***Lunch***
13:00 – 13:45	ToRs for 2014. **(Continued)**
13:45 – 14:30	Suggestions for ASC Theme Session Topics 2014; ICES Symposia
14:30 – 15:00	***Body and Mind Break (Coffee and Tea)***
15:00 – 15:15	Date and Venue for WGFTFB 2014 Meeting
15:15 - 15:45	Selection of New Chair
15:45 – 16:00	AOB & Concluding Remarks **(Co-chairs)**

APPENDIX 3

INDIVIDUAL PRESENTATION SUMMARIES

3.1. LOW-IMPACT AND FUEL-EFFICIENT FISHING GEAR (LIFE)

Introduction to the LIFE session *(by Thomas Catchpole)*

To provide context for the LIFE session, a brief description of the environmental impacts of fishing was presented, including the mortality of target and non-target species, knock-on trophic effects, seabed impact, ghost fishing, pollution, particle suspension and carbon emissions. It was noted that many regulatory drivers currently exist at regional, national, and international levels in an attempt to minimize these impacts. A brief review on rising fuel prices and CO_2 emissions was also provided. The global fishing fleet consumes approximately 40 million tonnes of fuel per annum although this accounts for only 1.2 percent of global fuel consumption. The fuel efficiency of global fishing activity was discussed, with an average of just over 500 kg of fuel being used to land 1 tonne of seafood. In some instances, fuel consumption is responsible for up to 60 percent of fishing costs. Globally, the estimated ratio of landed fish (live-weight) to CO_2 emissions by the fishing fleet is about 1:1.7.

Low Impact and Fuel Efficient (LIFE) Fishing: Challenges, opportunities and some technical solutions *(by John Willy Valdemarsen and Petri Suuronen)*

A variety of LIFE challenges and impacts were presented including removal of target and non-target species, unaccounted fishing mortality from abandoned, lost, or discarded fishing gear, direct physical impacts on the seabed and carbon emissions.

The issue of ranking fishing gears by environmental impact was discussed, including the fact that ranking often includes value judgments about a particular gear type and impact severity. Not only is this a difficult issue, but it is further complicated by operational choices by fishers such as towing speed, rigging, soak time, etc., that can cause the same gear to have varying impacts on the environment. Rising fuel prices pose a major challenge to the viability of many fisheries because it increases operating costs and alternative energy sources such as biodiesel are not yet a practical substitute for many fisheries. A summary of key demersal fishing gears in the context of LIFE fishing was provided (Table 1).

There are four major technical challenges for realizing LIFE fishing and they are: selective fishing gear design, reducing bottom impact of fishing gears, reducing drag (and hence, fuel consumption) of towed gears without reducing their catching performance, and improving catch per unit effort of alternative fishing methods to make them more economically viable compared to towed gears. The opportunities where these challenges can be overcome lie with gains in technical innovation, such as modified fishing gear and new instrumentation, improved management regimes to optimize yields, education and training of fishers to give them appropriate skills and consumer preference for change to more eco-friendly fishing practices. With a focus on trawling, a range of fuel saving options was presented, including:

- Larger meshes in the herding part of the trawl.
- Stronger and lower drag netting panels.
- Hydrodynamically efficient trawl doors.
- Reduced surface drag of floats and ground gears.
- Multi-trawl rigging and operation.
- Reduced towing speed.

- Utilizing fish behaviour observation while trawling.
- Increased herding of fish by artificial stimuli while trawling.
- Location of dense fish aggregations before trawling commences.

Table 1. LIFE characteristics of some demersal fishing gears (Adapted from Suuronen *et al*., 2012[1])

Gear type	Advantages	Disadvantages	Priority LIFE actions
Pot	Low energy use and habitat impact Selective (species and size) Flexible and transportable High quality catch, live bycatch	Low capture efficiency for many species Ghost fishing of lost pots	Enhance efficiency for a wider range of species Alternative baits De-ghosting technology
Trap-net	More expensive and operation is more complex than with pots	Capture depth limited Suitability limited to fewer species Capture of non-target species	Develop practices to prevent the entangling of non-target species
Gillnet	Low energy use Flexible and easily portable Size selective Relatively cheap to manufacture	Labour intensive Catch quality a concern Capture of non-target species Ghost fishing of lost nets	Develop practices and technologies to reduce bycatch
Coastal longline	Low energy use (usually) Minimal habitat impact Flexible and portable Species selective, good catch quality	Labour intensive, time consuming Bycatch of non-target species Snagging on epifauna Availability and price of bait	Capture of bait may be fuel-consuming Research and development of attractants and hook design
Bottom seine	Relatively low energy use Reduced seabed impacts Operation on smaller fishing grounds Good catch quality	Operation limited to cleaner grounds and shallow depths Not effective for non-herded animals such as shrimp	Operation on rough grounds, in sea currents, and deeper waters Bycatch reduction technology
Bottom trawl	Effective Versatile	Seabed impacts Fuel consumption Bycatch Costs Catch quality	A large variety of actions possible to improve this capture method

Options to reduce bottom impacts of trawling include:

- Converting to off-bottom trawling techniques.
- Reducing the impacted area of seabed while trawling.
- Reducing pressure against the seabed by trawl components.

[1] Suuronen, P., Chopin, F., Glass, C., Løkkeborg, S., Matsushita, Y., Queirolo, D. & Rihan, D. 2012. Low Impact and Fuel Efficient fishing - looking beyond the horizon. *Fisheries Research* 119–120: 135–146.

- Increasing trawling efficiency (and in turn reducing towing duration).
- Avoiding sensitive fishing habitats.
- Increasing the use of low impact fishing gears.

Three ongoing technical innovations in the context of LIFE fishing were then presented.

1. DeepVision technology. This innovation involves placing two or more cameras in the extension piece or lengthener section of a trawl to enable real time identification and size estimation of fish as they pass toward the codend. This information can be used to study the abundance and spatial distribution of target species in the water column. It can also be used to identify and select unwanted species from the trawl using automatic release systems.
2. Codend modification to release excess catch. This innovation includes the use of a rubber mat held against the upper panel of a codend, which is designed to expose an escape opening in the codend when a desired catch volume has been reached. As fish reach the codend, they are held behind a so-called fish lock. A high pressure region builds immediately ahead of the accumulated fish and directs water up and through the escape opening, thus pushing the rubber mat aside and allowing fish escape.
3. Maneuverable trawl doors. This innovation involves the motorized opening and closing of hatches in the trawl doors to adjust and optimize trawl spread and position (Figure 1). Communication to the doors is via an acoustic link to the vessel.

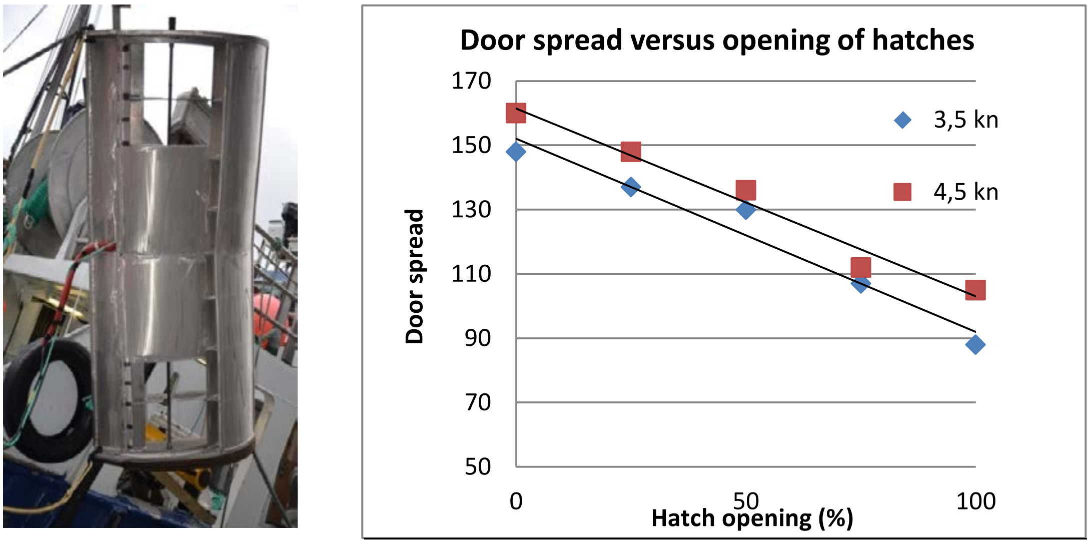


Figure 1: Manoeuvrable trawl door (left) and the effect of variable hatches on door spread at two towing speeds (right)

The presentation concluded with a note that solutions to optimize LIFE fishing vary among fisheries, but that a successful transition to LIFE depends upon:

- Developing acceptable technology and creating incentives and win-win situations.
- Achievable, realistic and sensible objectives.
- Adequate training and technical assistance for fishers, and encouragement of innovation.
- Regulatory regimes that facilitate the recovery of stocks.
- Making fishers part of the solution.
- Finding a balance between short-term costs vs. long-term environmental ambitions.

Propulsion system optimization for fuel saving trawler *(by Emilio Notti and Antonella Sala)*

This presentation highlighted the importance of optimizing the propulsion system of the fishing vessel to reduce fuel consumption and it was noted that this compliments efforts to achieve the same outcome through modification of fishing gear. The major components of a propulsion system are the main engine, the reduction gear and the propeller, and this presentation described recent research and development of each component.

Trawling is highly energy intensive over both key phases of vessel operation, steaming to and from the fishing grounds and trawling and both have significantly different power requests to overcome hull and gear drag.

Based on enquiries with engine manufacturers the following trends are apparent:

- Innovation in diesel engine design over the past 20 years has reduced fuel consumption by approximately 20 percent for the same power delivered.
- Research and development has shifted focus from reducing fuel consumption to meeting emission targets under International Maritime Organization (IMO) regulation, however, such an outcome also indirectly allows for a reduction in fuel consumption.
- The use of Liquefied Natural Gas (LNG) and biodiesel is presently more expensive than for diesel and provides relatively little fuel savings despite being an attractive option to reduce gas emissions.

Three innovative approaches to fuel savings based on diesel electric power systems were discussed, although their cost is presently considered too prohibitive for many fishers. The first, was the use of one or more auxiliary engines to generate electrical power, which in turn can be used to contribute to propeller thrust, reduce the work of the main engine and conserve fuel. This system can potentially operate in reverse, with the main engine generating electrical power should the auxiliaries for any reason provide insufficient output. Another option was a so-called 3Nergy system whereby, the main engine, auxiliary engine and a battery array where coupled to contribute to vessel propulsion. The final system involved using diesel engines to drive an electric engine via an electronic control system, which in turn drives the propeller. Whereas vessel thrust is normally controlled by controlling the rpm and load of the main engine, in this system the engine is operated at a specific rpm and the electric engine is operated at variable speed depending on the thrust demand. The benefits of these electrical systems are their high efficiency (approximately 100 percent), potential to eliminate reduction gears, less vibration and use of lubricants and reduced maintenance.

The purpose of the reduction gear (gear box) is to convert the power generated by the main engine and deliver the torque to the propeller via the propeller shaft. Generally, the reduction gear ratio is fixed and designed with one operating condition in mind. A two-speed reduction gear is a relatively recent option designed to match propeller load and engine power to two different operating conditions, steaming and fishing, thus, more efficiently utilizing the propulsion system and conserving fuel.

Several propeller systems were also discussed, including ducted systems (Kort nozzles) which can increase thrust by up to 25 percent for the same fuel consumption (Figure 2). An economic analysis of a bottom trawler fitted with a ducted propeller indicated a potential recovery of purchase and installation cost (payback period) of just over one year. Controllable pitch propellers, which overcome the issue of a fixed propeller pitch, can produce fuel savings up to 10 percent, while free running and contra rotating propellers fitted immediately behind the main propeller can contribute to thrust and also reduce fuel consumption by approximately 10 percent. Despite the array of possibilities and their fuel saving benefits, the uptake of these modifications by fishers is presently very low.

Figure 2: A ducted propeller

A comparison of the fishing gear efficiency on the trawl with knotted and knotless net webbing *(by Shigeru Fuwa, Saeko Kude, Keigo Ebata and Hiroyasu Mizoguchi)*

This presentation investigated the differences between knotted and knotless netting in a trawl in terms of the physical load on the crew, the physical characteristics of the netting, fuel consumption and catching efficiency.

The trawl was constructed from knotted polyethylene and had a headrope length of 15.5 m and a total length of 21 m. From wing ends to extension piece, the netting panels were respectively constructed from 90 mm, 57 mm, 43 mm, 38 mm and 38 mm mesh netting. Total netting weight was 196 kg. A second trawl with identical headrope length and total length was constructed from knotless netting. From wing ends to extension piece, the netting panels in this trawl were respectively constructed from 80 mm, 60 mm, 50 mm, 50 mm and 34 mm netting. The wing ends of this trawl were constructed from dyneema netting and the remainder from polyethylene. This trawl weighed 36 percent less than the knotted trawl.

The behaviour of the crew during deployment and retrieval of each trawl was observed using a video and analysed using the Ovako Working Posture Analysis System (OWAS). OWAS was developed to identify the most common working postures for the back (four postures), the arms (three postures), legs (seven postures) and the weight of the load handled (three categories). These postures and categories can then be combined to describe 252 different postures. These postures are then classified into four action categories that indicate the need for ergonomic adjustment based on the predicted load on the musculature and skeleton of the observed individual (Table 2). Observations of these postures are usually achieved by recording the posture of an individual at regular time intervals.

Table 2: Action category description and score

Action category	Description/Judgment	Score
AC1	No problem/Improvement unnecessary	0
AC2	Harmful to the body/Improve in the near future	2
AC3	Harmful to the body/ Improve as early as possible	4
AC4	Very harmful to the body/Improve immediately	8

To analyse the physical load on the crew (four persons), they were observed during both deployment and retrieval of the trawl (Figure 3). Two workload indexes were then developed to evaluate their posture,

$$C = \Sigma t_i / 4T$$

where C = index of total working time during deployment or retrieval of the trawl, T = total working time of all crew combined during deployment or retrieval of the trawl, t_i = working time of crew, and

$$I_w = \Sigma \Sigma t_i C w_j$$

where Iw = workload index and Cw = action category score. During deployment of the knotted and knotless trawl the average deployment time and action category was respectively 522 s and 516 s and 1.6 and 1.5. When hauling the knotted and knotless trawl the average retrieval time and action category was respectively, 508 s and 442 s and 1.6 and 1.5. There was no more than a 3 percent difference in the index of total working time when deploying or retrieving the knotted or knotless trawls. There was also almost no difference in the workload index between trawl types irrespective of deployment or retrieval.

There was a modest difference in fuel consumption between each trawl type. As towing speed was increased, this difference increased and reached a maximum of 6 percent at 3.2 knots. The catch per unit effort (CPUE) of the knotless trawl was three times greater than that for the knotted trawl, based on five catch categories: sea urchin, squid, fish, shark and stingray.

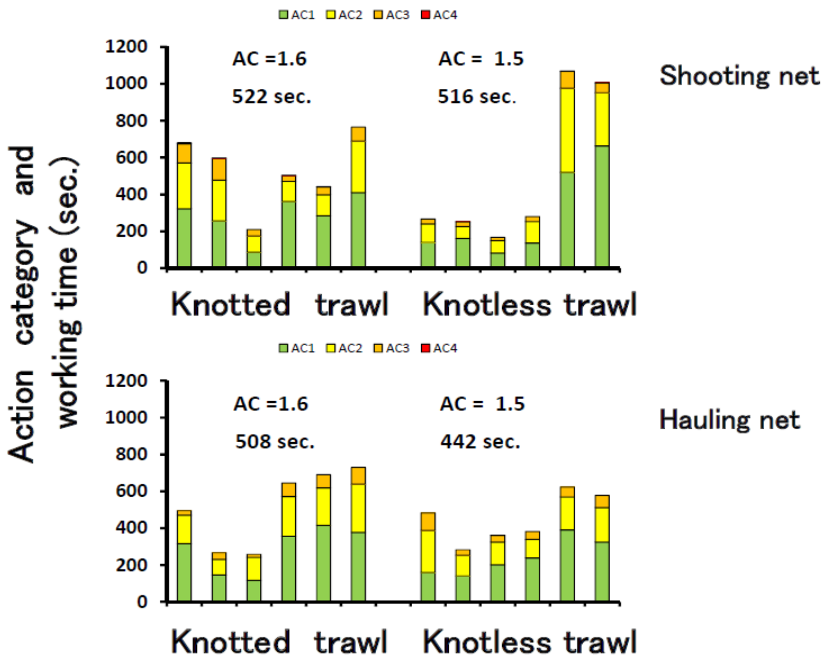


Figure 3: Action categories when shooting and hauling the net

Development of flatfish pulse trawling in the Netherlands *(by Bob van Marlen)*

There has been a long history of pulse trawl development in the Netherlands dating back to at least the early 1970s. The objective of this work has been to find an alternative to the heavy tickler chains used in flatfish beam trawling and thereby, reduce seabed impact, towing speed and fuel consumption. Between 1998 and 2006 there was a significant effort by the Institute for Marine Resources and Ecosystem Studies (IMARES) that included extensive testing at sea of different sized pulse beam trawls and survival experiments of sole, plaice and invertebrates after interaction with the gear. This early research was encouraging (Table 3).

Table 3: Major outcomes of pulse trawling research before 2006 (compared to conventional beam trawl)

Gear type	Landings (%)	Fish discards (%)	Benthic discards (%)	Sole >MLS	Plaice > MLS
7 m	65–88	54–178	69–150	91–130	38–71
12 m Tridens	95	86	75	122	83
12 m UK153	60–70	n/a	50–70	65–95	50–90

At the 2006 WGFTFB annual meeting in Izmir, Turkey, questions were raised regarding the influence of this gear on fishing mortality (assuming unchanged fishing effort), catch composition by size and species and impacts on non-target species. It was noted at this meeting that the outcomes of this research had to date been moderately positive, with reductions in the catch rate of undersized sole, reductions in place of all size classes, reduction in catches of benthic invertebrates and mortality of in-fauna species and considerable reduction in fuel consumption. Outstanding criticisms of the gear included evidence of increased mortality of non-retained species, both target and non-target species.

Since then, considerable effort has been made to address these concerns and to better understand the performance of this gear, including laboratory experiments to test the effect of electric pulses on elasmobranches, benthic invertebrates and cod held in aquaria. An ICES review of this work in 2009 confirmed the results of these experiments was mixed, with elasmobranches and benthic invertebrates being minimally effected while there was significant vertebral injury and mortality to cod less than 10 cm. A question was also raised regarding the possible increase in catching efficiency on larger cod.

In 2010, laboratory experiments were conducted on small (0.12–0.16 m) and large (0.5 m) cod with individuals subject to electrical stimuli. At a range of 250–300 V/m, no spinal damage to small cods occurred, however, over half of the large cod were damaged at a range of 40–100 V/m. If the frequency was increased to greater than 180 Hz, damage to large cod, did not occur.

In 2011, field trials compared the performance of a pulse trawl against a traditional beam trawl with tickler chains. The pulse trawl used 43 percent less fuel than the traditional trawl and by weight landed 19 percent less commercial catch and 43 percent less discard species per hectare trawled. There was little difference in catches of plaice and sole landings per unit area swept by both trawls. The proportion of observed spinal fractures in cod was 9 percent with the pulse trawl. There are presently around 50 vessels using pulse trawl gear, primarily to catch flatfish but also shrimp (Figure 4). Approximately 80 percent of these vessels are based in the Netherlands and the remainders are in Germany, the United Kingdom and Belgium.

Figure 4: A pulse wing trawl with a 12 m beam

Future work on pulse trawling includes:

- Investigating ways to decrease the deleterious effects of pulse trawling on cod.
- Better understanding of the characteristics and performance of different electrical pulses.
- Increase fieldwork sampling to better understand pulse trawl performance.
- Evaluating the direct mortality of benthic invertebrates of pulse trawls.
- Evaluating the effect of the introduction pulse trawls in the North Sea on major target and non-target species.
- Refining survival experiment protocols and replicating survival experiments to better understand impact of pulse trawl on undersized target species.

Reduction of hydrodynamic force acting on bottom trawl net. Model experiments in a flume tan *(by Keigo Ebata, Shinpei Teraji and Akira Ikino)*

The trawl fishery in Japan accounts for approximately 25 percent of total landings, and fuel costs account for 20–30 percent of total fishing costs. In the small-scale trawl fishery in Japan about 65 percent of fuel consumed during an entire fishing trip occurs while trawling. The purpose of the study therefore, was to reduce the hydrodynamic resistance of a bottom trawl to save fuel and reduce fishing costs.

Several model trawl nets based on a commercial design were constructed and tested in a flume tank. The conventional trawl was constructed from traditional polyethylene netting while each improvement (modification) was made using Dyneema netting. Each improvement was made to the upper panel and side panels of the conventional trawl (Table 4).

The model nets were constructed and tested in a flume tank at full size equivalent speeds of 2–4 knots. Tension sensors attached to the warps were used to evaluate the net resistance (drag force) acting on the model nets and vertical opening of each trawl was measured in five locations including wingtips and shoulder (gusset) of the headrope.

Table 4: Diameter and mesh size of the conventional trawl and each improvement

Net	Twine dia. (mm)	Mesh size (mm)
Conventional	0.99	60
Improvement 1	0.65	69
Improvement 2	0.65	100
Improvement 3	1.98	129

Compared to the conventional net, improvements 1 and 2 reduced net drag by 21 percent and 25 percent at four knots whereas improvement three increased net drag by 5 percent at the same speed. The differences in net resistance were greatest at four knots. The vertical opening of all nets was a little different at all measured locations and all towing speeds.

Best available technology makes drastic cuts in fuel expenses in trawl fisheries *(by Ulrik Jes Hansen and Poul Tørring)*

The results of fuel conservation research in the Baltic Sea and North Sea using best available technology was presented. The best available technology is based on the use of:

- Dyneema warps instead of steel wire rope.
- Pelagic doors with an inline chain to facilitate sweep contact with the seabed.
- Twin rig instead of single rig.
- Dyneema trawls with ten mesh polyamide (nylon) mesh bands to provide some elasticity.
- Use of four panel trawls and fly meshes.
- T90 in the codend.

The redesigned trawls using the best available technology were made larger in order to have main engine running at its design load, and the headrope and footrope was modified using fly meshes (drop meshes) to enable greater trawl spread. After an extensive period of testing, the results from both locations were promising (Table 5). Vessel profitability increased by around 40 percent by using Dyneema trawl warps, flying doors, and an innovative trawl design constructed with T90 netting.

The application of these technologies appears to be very promising with payback periods of 2–12 months and return on investment of 300–400 percent depending on vessel particulars. The Dyneema warps demonstrated 90 percent of original breaking strain after ten years of service and door spread was substantially increased. However, despite these seemingly attractive outcomes, the uptake of this gear is currently very low.

Table 5: Results of application of best available technology

Category	**Baltic Sea (Vessel 17 m)**	**North Sea (Vessel 31 m)**
Fuel consumption (%)	-7.5	n/a
Catch per hour (%)	+17	+18
Catch per litre (%)	+26	n/a
Investment cost (€)	52 000	120 000
Payback period (months)	11	18
Profitability (%)	+48	n/a

CIFTs initiatives toward development of green fishing systems for Indian waters *(by Leela Edwin)*

India is the second largest producer of seafood in the world and it is ranked 17th among the seafood exporting countries. Sardine and Indian mackerel comprise just over 20 percent of national landings annually, closely followed by penaeid prawns, perches, croakers, and cephalopods. Just over half the annual production of seafood in India is derived from pelagic species and just over 25 percent by demersal fish species while crustaceans and mollusk comprise 14 percent and 5 percent, respectively. It is estimated that the seafood production could increase 0.6 million tonnes from the current level of 3.3 million tonnes.

The fishing capacity of the fishing fleet has increased substantially over the past few decades. Between 1985 and 2005, the proportion of non-motorized craft reduced from 84 percent to 40 percent as fishers increasingly adopted motorized sources of propulsion, although some fleets have approximately four times as many boats as could be operating sustainably in Indian waters.

The discarding in many fleets is high, and the trawl fleet alone is thought to account for 1.2×10^6 tonnes of discards annually, although this includes the portion of the catch that is bought ashore for animal feed and other products.

The greenhouse gas emission of the Indian fleet is about 1.13 tonnes per tonne of live-weight seafood and is substantially less than the global average of 1.7 tonnes per tonne of live-weight seafood. Total emissions from the Indian fishing fleet are 3.17 million tonnes and is dominated by large scale bottom trawlers, which produce 3.5 tonnes of emissions per tonne of landed seafood. In contrast, purse seining and long-lining contribute significantly less than 1 tonne per tonne of landed seafood.

CIFT has been instrumental in many positive developments in the fishing industry, from the development of low cost fishing canoes to fuel efficient 15 m deep sea fishing trawlers, the introduction of purse seine technology, efficient trawl design and the development of bycatch reduction devices.

A recent initiative is the development of green fishing systems for tropical seas, including the design and construction of a 20 m trawler designed to optimize fuel consumption (objective 1) through the use of superior hull shape, bulbous bow, optimized propeller design, ducted propeller, appropriate sized engine, and the development of energy saving fishing gear systems (objective 2) using high performance netting and twine. A variety of activities and outputs for each objective has been established and progress is ongoing (Table 6). This is an exciting development and the first to combine government and private enterprise support such as boat builders, naval architects, mechanical engineers and net manufacturers.

Table 6: Activity and output for each objective

Objective	Activity	Output
Design and construction of new fishing trawler	Development of database of existing fishing vessel designs	Digital database of commercial fishing vessels in India
	Development and optimization of hull form through software simulation and model testing	Optimized hull design of a fuel efficient fishing vessel
	Construction of vessel and stability analysis	Energy efficient fishing vessel
Development of energy saving and selective fishing gear systems	Development of database of existing fishing gear designs	Digital database of commercial fishing gears in India
	Design of low drag trawl system	Standardize low drag trawls with energy saving features
	Design of purse seines with high sinking speed and operational efficiency	Standardized purse seine design

A comparison of two catch rate calculation methods: Application to a longline tuna fisher *(by Liming Song, Weiyun Xu, Daomei Cao and Jie Li)*

This presentation explored the relationship between catch rates of tuna and soak time in longline fisheries. This has not previously been studied in depth. Furthermore, the literature demonstrates inconsistency with respect to this relationship in other fisheries.

The purpose of the study was therefore, to develop a soak time calculation model by accounting for the longline catenary between floats, hook location and influence of water currents and tide, and compare catch rates based on effort units in hours and hook numbers. To build this model required data collection from a tuna longline fishing trip in the Pacific Ocean near Kiribati over a three-month period. A total of 34 000 hooks were deployed and hook depth and sink rate were measured and recorded using temperature-depth recorders (TDRs). An acoustic doppler current profiler (ADCP) was used at different depths to gain a better understanding of the influence of water current. There were 25 hooks between floats.

A total of 316 hooks were measured using the TDRs. The soak time of each hook (when it was stable) was calculated by the difference in total soak time and hook settling time, which was as long as 1.35 h for hooks in the centre of the longline and as short as 0.81 h for hooks adjacent to the floats. The longest recorded soak time was 15.5 h and shortest was 3.8 h. Total soak time at each set ranged from 12 000 to 16 000 h. Catches of bigeye and yellowfin tuna were landed at a rate of one fish per 150 and 167 hooks, respectively.

The soak time model quite accurately predicted the overall soak time of the longline between survey sites. Overall, there was very little difference in catch rates of individual fish per 1000 hooks or per 10 000 hours of soak time for both bigeye and yellowfin tuna at each sampling location. However, with the exception of the deeper sampling layers (200.0–239.9 m and 240.0–279.9 m), there were significant differences between the catch rates of both bigeye and yellowfin tuna. Despite this difference, both models tracked changes in catch rates between survey sites very closely, suggesting that soak time can be reflective of effective fishing effort. A reason given for the exception at greater depths was sampling bias associated with low catch numbers at depth.

Comparative baited pot trials to harvest northern stone crab (Lithodes maja) and white hake (Urophycis tenuis) *(by Philip Walsh and Rennie Sullivan)*

An attempt was made to test the efficacy of baited pots to catch commercial quantities of stone crab and white hake. Stone crab has never been targeted in pots before, but continues to be captured as bycatch in gillnet fisheries. White hake is also often caught as bycatch in gillnet fisheries, but their rate of predation is high.

A fishing experiment was performed near the Laurentian Channel over a 13-day period onboard a commercial fishing vessel. Four different pot types were tested: a square pot based on the Newfoundland style Atlantic cod pot with two large rectangular entrances (R1L), the same pot design, but with two smaller rectangular entrances (R1S), the same pot design with two circular entrances (R2C) and a conical pot based on the Newfoundland conical pot for harvesting snow crab and with two semi-circular entrances (C1L).

The square pots measured 1.98 m × 1.98 m × 1.02 m. They were a collapsible design with a double floor and a floating roof section. The roof section helped ensure the pot rested on the bottom right side up and increased internal pot volume. The conical pot measured 1.82 m in diameter at the base × 0.98 m in diameter at the top × 0.81 m high. All pots were constructed using 5/8-inch diameter round mild steel and 100 mm polyethylene netting. All funnels were constructed from 60 mm knotless polyamide netting.

The pots were fished in fleets of four pots approximately 182 m apart and were baited with 2.3 kg of squid and herring placed into fine mesh bait bags. A small cod was also placed at the bottom of each pot. The fleet of pots was hauled 12 times from depths of 120–440 m. Soak time varied. To confirm the presence of stone crabs and white hake a fleet of 12 gillnets was fished adjacent the pots and retrieved on four occasions.

A total of 66 crabs were caught by the pots and 284 crabs were caught in the gillnets (Table 7). A total of 140 white hake were caught in the pots and 384 were captured in the gillnets. The mean catch of crab per pot retrieval for pot R1L, R1S, C1L, and R2C was respectively, 0.25 +/- 0.18, 1.67 +/- 0.34, 0.41 +/- 0.19, and 3.67 +/- 1.45. The mean weight of crab recorded in pot R2C was 2.68 kg per retrieval and less than 1.0 kg in the remaining pots. There were significant differences in mean catches between R2C and R1L (p=0.009), R2C and C1L (p=0.012), but not between R2C and R1S (p=0.063) (Figure 5).

Pot R2C caught white hake during all sets and mean catch was eight fish per retrieval, although this increased to 11 fish when soak times less than 16 hours were tested in isolation. The mean catch from this pot was significantly different to all other pots ($p<0.001$). Comparison between all other pots types was not significantly different ($p>0.05$).

This work will continue in 2013, although the circular funnel pots appear effective toward stone crab and white hake.

Table 7: Catches of stone crab and white hake by gear type

Gear type	No. hauls	Total no. and percent stone crab captured	Total no. and percent white hake captured
R1L	12	3 (5%)	15 (11%)
R1S	12	14 (21%)	26 (19%)
C1L	12	5 (8%)	3 (2%)
R2C	12	44 (67%)	96 (69%)
Gillnet	48	284 (100%)	384 (100%)

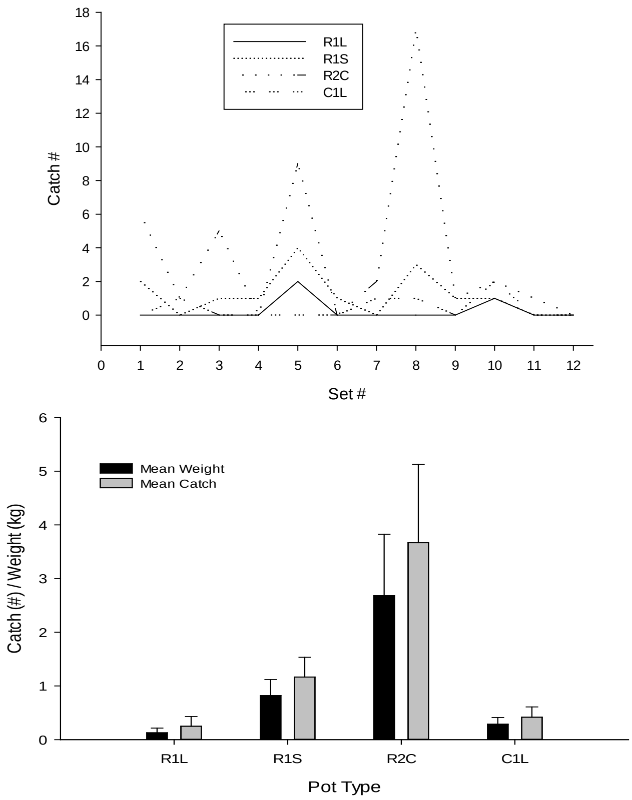


Figure 5: Catch results for Northern stone crab using each pot type

Operation system analysis of set net in Rayong, Thailand, from the view point of cost-profit simulation with fuel consumption assessment *(by T. Arimoto, T. Kudoh, Y. Takashima, K. Ebata, A. Boutson, A. Munprasit, T. Amornpiyakrit, N. Manajit, W. Yingyuad, Y. Minlee and S. Ishikawa)*

In 2003, the Japanese style of set net (Teichi-ami) was introduced to Rayong, Thailand for the purpose of encouraging community-based management of local fishery resources based on low environmental impact and sustainable and fuel efficient fishing technology (Figure 6). A key initiative associated with the introduction of this fishing gear was the development of processing and marketing efforts of high quality seafood from the set net.

The introduction of this fishing gear to the region was a multi-year process involving multiple stakeholders including SEAFDEC, the Tokyo University of Marine Science and Technology (TUMSAT), the Research Institute for Humanity and Nature (RIHN) and the Japan International Cooperation Agency (JICA). A highly systematic development network was applied with feedback mechanisms to ensure the project was a success (Figure 7).

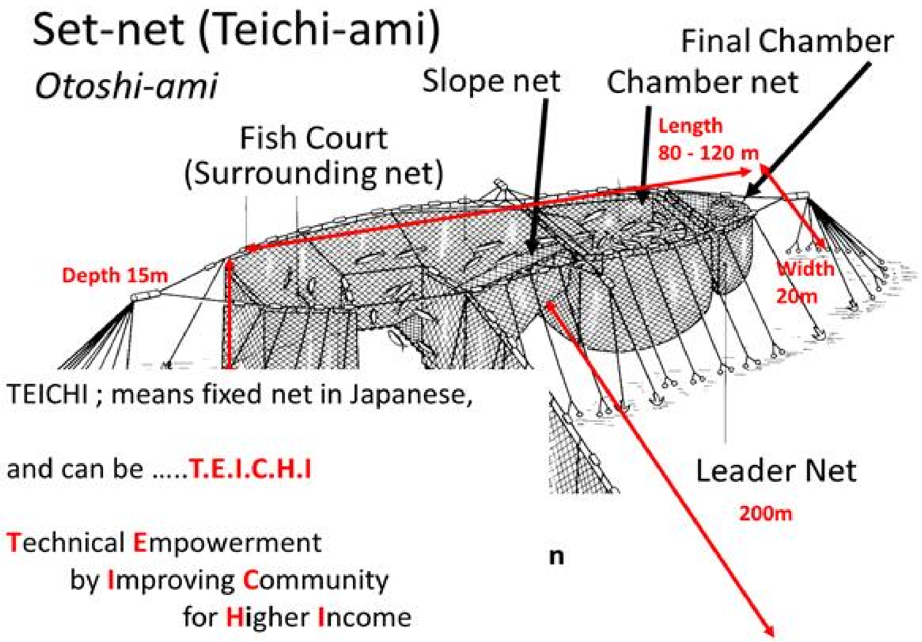


Figure 6: The Japanese-style of set net

In the first year of operation, significant problems and difficulties were experienced including anchors unable to cope with the strong local current and becoming entangled in the netting, bio-fouling of netting and the absence of a proven maintenance strategy for routine clean-up of the fishing gear. The initial set net measured 140 m long × 45 m wide with a 250 m leader net, but this was altered to 155 m × 20 m wide in an attempt to minimize the adverse impacts of strong current on net performance. The funnel leading into the main holding chamber was also altered by narrowing the funnel entrance and exit while at the same time making it significantly deeper.

As a result of these initial efforts, several key lessons were learnt to encourage higher profits, including:

- The catch from the set net is usually alive and with rapid retrieval of the catch, and the use of ice to cool the catch, fish prices per kg are relatively high.
- Increase the number of operation days and use less, but highly skilled fishers.
- Using specially modified boats to operate and maintain the set net, including the use of hauling and net-cleaning machines to improve net performance and to reduce down-time.

In 2003–04, the first year of set net operation, the gear was fished for a total of 52 operation-days and the average catch per day was 175 kg valued at just over Thai Baht 2000. In 2009–10, two set nets were in operation for a total of 86 operation-days and the average catch per day was 352 kg valued at just over Thai Baht 10 000.

The establishment of this gear has had a significant impact on the behaviour and livelihoods of local fishers. Hauling of the chamber can be achieved in a few hours every second morning by 3–4 boats with a total of around 12 fishers. Once completed, each fisher is available to conduct routine maintenance on the set net or operate his other fishing gear such as gillnets. Economic analysis of the set net fishery has revealed it is a significant source of supplemental income for local fishers.

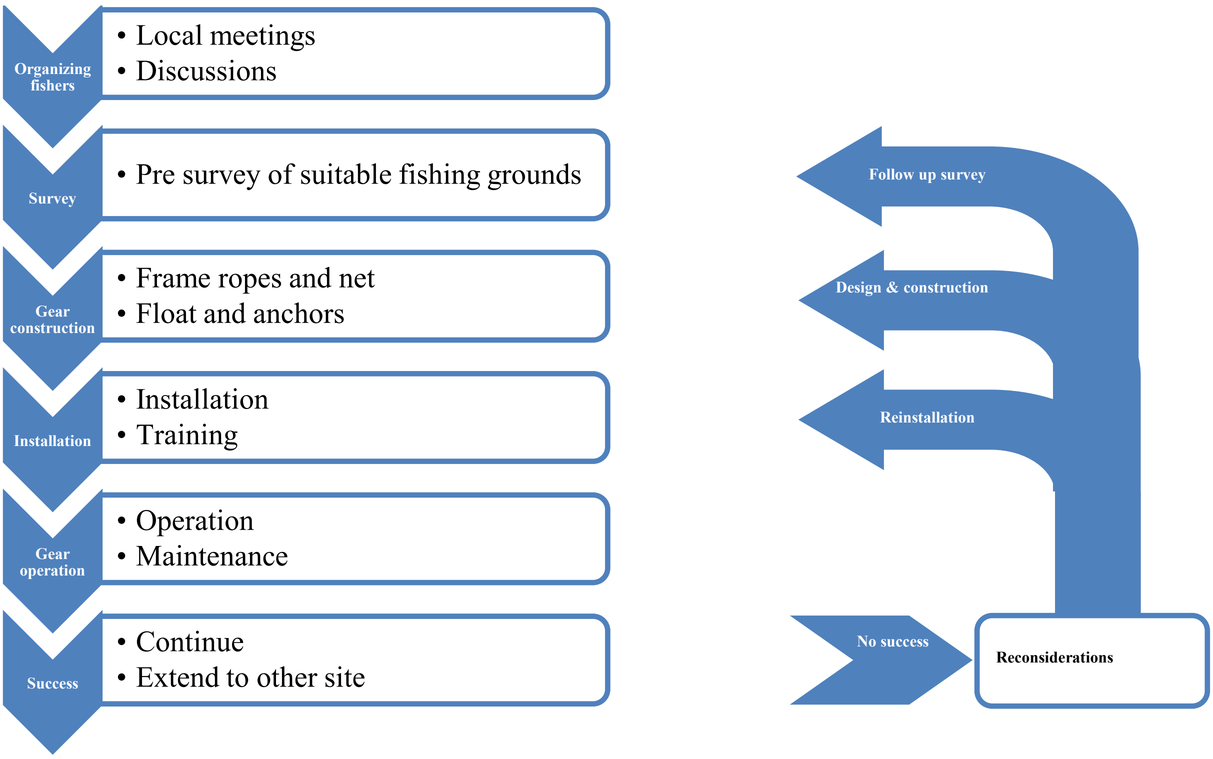


Figure 7: Set net development network

Seasonal variation in fishing operations and fuel consumption of small scale fisheries in Rayong, Thailand *(by Keigo Ebata, Anukorn Boutson, Isara Chanrachkit, Nakaret Yastook, Takafumi Arimoto, Takatsugu Kudo , Minlee Yap and Satoshi Ishikawa)*

Following the introduction of the set net to Rayong, Thailand in 2003, efforts were made to organize fishers into a committee to provide oversight of the fishing operation and associated management activities. As part of this process a field survey was attempted targeting 12 fishers in total, three of whom were involved in the set net operation, while the remainder were involved in gill net fishing, fish trapping, squid trolling, or hook and line fishing. The aim of the survey was to better understand the relationship between the fishing operation, fuel consumption, weather conditions and catch by species and volume. Survey data was collected through onboard interviews with fishers, collection of their log-book data, GPS records of the fishing boat and evaluation of weather conditions.

The onboard survey requested information from fishers about the size, shape, and construction material of the boat, propulsion equipment and other machinery, and any instrumentation used. A visual record of the fishing operation was collected, and questions asked about how the catch was processed until landed. The composition of the catch was recorded by species and size. A GPS unit was attached to the boat to record location at three–minute intervals so that fishing behaviour could be mapped. Fishers were asked to write a log-book every day for one year, including date, fishing gear, number of operations, number of fishers onboard, catch (species, weight, price), time of departure and return, fuel cost and volume, and any other remarks such as why fishing did not occur on a particular day. Weather information such as wind speed and direction was collected every three hours from the Rayong meteorological station.

The collection of this data enabled a comparison between fishing methods. For example, hook and line/squid fishers spend on average 12 hours per day catching 11.8 kg. Income was on average Thai Baht 1 913 and average fuel consumption was 5.8 litres. In comparison, at the same time of year crab gillnet fishers spent less than 3.6 hours per day at sea on average, catching around 6.7 kg of crab and other animals. Income on average was Thai Baht 984 and average fuel consumption was 4.2 litres. Further, fishers operating fish traps at this time of year spent on average 7.8 hours at sea to land 57.4 kg of fish. Income on average was Thai Baht 3 018 and fuel consumption was 10 litres on average.

The survey determined the following conclusions:

- The fishing operation is affected by the monsoon season, from May until September.
- The monsoon results in fishers changing their fishing gear due to the weather conditions.
- Analysis of seasonal variation in fishing gear, catch composition and volume and fishing location is ongoing.
- Not all fishers wanted to become involved in the set net operation, for reasons that remain unclear.

Energy saving fishing gears design using a numerical simulation *(by Chun-Woo Lee and Jihoon Lee)*

The context for this research was increased focus on efforts to reduce environmental impacts of fishing and sustainable management of natural resources, as well as current financial difficulties in the fishing industry. Energy consumption by fishing fleets is influenced by the type of fishing operation, catch preservation techniques, distance to and from the fishing grounds, and weather conditions. Current research includes a focus on CO_2 emissions with an emphasis on fishing gear design and operation, and improvement of fishing vessels.

A numerical approach to more efficient fishing gear design is an economical way to predict performance and outcomes, and provides an alternative to testing full scale or model fishing gear.

A numerical approach based on a mass-spring model was used to describe trawl performance. This model divides the netting into finite elements and places a ‘mass point’ in the centre of each element. Each mass point is assumed to be connected by a spring that has no mass and each mass point is assumed to be influenced by various internal and external forces and loads. By accommodating these forces on each element, computer simulation provides an opportunity to observe the geometry and drag of the trawl under varying conditions. Then, adjustments can be made in the search for a lower drag trawl system with lower carbon emissions.

Simulation was performed on a locally used trawl net and anchovy boat seine. A comparison between a trawl constructed with anterior panels constructed of fine knotless Dyneema or heavier knotted polyamide revealed a potential fuel saving is feasible of approximately 49 percent. In the case of the boat seine, a simulation of the effect of reducing the twine diameter using Dyneema twine revealed the feasibility of a potential fuel saving of up to 38 percent.

The results of the simulations have provided a way to evaluate the impact of alternative materials and gear design on fishing gear performance, with an aim of reducing fuel consumption and CO_2 emissions.

GEARNET: A bottom-up approach to gear testing and uptake *(by Michael Pol, Steve Eayrs and Pingguo He)*

GEARNET is a multi-disciplinary, multi-institutional network of gear researchers and industry members formed in response to a perceived historical lack of coordination around conservation efforts. The primary goal of GEARNET is to work with ground fish fishers to achieve more effective fishing under a catch share management system, including reduced bycatch, avoidance of waste and improved efficiency. GEARNET takes a bottom-up approach by working with groups of fishers (called sectors) to address their prioritized research needs. Historically, US fishers have been unaligned and individualistic; hence, it is hard to characterize the needs of individual fishers. A presumption with this approach is that by getting the gear right the fisher will use it.

In 2011, GEARNET funded fifteen proposals that were developed by sectors, including research efforts to reduce fuel consumption by trawlers, raised footrope gillnets, cod pot development and trawl modification to increase selectivity. Another 18 proposals were funded in 2013 from 13 sectors including work on topless trawls, semi-pelagic doors, raised ground cables (sweeps) and pingers to reduce marine mammal bycatch.

Several case studies were presented that showcase various levels of uptake by fishers and that explore factors that may be inhibiting the uptake. The first case study was the provision of 178 mm knotless Ultracross codends to a group of fishers in a sector that wanted to improve size and species selectivity of their fishing operation. Under the catch share system, all fishers in a sector are presumed to have a similar discard rate, which reduces the share of the total catch each fisher is allocated. However, because the fishery management authority is inflexible there is no way to adjust the allocation and ‘reward’ fishers that use this codend. The benefit of using this codend is therefore, largely altruistic in nature and possibly fragile and unsustainable in the long term.

In the second case study, several fisher-led projects were funded by GEARNET to develop more effective and selective haddock trawls. These projects included the lease of trawl gear so fishers could test their efficacy and modifications to existing trawl nets. Despite meeting the gear needs of fishers, this project took an ironic twist when they were unable to locate commercial quantities of haddock despite the allocation (quota) of this species being at a record high volume.

In the third case study, gillnet fishers were interested in testing raised footrope gillnets to avoid cod while landing Pollock or white hake. GEARNET funded the purchase and construction of gillnets raised 60 cm, 120 cm and 150 cm above the seabed. Despite 39 vessel trips by fishers, the data were inconclusive regarding the efficacy of these gillnets. While GEARNET scientists were not satisfied in their performance, the fishers were sufficiently encouraged to request further funding for additional sampling. This was provided and the project is ongoing.

In the final case study, a highly flexible, low interest financing package was provided for fishers to purchase semi-pelagic doors and a fuel flow metre. Repayments were capped at 10 percent of annual fuel cost and are made using money saved through the lower consumption of fuel. Since the inception of this project there has been very low enthusiasm despite relatively low risk. Reasons for this low uptake are not clear at this time.

In conclusion, GEARNET has found that a networked approach can solve the problem of lack of coordination around conservation efforts. However, the uptake of fishing gear has been found to be inhibited by regulatory inflexibility, resource unavailability and unpredictability and human nature. Interestingly, some fishers uptake gear with very little or no supporting evidence while in other instances no amount of supporting data seems adequate enough to encourage gear uptake. So while GEARNET was developed to solve a major problem with relevant research and gear uptake, other barriers have been identified and require further consideration.

Developing fishing gear to reduce environmental impact and increase the profitability of fishermen in the New England groundfish fishery: so, why are they so reluctant to use this new gear? *(by Steve Eayrs and Christopher Glass)*

A summary of four conservation research projects was presented prior to discussing change and gear uptake by fishers. The New England groundfish industry has a long history and individuals are highly conservative with respect to change. While change has occurred in this fishery since its inception, the boats and the gear to an extent reveal a conservative nature.

Times are tough in the fishery with allocations of many ground fish being reduced, most notable a 77 percent reduction in the allocation of cod. Landing prices are low and somewhat static, fuel prices are high and variable, fishers have to cover a portion of fishery observer/monitoring costs and crew are difficult to find.

The first project highlighted was a large mesh trawl study. In a comparative experiment, the catch and fuel consumption of a traditional trawl net constructed from 6 inch netting measuring 3.0 mm in diameter was compared against an identical trawl with the exception that 7 inch netting was used measuring 2.1 mm in diameter. After 34 tows, the results indicated a 23 percent reduction in fuel consumption with the large mesh trawl net and no difference in the catch of cod or monkfish (Figure 8).

In the second project, the performance of semi pelagic doors was compared against traditional bottom tending doors. This work was collaboration with a fisher who had been using these doors for two years previous to this work and was clearly satisfied with their performance. The results indicated a 12 percent fuel saving with almost no difference in the cod catch (Figure 8). Based on this result the payback period for these doors was just over one year for this fisher. On larger boats, it was estimated that payback periods could be as short as three months.

In the third project, the efficacy of acoustic catch sensors to provide a way to regulate catch volume in the codend was evaluated. All fishers in this project were positive in their review of these sensors, finding them relatively straightforward to operate. An unexpected outcome of this research was that fishers were shortening tow duration because the sensors indicated a predetermined catch volume in the codend and such a reduction translates to fuel savings.

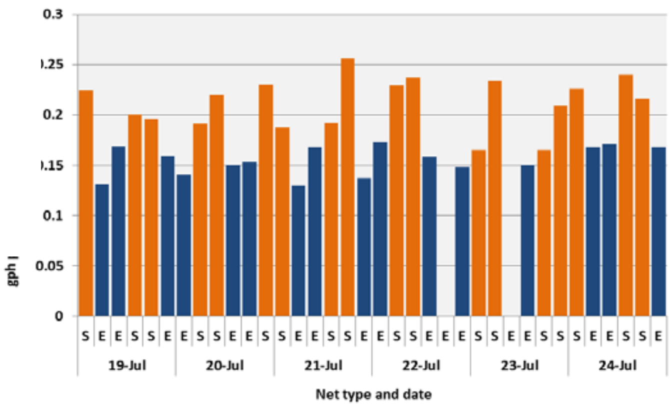
In the fourth project, energy audits of four fishing boats were completed. These took half a day with each boat and cost around US$4 000 per boat. The audits identified a range of suitable fuel saving options, estimated annual fuel savings per option, and payback periods. Importantly, they also allow fishers to model various fuel saving scenarios (Table 8). In this scenario, it was assumed a fisher with an annual fuel cost of US$30 000 wants to spend US$5 500 on fuel saving options, but rather than spend this entire amount at once a decision is made to purchase each item incrementally using money accrued through fuel saving. In this way it will take the fisher just over six months to purchase a fuel flow meter, upgrade the rudder, and install streamlined faring pieces around transducers and keel cooling pipes, after which a cumulative fuel savings of just over 23 percent will be realized.

Despite the success of each project, a variety of problems remain and adoption or uptake of this gear is poor. In the case of the large mesh trawl, netting material and a fuel flow metre was provided to an additional four fishers free of charge. After the better part of a year, only two of these fishers had constructed the large mesh trawl or installed the metre. Furthermore, one fisher only used the new trawl for several days before returning to his old trawl due to concerns over catch rates, and all found the slightly greater need for net mending a burden. A lack of consideration of the trade-offs from using this netting seemed the root cause for their reluctance.

Reducing fuel: Large mesh trawl study

- Semi-pelagic door: 22% smaller, 9% lighter
- Fuel consumption : ↓12%
- Seabed contact: ↓95%
- Door spread: ↓5%
- Cod catch: little different
- Payback period: 3 mths - 1.2 yrs

same net



Reducing fuel and seabed contact: Semi-pelagic door study

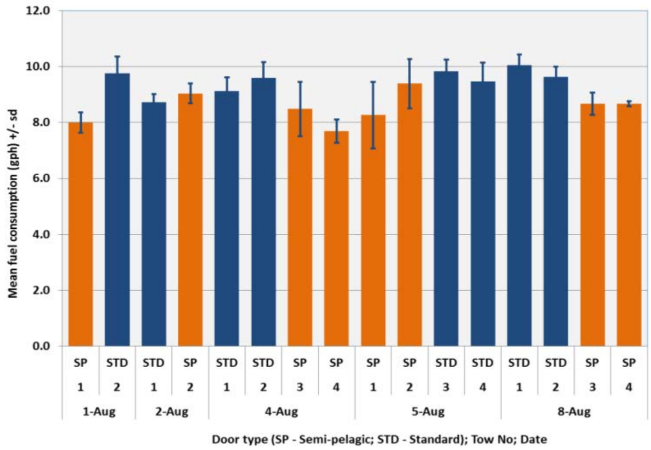


Figure 8: Results of large mesh, fine twine study with **S**tandard trawl (6″ × 3.0 mm mesh) vs Experimental trawl (7″ × 2.1 mm mesh) (upper) and semi-pelagic door study (below)

Table 8: Fuel savings and time to spend US$5 500 based on incremental adoption of each fuel saving option

Recommendation	Cost ($)	Fuel ($)	Savings (%)	Savings ($)	Fuel - Savings ($)	Cum. savings (%)	Time to save (mths)
Fuel metre	3 000.00	30 000.00	15.00	4 500.00	25 500.00	15.00	
Upgrade rudder	2 000.00	25 500.00	5.00	1 275.00	24 225.00	19.25	5.3
Fairing pieces	500.00	24 225.00	5.00	1 211.25	23 013.75	23.29	1.0
Total	5 500.00			6 986.25	6 986.25	23.29	6.4

The semi pelagic door finance model has attracted only two fishers. Despite the very attractive financial conditions (acknowledged by many fishers themselves) and fuel savings, uncertainty in the fishery has played a large role in their reluctance to adopt these doors. Even a US$2 000 subsidy paid to each fisher that installed the doors and metre was insufficient inducement to get greater uptake of this option.

The catch sensor project was funded to pay fishers US$250 per day to test these sensors or US$1 250 for multi-day fishing trips. Despite this funding and wide spread knowledge of the benefits of these sensors, this project was unable to find more than a handful of fishers to pay to test these sensors. Finally, despite the apparent value of the energy audits, no further audits have been conducted by fishers since this work.

Such lack of change uptake is an international phenomenon and not just limited to New England fishers. Even the presence of well-funded, extensive outreach projects is no guarantee of success.

It was suggested that a need exists to get to first principles regarding change. This included acceptance that we need to consider ourselves agents of change and better understand the motivation for change, how to tap into and exploit that motivation and how to make it permanent. It included acceptance that better outreach opportunities are required and that a metric of success in any gear conservation project should be the extent of gear uptake by fishers. It then called for an application of appropriate responses, considering win-win solutions and outcomes for the environment and fishers, using recognized principles of change management.

3.2. USE OF ARTIFICIAL LIGHT AS A STIMULUS ON FISH BEHAVIOUR IN FISH CAPTURE (LIGHT)

Introduction to the LIGHT session *(by Mike Breen)*

Light fishing has existed for thousands of years and the technology ranges from the use of simple torches on single boats to sophisticated and complex artificial illumination systems from multiple boats. Light fishing requires a multidisciplinary and complex approach to fishing; it is more than just fishing *per se*, but requires significant engineering of different types of light, from gas light systems to modern LED systems. It requires significant knowledge of physics, including light transmission in water and how it changes with conditions, as well as biology and physiology, including understanding how fish and other animals see and perceive the light, including knowledge of their response to light stimuli (Figure 9).

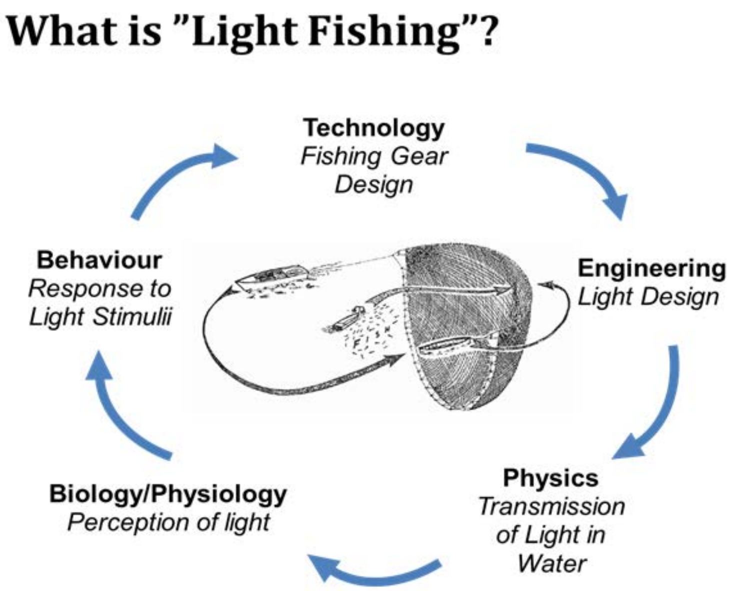


Figure 9: Light fishing requires knowledge of a variety of disciplines

An introduction to light and its measurement when investigating fish behaviour *(by Mike Breen and Amit Lerner)*

To a biologist studying fish behaviour, light is a stimulus that can have immediate and profound effects upon the behaviour of the individual. This stimulus is detected primarily by the eye, where photons of light are absorbed by the retinal molecule in the photoreceptor (rod & cone) outer membrane. This reception initiates a cascade of biochemical reactions that ultimately generate an electrical nervous impulse that is transmitted, via the optic nerve, to the optical centre of the brain. In order to understand how a light stimulus can be modified to manipulate behaviour, we must first be able to accurately and consistently describe the nature of the light arriving at the fish's eye. This presentation gave a concise explanation of the key characteristics of light (intensity, frequency/wavelength and polarization) and how they should be measured.

Light is a form of energy – part of the electromagnetic spectrum - that in physical terms is described as a "particle" or "photon" of energy (a fixed quantum of energy that is countable), but also as a wave with properties such as amplitude, wavelength, frequency, direction of propagation and velocity, and polarization. This contradiction in descriptions is often referred to as "wave-particle duality". A photon's energy is determined by its frequency and wavelength, where low frequency (long wavelength) light (e.g. red) has less energy than high frequency (short wavelength) light (e.g. blue). Therefore, "colour" is merely a perception of the energy of the received photons (Figure 10).

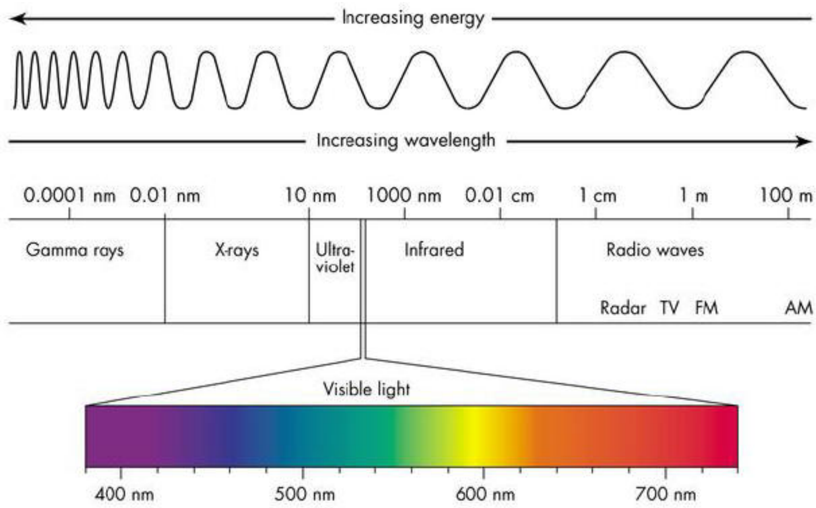


Figure 10: The Electro-magnetic Spectrum

Scientific literature presents a complex and confusing array of definitions and units to quantify light. For a biologist, it is more informative to measure the "intensity" of light arriving at the fish's eye in terms of the number of photons, measured in Einsteins (or mols of photons), as opposed to the total energy (Joules) or power (Watts). However, it is important that this intensity also be measured in terms of wavelength (per nm) or frequency (per Hz) of the received photons – so that the intensity of light across the subject's visual spectrum is comprehensively described. The remaining units generally describe the intensity of light spatially and temporally. To simplify and standardize measurement, it was recommended to use only "Radiometric units", which are absolute (see Table 9), as opposed to "Photometric units" (which are corrected specifically for human vision). Of these units, the most practical and informative for the biologist are Irradiance and Radiance.

Table 9: The Radiometric Units of Light, with their corresponding Photometric Units

Radiometric units	**Symbol**	**Unit**	**Photometric units**	**Symbol**	**Unit**
Radiant Energy	Q_e	J	Luminous Energy	Q_v	lumen.sec
Radiant Power	Φ_e	W (or $J.s^{-1}$)	Luminous Power	Φ_e	lumen (lm)
Radiant Intensity	I_e	$W.sr^{-1}$	Luminous Intensity	I_e	Candela
Radiance	L_e	$W.sr^{-1}.m^{-2}$	Luminance	L_e	candela.m^{-2}
Irradiance	E_e	$W.m^{-2}$	Illuminance	E_e	Lux
Radiant Exitance	M_e	$W.m^{-2}$	Luminance Emittance	M_e	Lux
Radiant Exposure	H_e	$W.s.m^{-2}$	Luminous Exposure	H_e	lux.s
Radiant Energy Density	ω_e	$J.m^{-3}$	Luminous Energy Density	ω_e	lux.s.m^{-3}

The presentation concluded by explaining how these could be measured practically. Of the many instruments available for measuring light, it is recommended that biologists use a "Spectroradiometer". This instrument can measure Radiance and Irradiance over a wide spectral range, ideally 350–750 nm (to cover the known visual range of most animals).

Fish behaviour and visual physiology in capture process of light fishing *(by Takafumi Arimot)*

Understanding the behavioural response of target species is a key factor in the efficient and sustainable development of any fishing technology. In light fishing, artificial light is generally used to attract target species, and the development of this technique has therefore, been dominated by the evolution of light source technologies, particularly in the past century. This evolution has been characterized by an escalating increase in the power output from the lights, as well as the energy costs of producing that light.

In Japan, purse seine, stick-held lift-net and squid jigging are the major fishing methods using light, and there are new challenges in trying to optimize these light fishing techniques. The main issues are associated with the excessive and inefficient production of light: i.e. light pollution affecting adjacent boats and coastal communities; the consumption of fuel to generate light; and, the CO_2 emissions associated with the generation of light. In some fisheries, such as purse seining, there are also selectivity issues due to the light attracting more than just the target species. An improved understanding of how the target species respond to and interact with artificial light fields and fishing gears is key to resolving these challenges. Two fundamental research questions are: why some species are attracted to light and what the attraction mechanism is.

How fish respond to light and where they orientate within the light field around the fishing boat can be observed using acoustic techniques. Of the possible responses, the most interesting to fishermen is "positive phototaxis" (attraction). It is recognized that this is not simple and within a gradient of underwater light intensity some species have an optimal level where they will gather. Possible reasons for fish responding to artificial light are: feeding on prey attracted to the light; preference for an optimal light intensity, maybe for schooling; a conditioned reflex; disorientation; or curiosity.

To understand what a fish sees, and therefore, why it responds in the way it does, requires more in-depth morphological and physiological approaches to describe the fish's visual functions: acuity; sensitivity; light/dark adaption; colour spectrum; and, movement detection. Histological examination of the retina can reveal a great deal about the form and function of the light sensitive cells (photoreceptors). There are two types of photoreceptors: the "cones" which are colour sensitive and used for "photopic" vision during daytime; and the "rods" which a more sensitive and used for scotopic (monochrome) vision when light levels are low, and move deeper into the retina when light levels are high, to protect them. Vertical histological sections through the retina allow us to determine the relative positions of the rods and cones, thus, giving insight into the adaptive abilities of the eye under different lighting conditions (Figure 11). Horizontal sections inform us about the distribution and density of the photoreceptors across the retina. This can be used to estimate and compare the visual acuity and maximum sighting distance between species and different sizes of fish (Figure 12).

Electro-physiological techniques, such as the electroretinogram (ERG), allow us to determine the sensitivity of the subject's eye to different light intensities and colours, as well as determining contrast thresholds under different ambient light conditions. This enables us to understand when a fish is capable of seeing netting and other components of the fishing gear.

Collectively, these methods are providing useful insights into the response of fish to light and a better understanding of the capture process of light fishing.

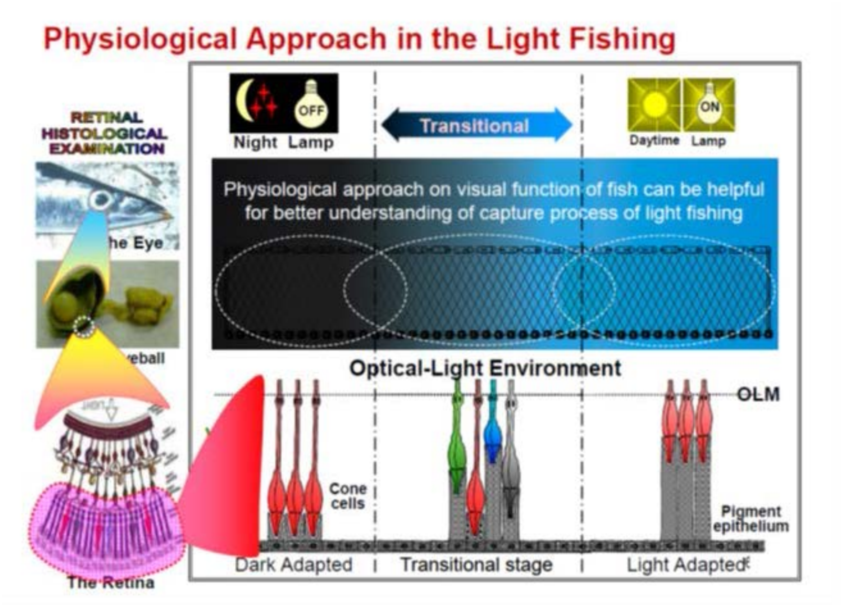


Figure 11: The adaption of cones to light intensity

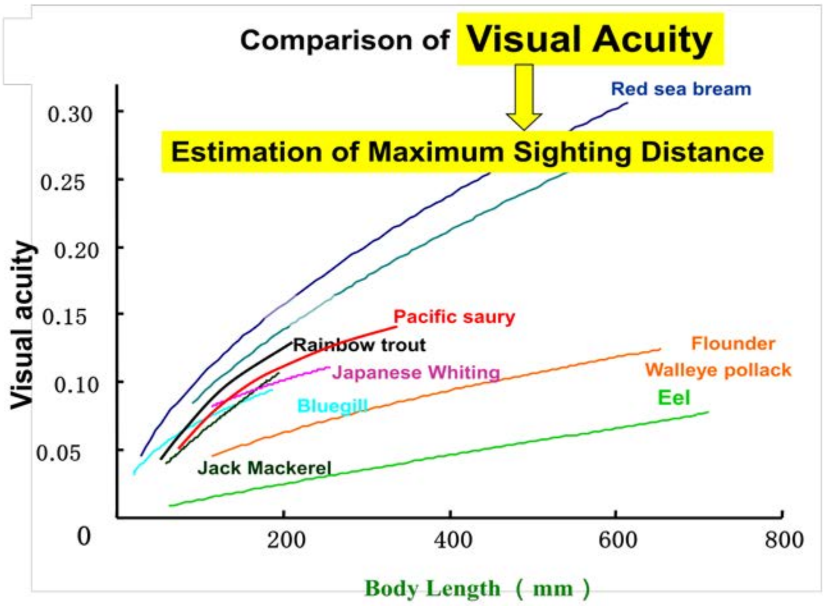


Figure 12: Change in visual acuity with body length and species

Marine optics – essential elements for fishing technology and fish behaviour *(by Yoshiki Matsushita and Hisayuki Awakawa)*

This presentation introduced the fundamental optical processes in the marine environment and showed how they can be used to improve the use of lighting technologies in Japanese fisheries.

The importance of light in Japanese fisheries was described. Much of the production from purse seining is derived using light to attract and accumulate fish prior to capture, while all production from stick-held dip net fishing and squid jigging is derived using light. Total Japanese production in 2009 was a little over 4 million tonnes of which purse seine, stick-held dip net and squid jigging respectively accounted for 29 percent, 7 percent and 4 percent of this production.

Light is electromagnetic radiation that is emitted by thermal (e.g. sun/star, incandescent bulb) or luminescent (e.g. fluorescent bulb, LED) sources. We can see star-light that has travelled very long distances because light travels in a vacuum without attenuation. However, once a light enters air or water, various processes (i.e. absorption, refraction, reflection and scattering) act upon it to change its key characteristics such as velocity, direction of propagation, wavelength spectrum, and polarization (Figure 13).

When light passes through the air – water interface light is both reflected and refracted in accordance with Snell's law, hence, it is possible to estimate the fraction of light that is reflected and the fraction of light that is transmitted into the water. Then, as light is transmitted through the water, a significant proportion is attenuated through absorption and scattering) according to the Beer-Lambert Law, where longer wavelengths in the red spectrum are absorbed more quickly than blue/green wavelengths which penetrate deeper before being attenuated. The extent of this attenuation is highly variable, depending upon the optical properties of the water mass, which are determined primarily by its dissolved and particulate contents (including plankton). This emphasizes the importance of obtaining reliable field measurements of the optical properties of a water mass when studying light fishing. To demonstrate these principles, a simple model was presented that permits estimation of the amount of light that reaches a given depth in the absence of light measuring equipment (Figure 14).

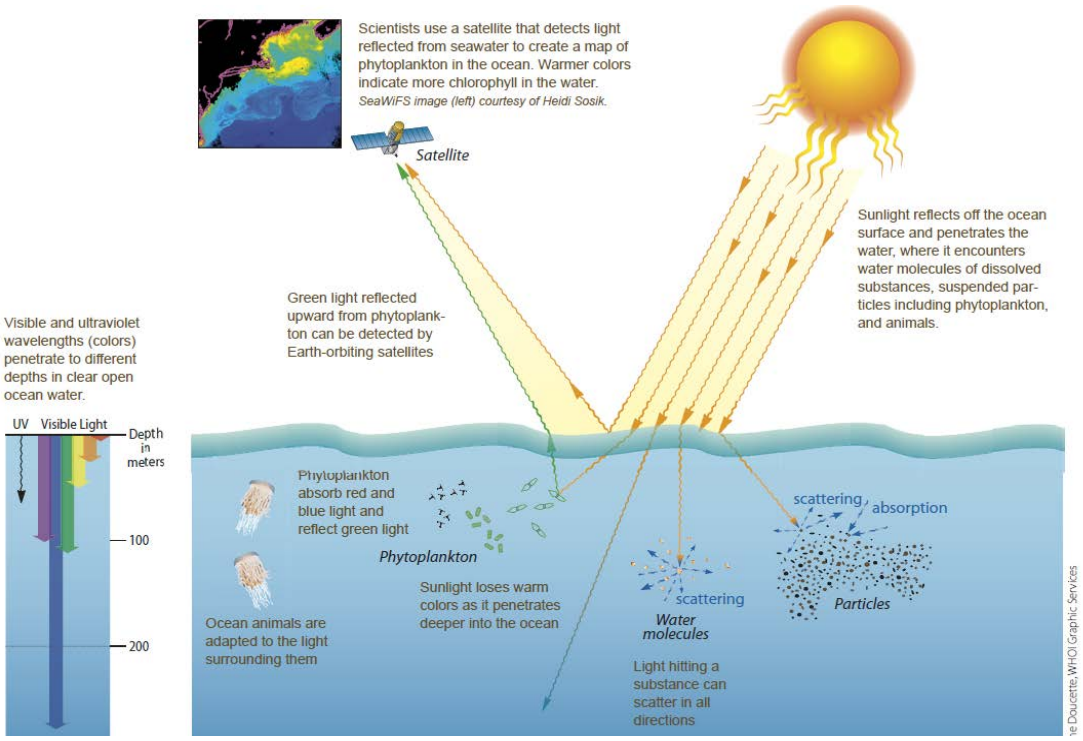
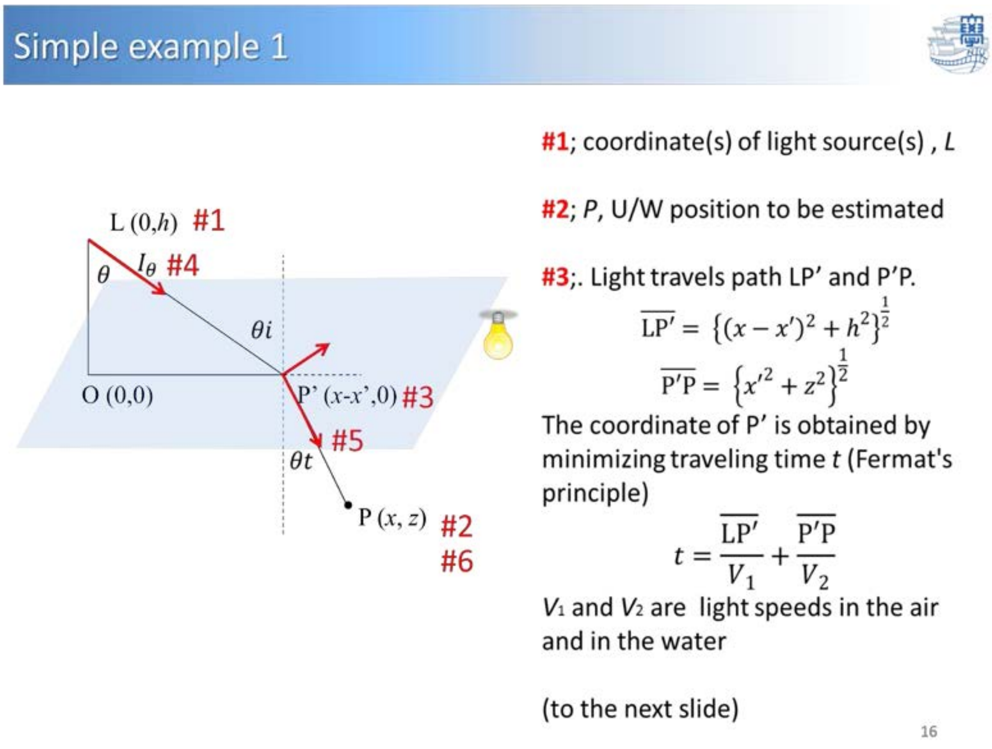


Figure 13: An overview of the optical processes affecting light entering seawater (Adapted from Johnsen & Sosik, 2004[2])

[2] Johnsen, S. and H.M. Sosik. 2004. What does the ocean really look like? Oceanus. 43(2): 24–28.



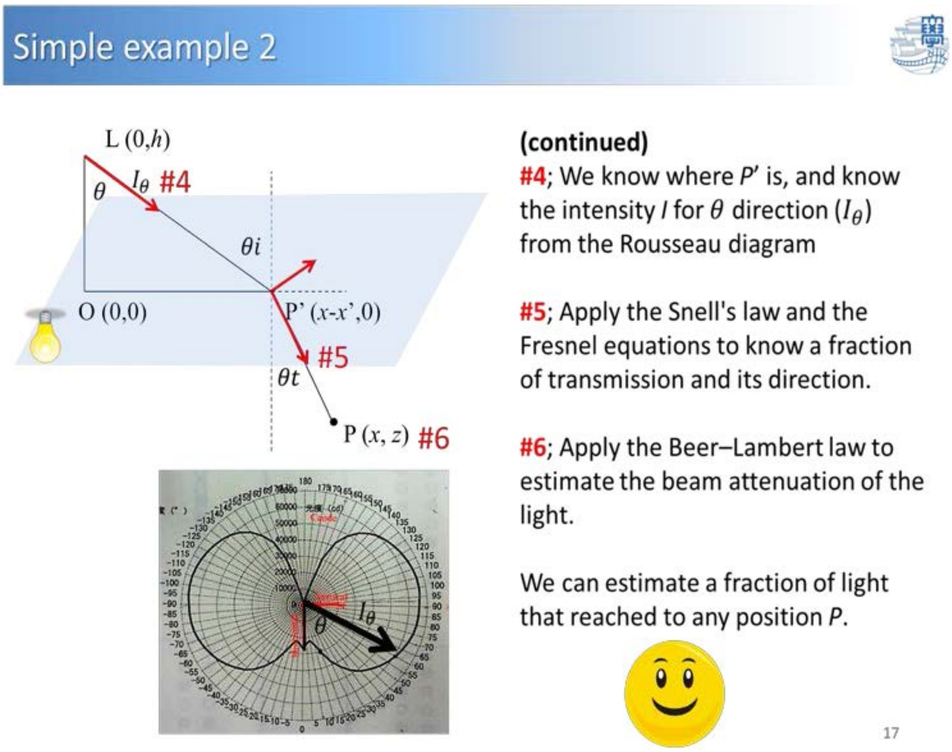


Figure 14: A guide to calculating the fraction of light that reaches a given depth

Review of light design: LED packaging and lighting *(by Professor Ja-Soon Jang)*

Light-emitting diodes (LEDs) have extensively penetrated into all lighting applications ranging from general illumination to fishery lighting because of their technological and practical advantages over traditional light sources (e.g. incandescent & fluorescent bulbs). These include: longer lifetime, higher efficiency, better chromatic performance and reduced environmental impact. In order to replace the traditional light sources with LED light sources, better understanding of LED packaging and module technologies and light design issues are essential. In this presentation, the development of LED technology was discussed including design, engineering, packaging and application. LED packaging and module technology, as well as design issues were reviewed. In particular, how to control colour rendering, angular colour uniformity, correlated colour temperature and efficiency. How to optimize these factors to obtain better optical properties of LED lightings was also discussed. Finally, design rules for LED lighting were introduced using some useful examples.

Research on artificial light sources for light fishing, with a focus on squid jigging *(by Heui Chun An)*

This presentation provided a brief history of light fishing and reviewed various studies looking at the use of artificial light in squid jigging.

Fishing with light has a long history dating back to at least the seventh century, when burning wooden torches were used. Since then, lighting technologies have evolved to produce increasingly more powerful artificial light sources. In Asia, this evolution began soon after the turn of the twentieth century with the replacement of wooden torches with kerosene and acetylene lamps. Incandescent lamps were introduced in the 1930/40s and mercury and fluorescent lamps in the 1950s, followed by halogen and metal halide lamps in the 1970s and 1980s, respectively. This development in increasingly powerful lights has driven a problematic increase in competition between fishing boats and fisheries, as well as very costly and environmentally damaging energy usage. So in the latter part of the 20^{th} century legislation was introduced to limit energy output from light fishing boats and more recently there has been a priority to find more energy efficient light sources. The turn of the twenty-first century saw the introduction LED lights as a means of reducing energy usage.

Artificial lighting is used to attract fish towards a variety of gears such squid jigs, fish jigs and lift nets, to induce fish into a gear such as a stick-held dip net or a scoop net and to herd and aggregate fish into a desired location such as purse seining with light. Lighting in the form of strobe lights has even been used as a deterrent to keep fish away from pipe intakes.

In the daytime squid tend to remain at depth and avoid shallow water brightly illuminated by the sun. At night time they rise toward the surface. When a boat is using artificial illumination, squid are attracted towards the light, but avoid highly illuminated areas, often aggregating in the shadow zone below the vessel (Figure 15). In one notable study (Arakawa *et al*., 2012) underwater lamps were used at 50 m in addition to illumination from the vessel. Squid were observed moving away from the underwater lamp when it was turned on, and then re-aggregating below the vessel when the lamp was turned off. CPUE was reduced by about 25 percent when the lamp was turned on. In another study, it was found that squid catch increased substantially when onboard light power output (kW) was increased, but that maximum catching efficiency was realized by vessels 11–15 gross tonnes using 100–200 kW of power.

A comparison of different fishing lights found LEDs were superior to metal halide and incandescent lamps (Table 10). With an increase use of LED lights in squid operations a recent study found that catch rates were highest when blue and white lamps were used, and lowest when red were used.

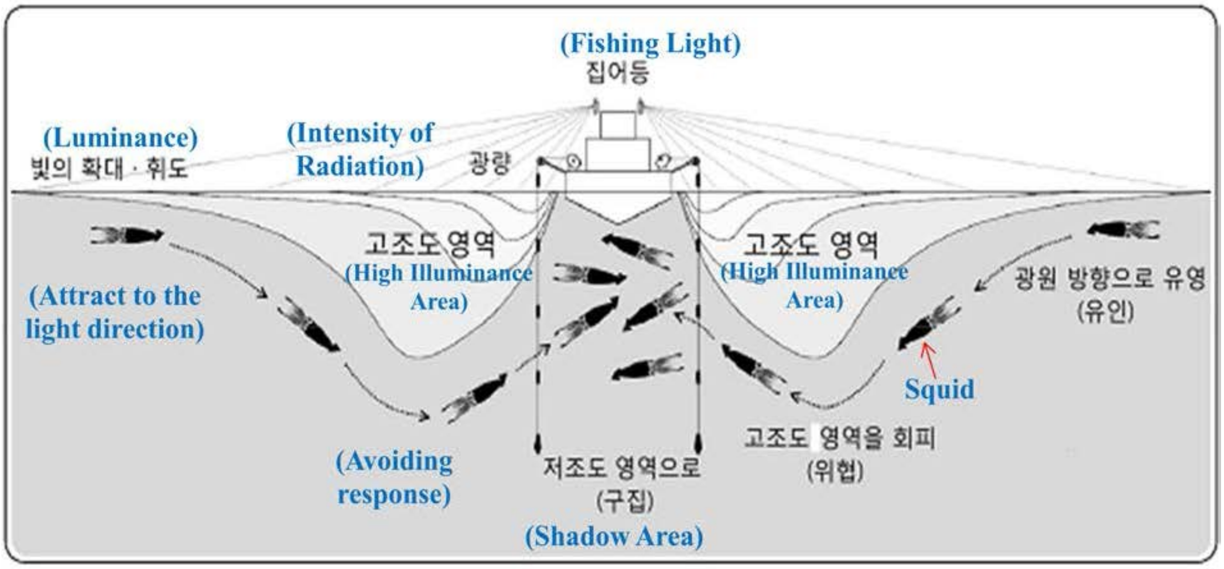


Figure 15: Attraction response of squid to fishing lights. Source: Shikara, 2010

Table 10: Comparison of different fishing lights

Parameter	Incandescent lamp	Metal halide lamp	LED lamp	
Fishery type	Stick held dip net, anchovy scoop net	Jigging, angling, purse seine	Stick held dip net, jigging, angling, purse seine	
Underwater penetration	Not so good	Good	Good	
Lamp re-start	Good	Not so good	Good	
Colour temp (K)	2 600–3 000	4 000–4 500	6 000–12 000	Blue, Cyan
Duration (h)	500–1 500	3 000–5 000	30 000–50 000	
Luminance efficiency (lm/W)	10–20	85–125	100–150	50–70

Light output arrangement in light fishing through the use of simulation model of underwater illuminance distribution *(by Sugeng Wisudo, John Haluan and Takafumi Arimoto)*

In Indonesia, light fishing is used in both fixed and floating Bagan fishing gear, purse seining with a raft of lamps and squid lift net fishing. Like many other countries, light fishing in Indonesia commenced by using fire sticks or torches. This was used until the 1950s and was then superseded by the kerosene lamp which is still in use today. Electric lamps (either incandescent, mercury, fluorescent, halogen, or metal halide) were systematically introduced and are also still in use today. Using these lamps, it is important to compare their light intensity to ensure that excessive illumination is not occurring.

This presentation described the measurement and modelling of the underwater light fields from a number of sources in Indonesian fisheries using the Bagan lift net (Figure 16). The light fields from different Bagan lift net gears were described in terms of illuminance, including: bamboo-raft Bagan, engine-boat lift net (Bagan motor), derrick held lift net (Bagan kambang), where illuminance is the photometric (i.e. corrected for human vision) equivalent of “irradiance”. In addition, the light fields from a variety of light sources were described, including different lighting power outputs (2 500W and 5 000W), lamp types (kerosene, incandescent, halogen, mercury and fluorescent) and number of lamps (1, 2 and 4).

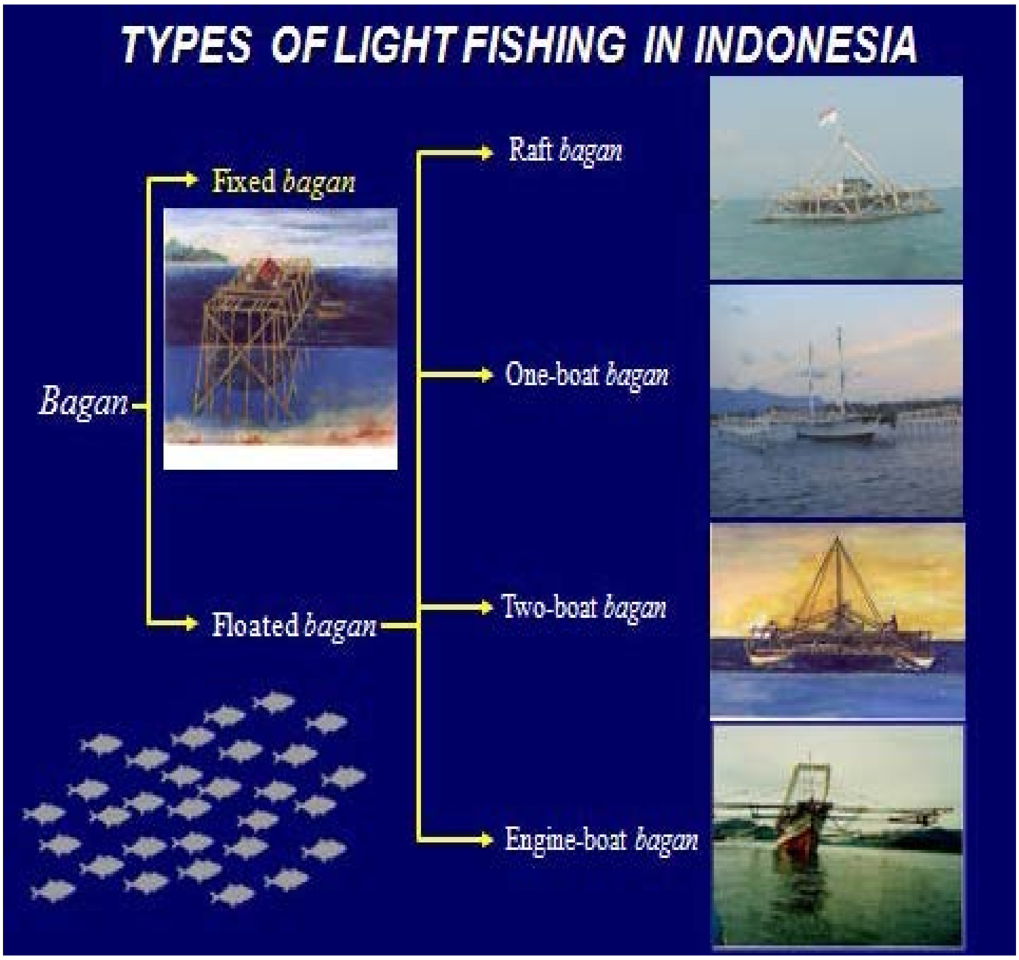


Figure 16: Types of light fishing in Indonesia

The modelling exercise used three different forms of model, based on different assumptions about the nature of the light source, i.e. directional light source, point source and line source. The underwater light fields for a number of light sources were modelled, in terms of luminance, using affordable and easily available software (Excel) and compared with field measurements (Figure 17). Of the three model types, the directional and point source light source model provided reasonable fits to the observed data. The authors hope to develop the models further to improve their accuracy and provide estimates of irradiance. The ultimate aim of this promising work is to develop a method for optimizing the lighting power output and thus, minimize excessive energy usage in these fisheries.

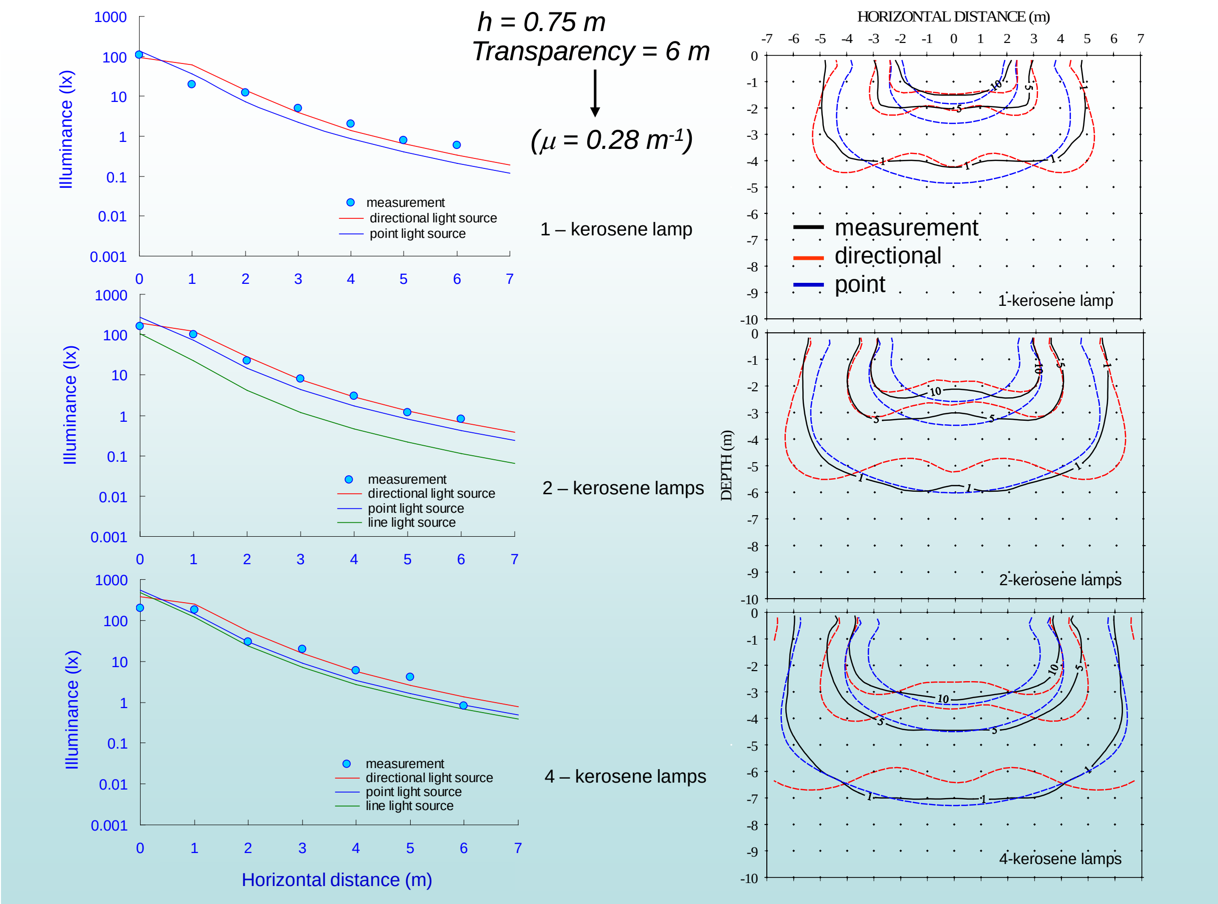


Figure 17: Predicted luminance of 1, 2 & 4 kerosene lamps from three different models

Energy harvesting in the marine environment *(by Dan Watson)*

Energy sources for light fishing currently range from fossil fuels to electrical batteries. However, the fishing process and the ocean itself may present alternative methods for self-powering lights using renewable energy sources. The marine environment has many potential sources of energy that can be captured and utilized including electromagnetic waves, vibration, heat, electrical potential and kinetic energy. In the fishing environment, wave power is a potential source of energy that is not currently captured, while in trawl fisheries the movement of water through the gear is also potential energy source. This presentation gave an overview of the potential energy sources and the prototype technologies that could be used to harvest these renewable energies.

A project known as “SafetyNet” (http://www.sntech.co.uk/) was described that is developing prototype devices for generating low cost energy on fishing gear (Figure 18). Such energy harvesting devices are required to be reliable, cost-effective and with minimal need for maintenance, while the energy harvesting process requires an energy source, a way to capture it, a storage system and an effective, regulated delivery system.

The goal of the project was to generate sufficient power to illuminate a super bright white LED by producing 3–3.6 volts. Devices investigated so far include linear-and random motion harvesters, as well as micro-turbine units. These devices, while practical, require significant and continuous motion, and so may be suitable for towed fishing gears. However, it is believed that the most promising harvesting technology would be a robust and efficient salt-water battery, using the electrolytic potential of seawater (that normally corrodes exposed metals) to generate electricity. The benefits of such devices include low cost, reliability, the absence of moving parts, and operation in both static and active gears.

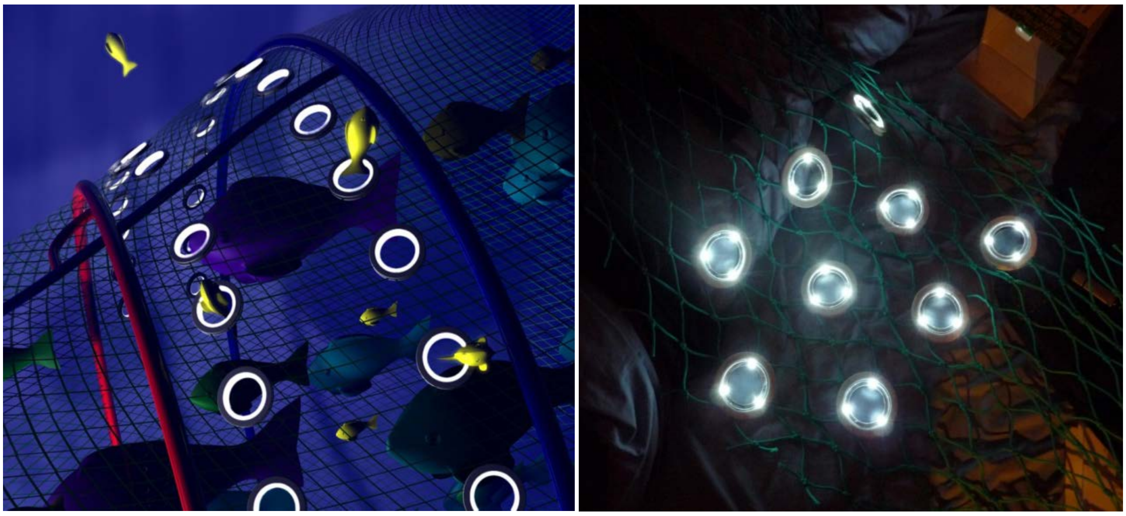


Figure 18: LED fish escape rings to facilitate the escape of bycatch from a trawl

The biology of underwater vision *(by Ronald Kroger)*

The biology of underwater vision is very diverse between species and highly adaptable within-species to enable vision to function optimally over a wide range of functional needs and optical conditions. Visual performance is limited by various internal and external factors, such as spatial, temporal, spectral and polarization resolutions, as well as sensitivity to light and the environment inhabited. The underwater visual environment is highly variable, changing with depth, water type, weather condition, season and so forth. Furthermore, visual needs and conditions often change during the lifetime of an animal. This has led to a multitude of different visual adaptations in marine species, both anatomical and behavioural. Many fish and crustacean have a wide spectrum of colour sensitivity and resolution, with some species sensitive to ultra-violet (UV) light; while most squid and cuttlefish are colour blind.

The fine-tuning of visual capabilities occurs over various time-scales, from minutes to months. The adaptability of photoreceptors in the eye to light and dark conditions is well established. However, experiments by Professor Kroger’s team have also demonstrated how photoreceptors can adapt to differing predominant colour spectra. Groups of fish held in aquaria under different lighting conditions (bright white, dim white, red, green, blue, yellow and violet) were found to have marked changes in the number, length and neural-connectivity of the colour sensitive photoreceptors (cone cells). In particular, fish held under blue light conditions were seen to significantly reduce the number and length of the blue sensitive cone cells, as well as reducing the neural connections to them. It is believed that this response actively decreases the fish’s sensitivity to the predominant blue light, thus, increasing the relative sensitivity to the other colours of the spectrum.

The refraction angle of light varies according to its wavelength (colours), hence, a prism separates white light into its component colours. To accommodate this effect, many fish species have developed multi-focal lenses to allow different colours of light to be focused correctly on the retina. Furthermore, in species naturally exposed to varying light conditions (e.g. cod), these lenses have also been shown to be highly adaptable (rapidly modifying their optical properties) thus, allowing them to focus correctly under varying light conditions (e.g. predominantly red light in turbid coastal waters or

blue light in oceanic waters). Other species that live in more stable natural light conditions (e.g. arctic cod) show little adaption. Water temperature also influences visual speed (capability) and some species such as swordfish are specially adapted to heat the eye and optimize visual capability in cold water.
A fish eye also changes substantially during its lifetime due to growth, which can significantly affect its visual acuity and sensitivity.

Knowledge about the limitations and adaptability of fish vision may make it possible to target species and/or developmental stages by using various types of light. However, underwater vision is a short-range sense, with visual distance being limited to less than 50 m even in the clearest open-ocean water and much shorter in most coastal waters.

Polarization vision in the sea *(by Amit Lerner)*

Polarization is the third quality of light, after intensity and colour. When considering the properties of a photon in terms of a wave, we can imagine this wave oscillating in a plane - called the axis of polarization (or the e-vector orientation) - which is perpendicular to the direction of propagation. Where this axis does not change its orientation with time, we say the light is linearly polarized. A beam of light is said to be 100 percent linear-polarized when all the photons have the same fixed axis of polarization. Conversely, the light is unpolarized when there is no common axis of polarization. It is also possible to have partial polarization, were a proportion of the photons share a common axis, while the remainders are randomly oriented. In addition to the linear form of polarization, light may also have circular and elliptical polarization, where the axis of polarization effectively rotates relative to the axis of propagation. Therefore, polarization has three parameters: degree of polarization (%; linear); e-vector orientation (linear); and state of polarization (circular/elliptical).

The physical processes that affect polarization are refraction, scattering, reflection and absorption. For example, increased scattering decreases polarization, and therefore, light in turbid coastal waters will generally be less polarized than in clear oceanic waters. Furthermore, while the intensity of light decreases by up to 99 percent at 80 m depth, polarization only decreases by around 43 percent, and can be as high as 40 percent at depths greater than 200 m. This suggests that marine organisms with the ability to perceive polarized light may have a distinct advantage over organisms that can detect light intensity alone; even at depths where light is normally considered to have limited ecological influence.

While polarization is hardly perceived by humans, more than 70 aquatic species are known to be sensitive to polarized light. Many of these are invertebrates such as cephalopods (cuttlefish, squids, octopuses) and crustaceans, while around eight fish species are also known to be sensitive to polarized light.

Marine animals may use polarized light to facilitate navigation and communication, as well as to hunt prey. For example, *Calanus finmarchicus* is a species of zooplankton that is almost transparent and therefore, difficult to observe under non-polarized light. However, under polarized light their contrast increases making them more visible and presumably more easily detectable as prey to animals with polarized vision. One species of fish, the hardyhead silverside fish *Atherinomorus forskali*, has been shown to respond to polarized light in aquaria. This species is planktivorous and feeds on transparent plankton such as *Calanus*. If other commercially important species can be found to be similarly responsive to polarized light, conceivably it could be used to manipulate their behaviour during the capture process, to either increase catch efficiency or improve selectivity. Alternatively, manipulating the behaviour of potential prey species could also be used to attract species that prey upon them.

Development of the evaluation method on the effect of artificial fishing light *(by Kazuhiko Anraku and Tatsuro Matsuoka)*

Many light fisheries in Japan have adopted LED lighting to conserve energy including saury stick-held dip net fishery. Therefore, it is essential to compare the efficiencies of conventional lights, such as halogen and incandescent, and the newly developed LED lights for optimum installation of LED fishing light into commercial fisheries.

Light emitted from the source travels in the water and is perceived through the vision of target animals; hence, both the water properties and visual sensitivity to the light spectrum are the factors that have to be incorporated into numerical simulations. On the assumption that the peak spectral sensitivity of fish is optimized to its surrounding environment, a relationship exists between the characteristics of the light source, attenuation of light as it travels through water, and the spectral sensitivity of fish (Figure 19).

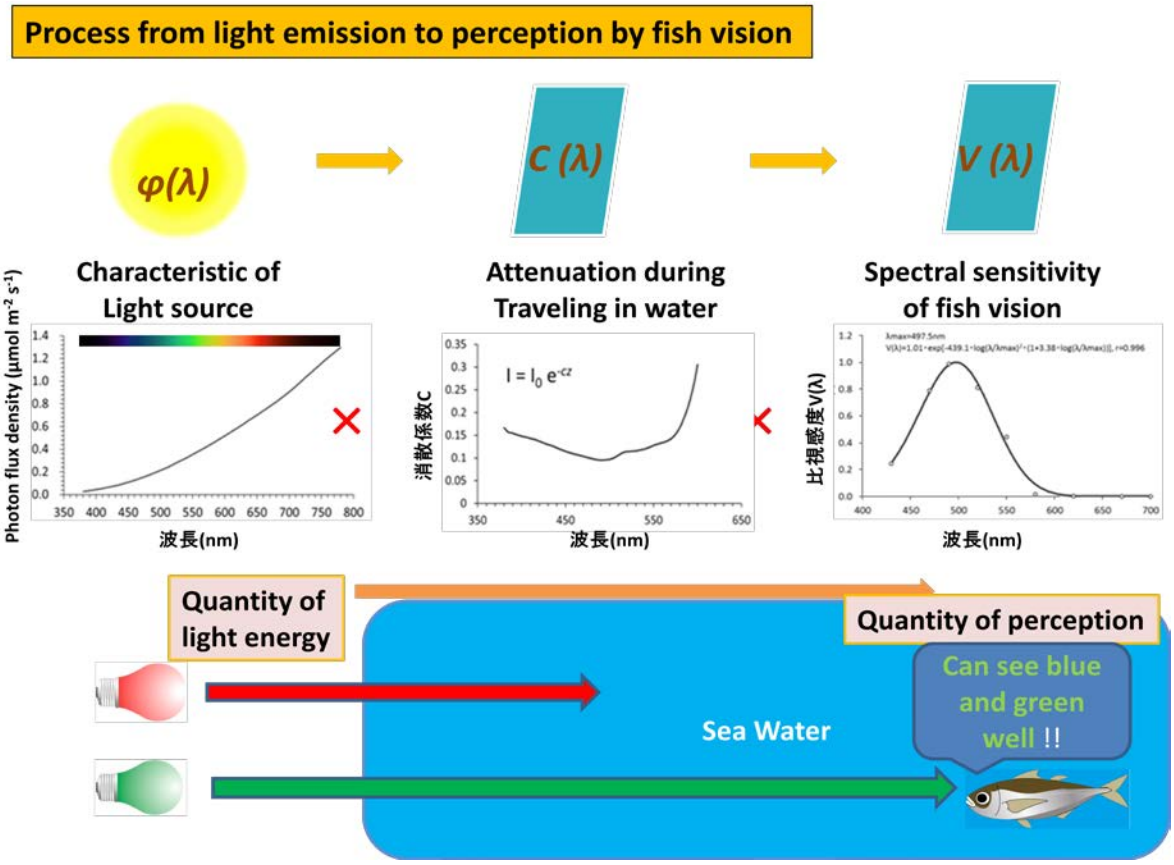


Figure 19: Process from light emission to perception by fish vision

Measurement of spectral sensitivity can be achieved with an electroretinogram (ERG). Silver wires are attached to the fish, one on the cornea and one in skin of the fish and connected to a receiver–amplifier. The photoceptors in the eye respond to light stimuli and an electrical potential is measured, amplified and recorded. During this process the fish is held in place, a light source shone into the fish eye but filtered to regulate and ensure a single, desired wavelength reaches the eye. Using nine wavelengths (431, 469, 489, 520, 551, 580, 620, 669 and 689 nm) the sensitivity to light was evaluated for jack mackerel, *Trachurus japonicas*, and found to reach a peak at a wavelength of 497.5 nm.

To measure the spectral characteristics of artificial light sources, Photon Flux Density (PFD) (≡ Irradiance) was measured downward from the horizontal plane to the vertical plane using a spectroradiometer at a distance of 1 m from the light. The attenuation of the light in seawater was measured using a portable spectroradiometer. Data was collected every 3 seconds at depths between 2–50 m, allowing the relationship between attenuation and depth to be analyzed using Beer-Lambert law. Comparison of the emitted light field (PFD) (at 1m in air) from two light sources (3kW incandescent lamp and 1kW blue-green LED) with the Iso-PFD Distance, when corrected for in-water attenuation, demonstrated that the effective light levels at depth were comparable, despite the much greater energy output from the incandescent lamp (Figure 20). This suggests that LED lamps, with the appropriate spectral characteristics, could be an effective and energy efficient replacement for incandescent light sources.

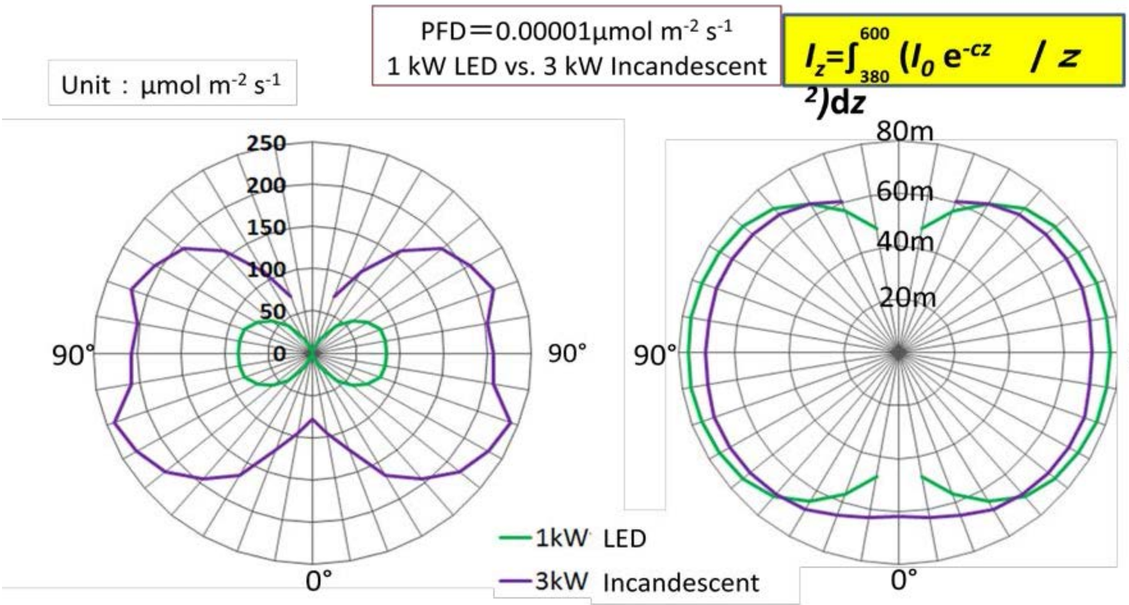


Figure 20: A comparison between the emitted light field (Photon Flux Density, PFD) (at 1m in air) from two light sources (left) and the Iso-PFD Distance when corrected for in-water attenuation (right)

Visual threshold of rockfish (Sebastes imermis) response to different wavelength of LED lamp *(by Hyeon-ok Shin and Jin-Wook Jung)*

Understanding how the fish is aggregated to a luring lamp in fishing industry is still a challenge in fishing technology and science.

In this presentation, a study was described in which adult rockfish were held in a test tank and exposed to LED lights of various colour (wavelength) and intensity. An electrocardiogram (ECG) was used to identify when fish responded to the light. The average visual thresholds with respect to illuminance (i.e. the photometric equivalent of irradiance) of rockfish to red and green light were 0.55 lx and 0.56 lx, respectively, but rockfish showed no response to blue light.

It had previously been determined that the growth rate of rockfish held in aquaria was different when stimulated by difference coloured LED light. It was postulated that the high contrast of feed under red and green light better enabled fish to source the feed visually, resulting in higher growth rates than when blue light was used.

Attracting effects on swimming behaviour patterns of the chub mackerel (Scomber japonicas) and common squid (Todarodes pacificus) by LED luring lam *(by Kyounghoon Lee)*

Since 2010, significant efforts have been made in South Korea to assess greenhouse gas (GHG) emissions in the fishing industry, including offshore fisheries, aquaculture and seafood processing factories. A holistic approach to fishing boat design is being applied that includes energy saving boat design, the use of energy efficient fishing systems including LED lamps, engine systems designed to reduce GHG emissions and efficient seafood transportation and storage systems and processes.

This presentation described an experiment to evaluate the effectiveness of LED lamps to attract chub mackerel held in a large tank. Chub mackerel are commonly caught using a purse seine with metal halide lamps. These lamps are not very efficient, hence, fuel consumption and GHG emissions are relatively high. The LED lamps tested were white (454 and 560 nm), blue (454 nm), red (634 nm), yellow (596 nm), and green (523 nm). A DIDSON acoustic camera was used to observe fish response in the tank. Generally, the blue LED was most effective at attracting the chub mackerel, followed by yellow and then white. Interestingly, red light was more effective than white light during the day, but completely ineffective at night.

Progress of fish luring lamps for squid jigging in China *(by Weiguo Qian, Yingqi Zhou, and Xinjun Chen)*

Squid jigging in international waters by Chinese fleets commenced in earnest in the 1980s and there are now over 400 vessels engaged in this type of fishing in the Pacific, Atlantic and Indian oceans. Approximately 35 percent of the fleet is comprised vessels between 67–78 m while the remainder is comprised of vessels measuring 37–45 m. Around 60 percent of the catch is caught using jigging machines and the remainder by hand jigging. Total landings are over 300 000 tonnes per annum.

The use of underwater fishing lamps (UFL) to target squid in the north Pacific ocean and SW Atlantic ocean commenced around 1997. Midsized vessels are usually equipped with one 5 kW metal halide lamp (MHL) and one 5 kW halogen lamp (HL), while larger vessels may have double this number of lamps. The UFL is lowered to 180–280 m to attract squid and the jigging machines are set to a depth 100 m below the lamps. The use of LED UFLs started around 2005. Green LEDs between 480 W and 1 kW are commonly used now and sometimes operated at depths of 300–400 m. Examples of the measured underwater light field, in terms of illuminance, were presented for a 5 kW MHL.

Metal halide lamps (MHL) are still commonly used as surface fishing lights from these vessels, typically white in colour and 1–2 kW each. To produce a desired shadow zone below the vessel these lamps are located 1–1.5 m inboard from the side of the vessel and 2.5–4.5 m above the deck. Between 40–80 lamps are used depending on the size of the vessel and capacity to generate electrical power with a total power output often in the range of 100–360 kW. A common practice is to “change colour” later in the fishing operation, by switching between MHLs and incandescent lamps (ILs). A typical arrangement onboard is one 500 kW IL to 5–7 MHL. With this changeover, underwater illuminance is decreased and the squid often respond by moving closer to the vessel. Catch rates often increase after this, presumably because a greater number of jigs can be hauled per unit time.

To avoid competition between vessels (and their associated light fields) there is a minimum distance that vessel fishing with lights should maintain between each other. Research has shown that 0.01lux is the minimum response threshold for most squid. Therefore, the optimal distance between vessels will ensure that associated light fields of greater than 0.01 lux should not overlap between vessels. The following relationship is proposed as a way of calculating this optimal distance (Lz):

$$L_Z = 113.54 \times [\mathrm{Ln}(P_1) + \mathrm{Ln}(P_2)] - 111.982 + L_2 + L_H$$

where P_1 and P_2 = electrical power used to illuminate each vessel, L_H = length of cable between vessel and parachute anchor (of the second vessel) and L_2 = length of the second vessel.

In an additional study, the catching efficiency of four diameters of fishing line was tested, 0.75 mm, 0.85 mm, 0.90 mm and 1.00 mm. The premise for this work was that the line diameter may influence catch rates because squids have a well-developed visual ability and therefore, observed lines may affect their response to the jigs. The results found no significant difference in catch rates between line diameters. A further study comparing white and grey fishing line also found no significant difference in catch rates. There was a jig colour preference for many squid species; Japanese common squid (*Todarodes pacifucus*) preferred yellow and green jigs while bright green, light green and light blue were preferred for nylon squid (*Ommastephe bartrami*) and yellow, light green and light blue were preferred by wellington flying squid (*Notodarus sloanii*).

Fishing efficiency of LED fishing lamp for squid jigging and hair tail angling in Korean water *(by Young-il An and Professor Takafumi Arimoto)*

Squid jigging in the Northwest Pacific Ocean has previously been reported to use approximately 1 700 litres of fuel per tonne of landed squid although documented evidence for Korean vessels indicates that this ratio may be doubled at least.

In the Korean coastal squid fishery metal halide lamps, either water or air cooled, are used, as well as LED lamps. In a comparative experiment, catches between a vessel fitted with LED lamps (120 lamps, 300–360 W and 43.2 kW) and vessels fitted with metal halide lamps (80 lamps, 1 500 W, 120 kW) was evaluated. The size of the vessel using the LED lamps was similar in gross tonnage to the smallest vessels using metal halide lamps but had the same number of jigging machines.

From the boat with LED light the average fuel consumption rate was 42.7 litres per hour, or about 2.56 litres of fuel consumed for each individual squid that was caught. The catch rate of squid was slightly lower using the LED (~ 6 percent) lamps but a significant fuel saving was realized; this meant that the installation costs of an LED system would be recovered in just over two years' time.

In a similar experiment targeting hairtail herring, catches between a vessel fitted with LED lamps (70 lamps, 300 W, 21 kW) was compared against multiple vessels using metal halide lamps (70 lamps, 1 500 W, 36–99 kW). Catch rates using the LED lamps were on average 34.7 percent greater than that for the metal halide lamps.

Application of the low-power underwater light to a large scale fish-trap fisher *(by Daisaku Masuda, Shuya Kai, Taisei Kumazaw and Professor Yoshiki Matsushita)*

The large scale fish trap (set net) is considered an efficient and low impact fishing gear that depends largely on fish behaviour. In this presentation research to increase the efficiency of this gear using light at night time was described.

A single 55 W metal halide lamp was attached to a buoy adjacent the leader net and approximately 20 m distant. The lamp was battery powered and located 5 m below the sea surface (water depth was 15 m). Just before sunrise, the lamp was switched off and fish herded towards the main body of the fish trap. A total of 101 hauls were sampled in 2008 with the light on for 46 hauls and light off for the remainder. In 2009, only 23 hauls were sampled, with the light on for 11 hauls, and in 2010 a further 33 hauls were sampled and the light was on for 16 hauls (Figure 21). In 2007, the total catch from this gear was 109 tonnes of which almost 75 percent was comprised of round herring, followed by chub mackerel and jack mackerel. In 2008, squid comprised just over one-third of total catch volume, followed by yellowtails (amberjack) and the total catch weighed 19 tonnes. In 2009, chub mackerel were responsible for about 80 percent of the 108 tonnes of fish that were landed.

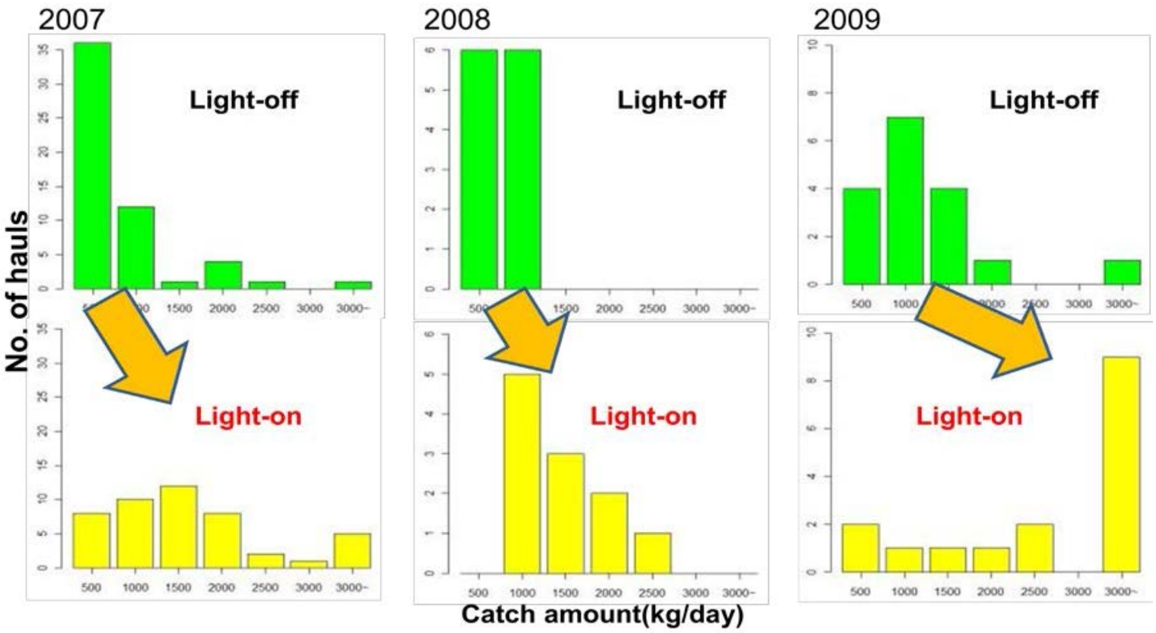


Figure 21: Frequency of daily total catch of the fish trap during illumination and non-illumination

For each year of sampling, catch rates were typically less than 1 000 kg/day when the light was not used and seldom did they increase beyond this threshold. In contrast, when the light was used catch rates were typically above 1 000 kg/day, and sometimes as high as 3 000 kg/day. During all the tested years, annual catches of all fish combined were significantly larger when lights were on. Furthermore, annual catches of round herring and chub mackerel were also always significantly greater when lights were on.

More research on marine optics and fish behaviour are necessary to optimize the light field around the set net, to avoid conflict with adjacent fish-traps and other mobile fishing sectors.

Using artificial light in fish pots to capture flatfish species while excluding snow crab *(by Andrew Murphy, Scott Gran and Rennie Sullivan)*

Following the collapse of ground fishing off the coast of Newfoundland, snow crab emerged in the early 1990s as a viable alternative target species. In the Green Bay region, the turbot fishery using gill nets clashed with the snow crab fishery because it resulted in significant mortality of snow crab (*Chionoecetes opilio*). Ultimately, the turbot fishery was closed and over 600 fishers were displaced.

A viable alternative was sought to resurrect the turbot/Greenland halibut (*Reinhardtius hippoglossoides*) fishery and avoid conflict with the snow crab fishery. The use of modified collapsible fish pots based on the local cod pot design was subsequently considered for testing, and this presentation describes results from these tests. The pots measured 2m × 2m × 1m with a bag of netting on the top to produce greater holding volume for fish. They also were designed with two entrance funnels. Two experiments were designed in depths of 340–530 m over muddy bottom. In the first experiment the effect of funnel design (conical, trapezoidal), trigger spacings (thin metal rods that act as one-way devices with a spacing of 52 mm, 109 mm, 166 mm), trigger diameter (3 mm and

5 mm) and light (presence/absence) was evaluated using baited pots. In the second experiment, the effect of funnel design (conical, trapezoidal) and bait light (presence/absence) was evaluated with 5 mm trigger diameter, 166 mm trigger spacing, and light. A total of 12 pots were used, six trapezoidal (60 cm × 20 cm) and 6 conical (40 cm × 40 cm). Exploratory gillnets were also located to check local fish composition. A light source with two green LED lamps was used powered by 2AA batteries. Soaking time was about 24 hrs.

Catch data is presented in Table 11. From experiment 1, it is clear that the catch of both American plaice and snow crab are significantly higher in pots containing lights. Catch rates of American plaice (*Hippoglossoides platessoides*) were also significantly higher when the trapezoidal funnel entrance was used in comparison the conical entrance. In experiment 2, the absence of bait further increased catch rates when this entrance was used. The presence of bait resulted in no difference in catches of this species when the conical entrance was used. In the case of snow crabs, the presence of bait when using the conical entrance increased catch rates significantly beyond that when bait was not used and when bait or no bait was being used with the trapezoidal entrance.

Table 11: Total catch summary for experiment 1 and 2. Totals indicate numbers of individual finfish and weight (kg) for crabs. The number of pot hauls per treatment is indicated by (n).

Species	Total (Exp. 1 & 2)	Total (Exp. 1)		Total (Exp. 2)	
		Light absent (n = 48)	Light present (n = 60)	Bait absent (n = 18)	Bait present (n = 18)
American Plaice	422	3	265	98	56
Turbot	5	5	0	0	0
Atlantic cod	32	9	17	5	1
Redfish	9	4	3	1	1
Spotted wolfish	4	4	0	0	0
Misc. fish	6	3	2	1	0
Snow crab	1802.0	556.0	948.0	49.0	249.0
Toad crab	12.6	1.6	7.3	2.0	1.7

3.3. SELECTIVITY OF TRAWLS IN MULTISPECIES/CRUSTACEAN FISHERIES (SHRIMP)

Introduction to the SHRIMP session *(by Pingguo He and Bundit Chokesanguan)*

The session was introduced with a primary focus on:

- species and size selectivity – new technologies and approaches;
- future of bycatch reduction in multi-species trawl fisheries;
- alternative fishing practices for tropical shrimp trawl fisheries;
- balanced harvesting vs. selective fishing; and
- social and market implications.

Selectivity was defined as the characteristic of a fishery or fishing gear that retains certain groups of fish by size, species, sex, or other physical or biological factor. Three key factors that influence fishing selectivity are the fishing gear, the fish, and the behaviour of the fishers.

It was noted that in some fisheries, so-called shrimp or prawn trawls do not really exist and in reality these gears are multispecies trawls because of the variety of species landed and the relatively small proportion of shrimp in the catch by volume and/or value. However, in other fisheries there is relatively little or no retention of other species for commercial purposes, although discard levels may still be high and responsible for a large portion of global discards.

Understanding and managing impact on bycatch in Australia's Northern Prawn Fishery *(by David Brewer, Shane Griffiths, Shijie Zhou, Steve Eayrs, Ilona Stobutzki, Rodrigo Bustamante and Cathy Dichmont)*

The main drivers for fishery behaviour both in Australia and elsewhere are food security, income generation and poverty alleviation, individual fishers and their behaviour (often risk adverse), and the industries that depend on fish and fishery products (including bycatch species). The challenges for dealing with bycatch is to get the balance right in terms of food security, income and long-term sustainability, as well as finding the right blend of incentives to encourage fishers to change behaviour.

In Australia, marine research is particularly challenging because the marine management area is the third largest in the world. The bycatch problem in Australia is driven by strong environmental legislation, a desire to achieve ecosystem based management (EBM), international instruments e.g. IUCN red list, international accreditation, and market regulation.

The Northern Prawn Fishery (NPF) currently supports 52 trawlers measuring 14–29 m in length. Annual shrimp landings are around 9 000 mt and are based on ten target shrimp species. The fishery is managed using a blend of input controls including tradeable headrope units and the target is to maximize economic yield, not sustainable yield. As part of legislative and EBM goals the NPF has been striving towards demonstration of (almost) zero impacts on threatened, endangered, and protected species, minimized impacts on all non-target species, demonstrated sustainability of all species that interact with fishing gear and promotion of a partnership approach between the fishery, science and management.

Step one of the bycatch reduction initiative in the NPF was to assess trawl impacts by documenting the range of species encountered by gear. The next step was the development and testing of a range of TEDs and BRDs. This involved a multi-year extension programme that included fishing technologists armed with a variety of TEDs and BRDs being available to showcase the performance of these devices opportunistically during commercial fishing operations. It also provided fishers an opportunity to learn how to rig and operate these devices with support from fishing technologists in preparation of their mandatory introduction in 2 000. This was, however, a particularly challenging time as most fishers were not interested in this gear or reducing bycatch.

In 2001, the performance of several approved TEDs and BRDs was quantified. Overall, the TEDs performed reasonably well with a small loss of shrimp (<6 percent), up to 41 percent reduction in damaged shrimp, up to 8 percent reduction in small bycatch, and reductions in sawfish, large sponges, and turtles by 73 percent, 91 percent, and 99 percent, respectively. The reduction in sharks and rays was 21 percent and 39 percent, respectively.

In addition to TEDs a variety of approved BRDs was permitted for use in the fishery to reduce fish bycatch. Many fishers initially preferred the bigeye BRD to reduce fish bycatch but scientific testing found that it did not perform as hoped; hence, in 2005 it was banned from the list of approved devices. The fisheye or square mesh panel then became the preferred BRD for many fishers. It was found that these reduced bycatch by up to 7 percent compared to a traditional trawl with minimal loss of shrimp catch, but only if placed 120 meshes from the codend drawstring. When located 60 meshes from the drawstring, bycatch reduction increased up to 25 percent with no loss of shrimp. However, fishers were unprepared to relocate their BRD for fear of shrimp loss. Square-mesh codends were also tested in the fishery and found to reduce bycatch by up to 33 percent without shrimp loss while in an adjacent fishery bycatch reduction increased to 44 percent with these codends. The NAFTED, a hybrid grate designed to exclude large animals from the trawl as well as fish bycatch, was developed and performed well, but was ultimately not adopted by fishers. A BRD developed by a local netmaker, called the Popeye fishbox, was tested located 100 meshes and 70 meshes from the drawstring and found to reduce bycatch by 28 percent and 52 percent, respectively with almost no loss of shrimp. At 70 meshes from the drawstring it also reduced sea snake catches by 85 percent - an important result given the protected status of these species, as well as 33 percent and 35 percent for sharks and rays, respectively.

The next step in this process was to ensure long-term sustainability by identifying which species were at risk of overfishing (Figure 22). With this knowledge, BRDs could then be developed or modified to exclude these species or additional management options could be introduced to help ensure their protection. This required a multi-step, qualitative and semi-quantitative (productivity – susceptibility analysis) assessment process including ranking of the presence or absence of a threat, evaluation of the spatial and temporal scale of a threat, and ranking of the consequence of not taking action against a threat. This process is primarily useful to rank species on a relative basis, hence, the next step was to estimate the actual risk to fishing using a quantitative approach based on the proportion of the population actually impacted by the fishery and an evaluation of sustainability based on using a simple population model. This model required presence and absence data for each impacted species in both fished and unfished areas, information about their susceptibility to capture, proportion that escape capture (using BRDs or otherwise), post-capture survival and natural mortality.

The final step was to monitor the impact of fishing on at-risk and other species using fishery independent surveys, observer programmes, and logbook data, and to identify alternative methods to manage species sustainability if deemed necessary.

The Northern Prawn Fishery is a well-managed recognized fishery and has recently received MSC accreditation for sustainability. Key characteristics of this fishery are: an effective governance structure; transparent and accountable management; strong industry leadership; economic prosperity; limited access; strong monitoring, control, and surveillance, and compliance by fishers; an understanding of fishery resource status and system vulnerabilities, and target and reference points in an established assessment framework. However, an artefact of this development in the fishery is that despite modest selectivity, there is now little incentive, enthusiasm, or funding to further refine BRDs and improve performance.

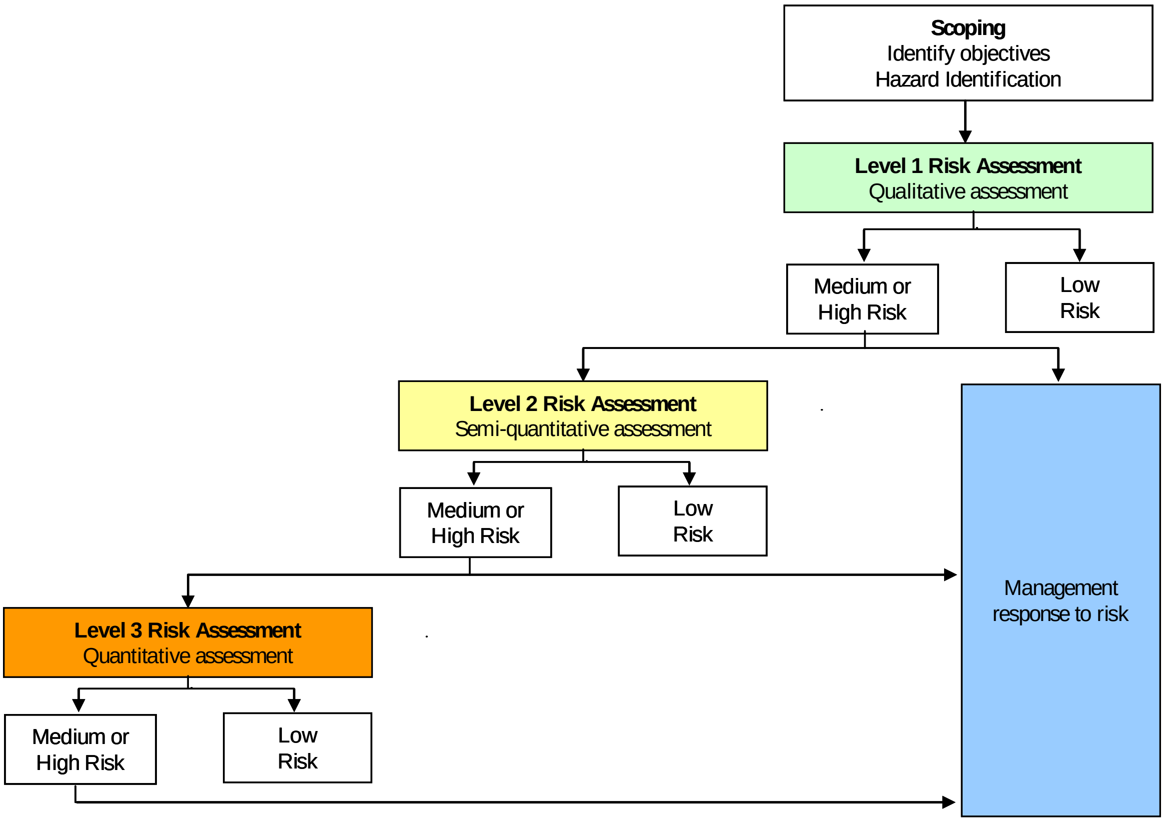


Figure 22: Framework of CSIRO's environmental risk assessment (ERA) to evaluate the risk of fishing activity

Incorporating human dimension in the bycatch management of shrimp/bottom trawl fisheries *(by Petri Suuronen and Daniela Kalikoski)*

The world shrimp catch is about 3.4 million tonnes per year of which about 1.3 million tonnes is derived from tropical shrimp fisheries. There are approximately 400 000 shrimp trawlers globally, many of which are located in Asia where shrimp are an important fishery export. Environmental concerns with shrimp fisheries include capture of large quantities of bycatch, much of which is so-called "trash" fish. Shrimp fishing contributes some 1.9 million tonnes or 27 percent of global fishery discards. It is also a major contributor to changes in species composition, being responsible in some regions for a significant reduction in the abundance of larger and longer lived species and increased biomass of short-lived and faster recruiting smaller species. In many countries, inadequate governance structures have led to failures in the management of shrimp fisheries and this is driven by a highly complex enforcement environment often characterized by:

- a large number of impacted species, fishing vessels and landing sites;
- inconsistent management measures due to lack of consensus between stakeholders, including a reluctance to place demands on poor people; and

- inadequate surveillance and enforcement capacity, due in part to political considerations affecting enforcement priorities and lack of incentives to comply with regulations (which is key).

An additional issue many of these fisheries contend with is conflict between large-scale industrial fisheries and small-scale fisheries. Industrial trawlers frequently encroach on banned inshore areas, remove significant volumes of shrimp and other animals, destroy nursery grounds, and damage fishing gear that belong to small-scale fishers. Industrial trawlers may also produce large volumes of discards that may be the target species of small-scale fishers. In small-scale fisheries, fishers often take immature shrimp and other fish and in doing so impact directly on the recruitment of these animals into the fishery.

BRDs are effective options to reduce fishing mortality of juvenile fish and non-target species, however, in many fisheries, including multi-species shrimp/bottom trawl fisheries in Southeast Asia, the uptake of these devices has been weak or non-existent. The development and testing of these devices has focused heavily on their technological performance, but relatively few efforts have focused on the human and institutional context of BRDs. There is also little scientific knowledge regarding how fishers respond to BRDS and their attitudes towards these devices. Key outstanding questions include:

- What are the incentives for fishers to use these devices?
- How does the social-political context and market forces affect the willingness of fishers to accept these devices?
- What are the key areas for further research?

This is a major shortcoming because the acceptance of technological solutions does not occur in a social or cultural vacuum. Furthermore, consideration is required to understand how to motivate fishers to change. Therefore, there is a need to consider that:

- Fishers need to be involved in management of the fishery, and management actions should focus on desirable, possible, and practical solutions.
- Management programs need to be adaptive, and make continuous improvements rather than consist of top-down regulations that are not performance based.
- Regulations are needed to provide incentives to reduce bycatch and disincentives to continue unsustainable fishing practices.
- Alternatives are needed to the common practice of vessel owners paying crew from the sale of bycatch.

A suggested approach for consideration was adaptive co-management, whereby fishers and other key stakeholders work together to improve the regulatory process. Advantages of this approach include congruence between rules and the condition of the resource, enhanced sense of ownership encouraging responsible fishing, increased monitoring and compliance with regulations, agreed sanctions to rule breakers (including social sanctions), an arena to solve conflicts and recognition of fishers' rights. Another option is consideration of market forces and certification schemes, especially as many shrimp fisheries in the developing world rely upon international trade. Overall, an ecosystem approach to fishing (EAF) is required to bring stakeholders together and to work together to sustainably manage the fishery with due consideration of the social context.

Research on bycatch of shrimp trawl fishery in Arafura Sea: volume, reduction devices and utilization of discarded bycatch *(by Ari Purabayanto)*

In Indonesian waters, Presidential decree No. 39/1980 banned the operation of trawl nets; however, a trawl fitted with a bycatch excluder device (BED) or turtle excluder device (TED) is permitted in the Arafura Sea. Despite the requirement for these devices, discarding of large volumes of bycatch remains a problem.

This presentation described research conducted in 2004–11 to quantify the composition of bycatch in the Arafura Sea, and then find solutions to reduce or utilize the bycatch. Based on observer data it had been found that more than 10 kg of bycatch was landed for every 1 kg of shrimp and total bycatch was estimated to be 332 186 tonnes per year.

In 2004, several devices were tested to reduce bycatch including the Super Shooter (SS) TED and the JTED. The SS reduced bycatch by 5 percent when bar spacing was 12 cm and 60 percent when bar spacing was 4 cm, while the JTED excluded 33 percent of fish bycatch. In 2007, the SS, a square-mesh window (SMW), and a fisheye (FE) were tested; all devices resulted in a shrimp loss of over 20 percent while bycatch reduction performance for the SS, SMW, and FE was +5 percent, -6 percent, and -13 percent respectively. Fishers were questioned about the performance of each device, including ease of operation and their acceptability, and the SMW and FE scored 27 from a total of 40 points compared to 20 points for the SS.

Instead of discarding bycatch, consideration was given to the utilization of these animals through the development of a community-based fish processing industry producing surimi and peptone. The first step in developing these products was testing a Suritech fish meat and bone separator onboard a shrimp trawler. On average, it was found that meat recovery was 34 percent and meat-bone separating volume was just over 60 kg/hour, being based on the effort of two crew (Table 12; Figure 23).

Table 12: Performance of the Suritech meat-bone separator of bycatch

Species	Fish sample wt. (kg)	Minced fish (kg)	Sample wt. to minced wt. ratio	Separation time (min)	Separating rate. (kg/h)
Threadfin bream	4.03	1.57	0.39	3.64	69.13
Grunter	3.50	1.15	0.33	3.35	62.81
Sulphur goat fish	3.90	1.20	0.31	4.51	52.65
Croaker	5.00	1.70	0.34	5.10	58.82
Average	*4.12*	*1.41*	*0.34*	*4.15*	*60.86*

While the use of the SS is obligatory in this fishery, violation by fishers is common due to low awareness and low enthusiasm and both weak management control systems (MCS) and law enforcement. Efforts to utilize bycatch continue as is viewed as a positive step to overcoming the problem of discards, as well as, contributing to local food security and poverty alleviation.

Figure 23: The fish meat-bone separating process

Selectivity of five codend designs to improve size selectivity for deep water rose shrimp (Parapenaeus longirostris) in the Aegean Sea *(by Adnan Tokac, Huseyin Ozbilgin and Hakan Kaykac)*

Bottom trawling is very important in Turkey, being responsible for approximately 90 percent of demersal fish production. Poor selectivity, however, is a major problem with a wide variety of fish species (>50) being caught in addition to shrimp.

This presentation described an effort to evaluate the selectivity of five different codend designs using a covered codend approach. The commercial codend was constructed from 40 mm PE and measured 300 meshes in circumference (300 MC). The experimental codends included a 200 mesh circumference codend constructed from 40 mm PE (200 MC), a codend constructed from 40 mm PE with a circumference comprised of 150 meshes in the bottom panel and 75 square meshes in the top panel (SMTPC), a codend constructed of 48 mm PE measuring 275 meshes in circumference (275 LMC), and a square mesh codend constructed of 40 mm PE measuring 150 meshes in circumference (SMC). A total of 50 valid hauls was completed.

The minimum landing size for shrimp is 20 mm, however, the L50 length for each codend was substantially lower; the L50 for the commercial codend was only 12.06 mm (Figure 24). The selection range for the SMC was lowest and relatively knife-edged. None of the modifications tested was deemed sufficient to achieve the goal of sustainable shrimp exploitation, and larger mesh sizes should therefore, be considered. However, with concerns over loss of marketable fish, research in this direction should also focus on species selectivity.

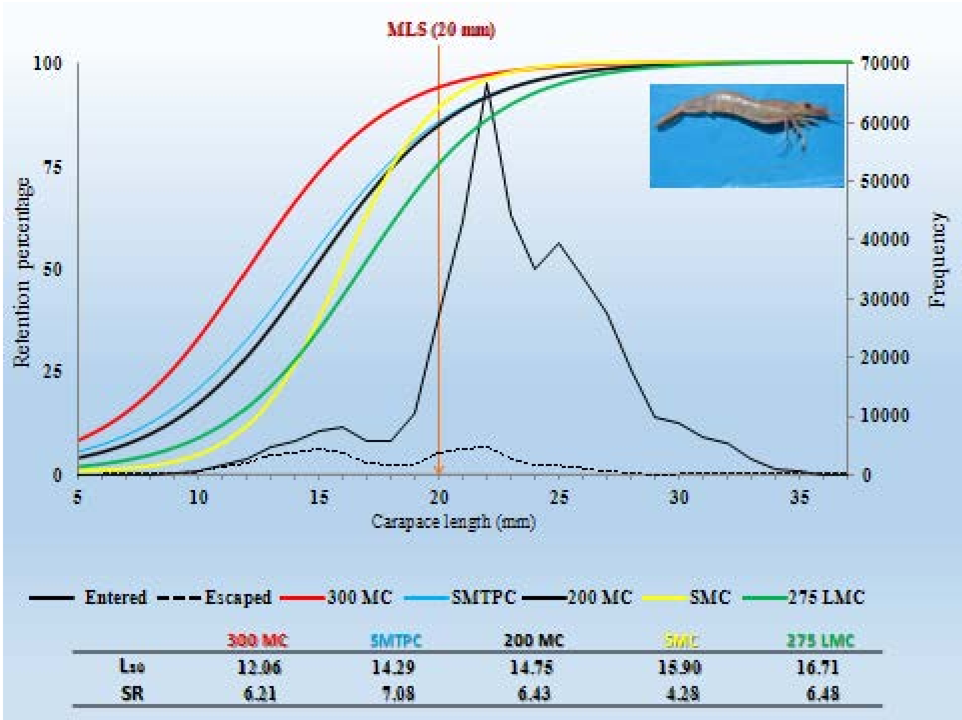


Figure 24: Shrimp selectivity characteristics for each codend type in the Aegean Sea

Discard ratio of fish and shrimp trawls in the North Eastern Mediterranean *(by Gökhan Gökce, Ahmet R. Eryasar, Yeliz D. Ozbilgin, Adem S. Bozaoglu, Ebrucan Kalecik and Huseyin Ozbilgin).*

In the Mediterranean Sea approximately 728 fish species have been identified and many fisheries are subsequently characterized by their multi-species nature. Fisheries in the region are usually managed using effort controls and closed areas.

This presentation described an effort in 2009–12 to understand fisheries and their problems in the Mersin region of Turkey by observing fishers and their fishing operation and sampling of the catch (Figure 25). A total of 91 days was spent at sea during this time, during which a total of 136 species were identified; 73 species were retained and the remainder were discarded. The dominant species

Figure 25: Catch sampling

by weight included red mullet (17 percent), crab (10 percent), tiger prawn (5 percent), cuttlefish (5 percent), pony fish (4 percent), lizard fish (4 percent), karamote shrimp (3 percent), horse mackerel

(3 percent), and jellyfish (3 percent). All species were retained by fishers except for pony fish, jellyfish, and crab. Almost half the catch by weight is discarded; in the case of red mullet, approximately 71 percent by number are less than the minimum landed size and yet only 6 percent of these fish are discarded by fishers – the remainder being retained for sale. Similarly, 67 percent of landed lizardfish and 70 percent of tiger prawns are below the minimum landing size and most are also retained for sale. Overall, around 47 percent of the total trawl catch from this region is discarded by fishers, although this varies between 7 percent and 94 percent.

Systematic research on northern shrimp trawls to reduce discard *(by Pinnguo He)*

Northern shrimp trawls are very similar to fish trawls in design with the exception of smaller mesh sizes. The issue is to modify this trawl to retain shrimp, but not fish bycatch and this presentation described a number of efforts to achieve this goal.

The possibility of lifting the doors or lower bridle off the bottom is an option given there is no requirement to herd fish into the trawl and shrimp are not herded. Testing this option in 2004 indicated shrimp catch was at least comparable to catches when bottom tending doors were used. Floating bridles were also tested and found to significantly reduce catches of flounder, hake and redfish, but not shrimp.

Another option was a topless or upside down trawl created by removing the square and much of the upper panel (Figure 26). The shrimp catch remained unchanged, but there were significant reductions in herring but not whiting and flounders (American plaice and winter flounder), presumably because these species are typically located close to the seabed. The proportion of shrimp in the catch increased from 70 percent to 90 percent as a result of this modification. The Nordmøre grid was tested located in the extension ahead of the codend, and further modified by the removal of all netting ahead of the grate – the grate and codend were attached to the trawl via thick ropes (Figure 27). With this modification, the shrimp catch was largely unchanged, while catches of silver and red hake and flounders were significantly reduced.

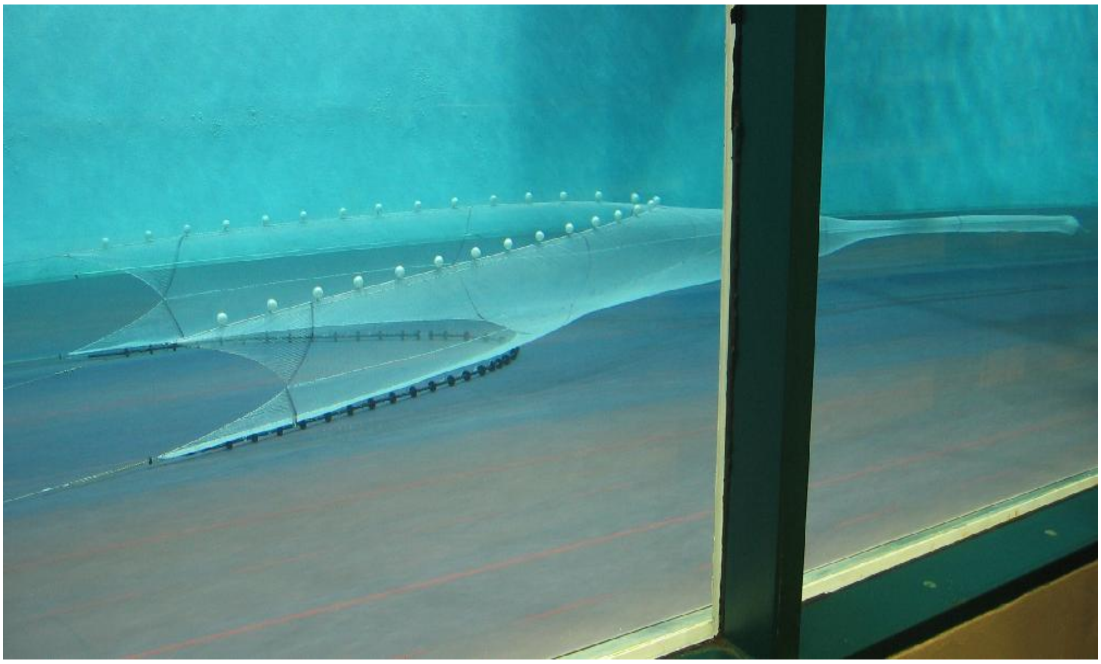


Figure 26: The topless trawl tested in a flume tank

Figure 27: The rope grid

When shrimp trawling collides with crab fisheries: a case study from Newfoundland, Canada *(by Truong Nguyen, Paul Winger, George legge, Earl Dawe and Darrell Mullowney)*

There is a concern that declining catch rates of snow crab could be due to the effects of shrimp trawling on snow crab fishing grounds. The purpose of this research was to use a trawl mounted video camera to observe the interaction of snow crab with shrimp trawl footgear (Figure 28). Observations were recorded over a three-day period and a total of 15 tows of 1–2 hours duration. Fishing depth was around 214 fathoms.

Figure 28: Image of crab immediately prior to encounter with the foot gear

Almost all observed crab were located on the surface of the seabed (92.9 percent) and the remainder were either in the mud (6.8 percent) or unknown (0.4 percent). Most observed crab were walking just prior to interaction with the footgear (86.8 percent), and the remainder were either not walking (11.8 percent) or unknown (1.5 percent).

The proportion of observed crab that collided with the footgear was 52 percent. Just over 25 percent of crabs did not collide with the footgear and passed between the rubber discs, while most of the remaining crab moved outside of the field of view and their fate was unknown. Of those crabs that collided with the footgear, the duration of collision was typically less than one second before they fell out of view (90 percent) and for most of the remainder the duration of collision was 1–10 seconds (8 percent). Almost 95 percent of all crabs that collided with the footgear passed underneath the footgear and remainder over the footgear and into the trawl.

The mean orientation of observed crab relative to the centre of the footgear was 193 degrees (towing direction = 0 degree) while their mean direction of movement over the seabed was two degrees. With a high proportion of crabs colliding with the footgear, there is a need to develop suitable trawl modifications to mitigate any adverse impacts on snow crab.

Fjord fishing: Trawling for shrimp and commercial sized cod *(by Eduardo Grimaldo)*

The shrimp fishery in the fjords of Norway is prosecuted by small vessels. In the 1960s and 1970s there were hundreds of small boats involved in this fishery, although a substantial portion of the catch was large finfish. Using small mesh nets there were also substantial catches of small fish requiring considerable sorting time. In the 1990s, the sorting grid was introduced into the fishery. In recent years, the fishery has been characterized by low profitability, few and old boats, few processing plants and few young or new fishers entering the fishery.

To improve profitability, consideration was given to reducing operating costs including catching two commercial species simultaneously and using highly efficient semi-pelagic trawl doors to reduce fuel consumption. An experiment was subsequently developed to place a cover net over the escape opening immediately ahead of the Nordmøre grid. This way large cod could be retained in the cover net while shrimp pass through the grid and enter the codend. The cover net was constructed from 135 mm square-mesh netting to allow small fish to escape (Figure 29).

Figure 29: Square-mesh cover net with a catch of cod

Nine test tows were completed with a towing time of 2.5 to 5.0 hours. The cod catch varied between tows but with one exception was an order of magnitude greater than the shrimp catch by volume. Such an approach has meant that the cod catch sometimes comprised up to 60 percent of total catch income. Furthermore, simultaneous landing of these two species has meant a considerable reduction in fuel consumption, thus, further increasing the profitability of fishers, as well as reducing seabed impact.

The promotion of responsible trawl fishing practices in Southeast Asia through the introduction of Juvenile and Trash Excluder Devices (JTEDs) *(by Bundit Chokesanguan and Suppachai Ananpongsuk)*

This presentation described the design, construction, and experimentation of the JTED over many years with support by the Japanese Trust Fund and by FAO/GEF. Four types of JTED were initially developed: a rectangular shaped window JTED; a semi-curve window JTED; a rectangular rigid sorting grid JTED; and a semi-curve rigid sorting grid JTED (Figure 30).

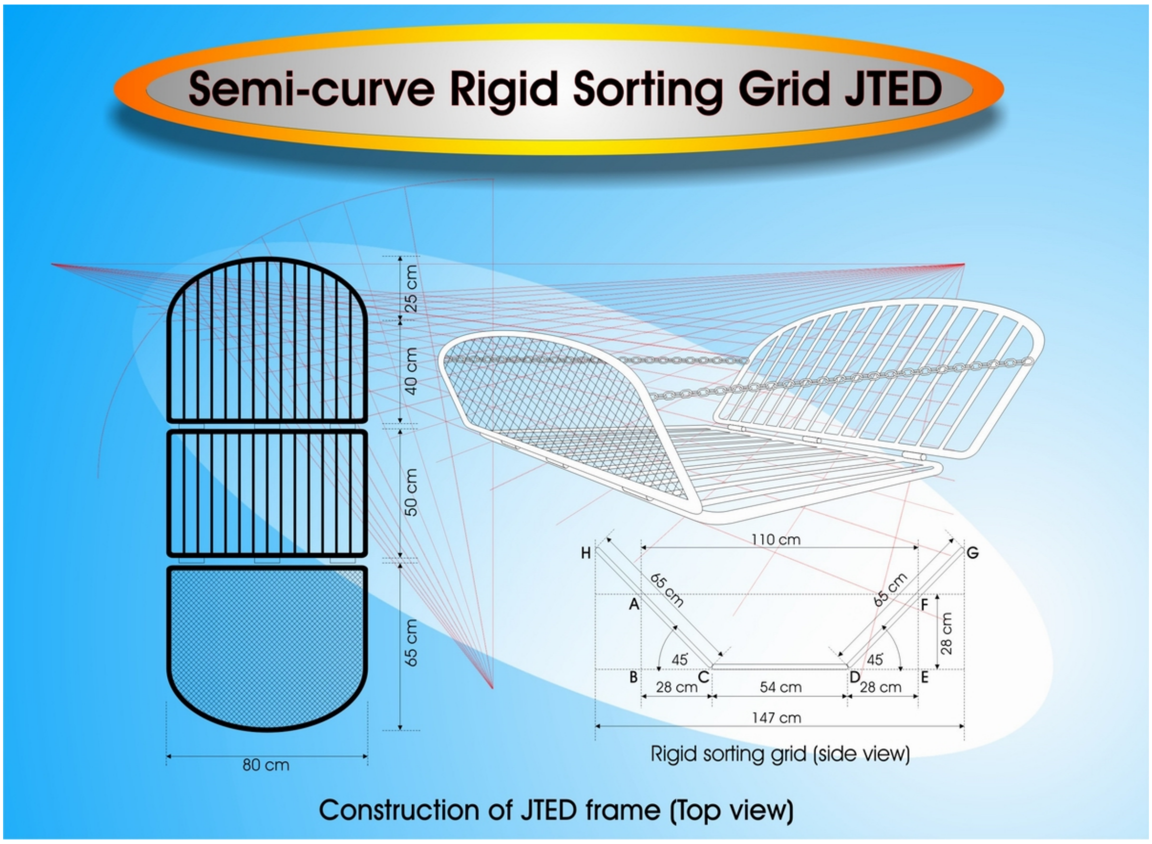


Figure 30: The Semi-curve Rigid Sorting JTED tested by SEAFDEC

After initial flume tank testing, at sea tests were carried out in Thailand, Brunei, Vietnam, Malaysia, Indonesia, Philippines, Myanmar, and Cambodia between 1998 and 2004. The results were compiled to produce short reports by country and then compiled to produce a full paper documenting all tests and outcomes. Considerable outreach efforts were also taken, including demonstrations at sea, workshops, training exercises and videos.

Overall the results suggest that JTEDs with a bar spacing of 1.2 cm and 2.0 cm perform well to reduce the capture of juvenile fish, although continuing modification is required to optimize performance

(Table 13). A need to encourage fishers to change their attitude and improve their fishing operation by using the JTED is also recommended.

Table 13: Performance of various JTEDs. RS = rectangular shaped grid, Rec – rectangular window

	RS 1	RS 1.2	RS 2	RS 3	Rec 1	Semi 1
Juvenile escape rate (%)	56.7	71.0	77.0	74.3	68.5	61.1
Commercial fish escape rate (%)	9.7	11.0	16.0	50.3	46.7	47.3

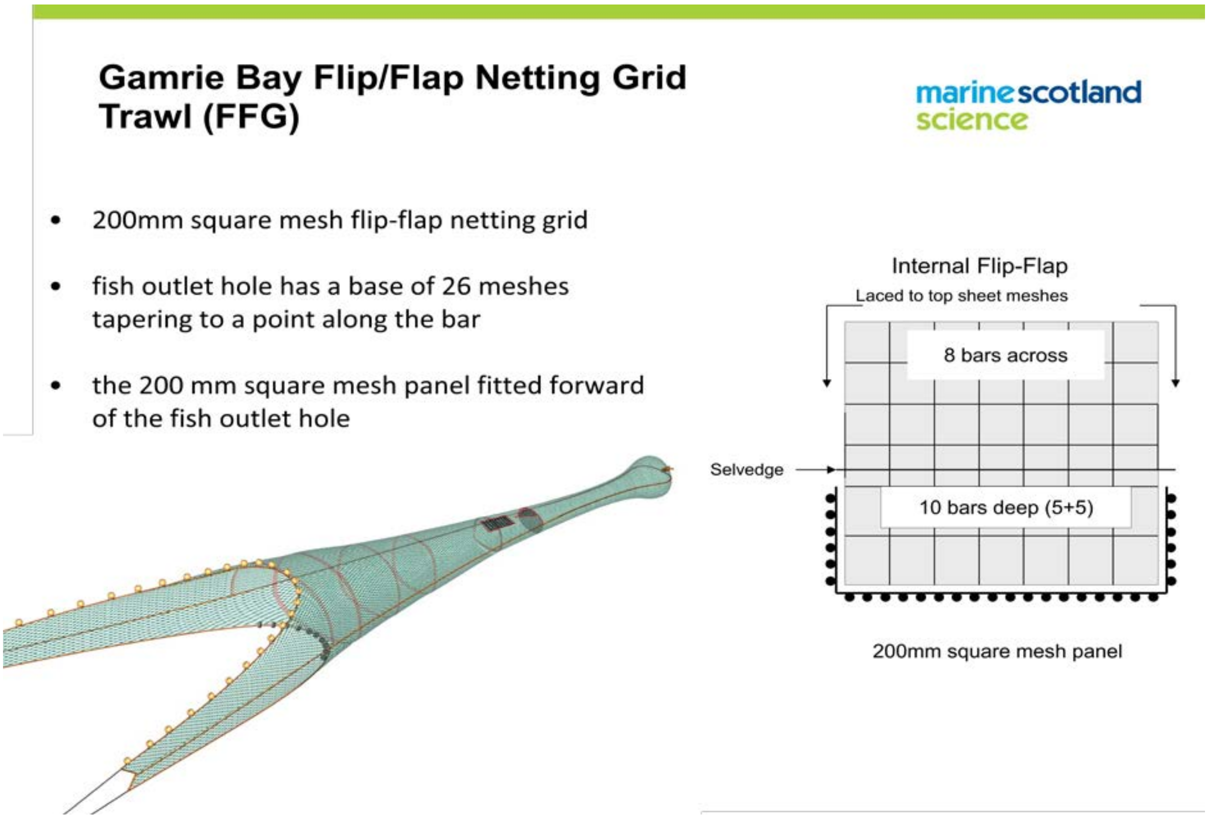
Netting grid in Nephrops trawls to reduce the capture of cod in the North Sea *(by Barry O'Neill, Rob Kynoch, Jim Drewery, Alex Edridge and Jim Mair)*

The Nephrops (Norway lobster) fishery lands around 25 000 tonnes of product annually valued at around GBP84 million making it Scotland's second most valuable fished species. Trawling is responsible for Nephrops landings valued at approximately GBP70 million while the remainder is derived from landings using creels, especially from in shore waters on the west coast. Nephrops are limited to regions of muddy sediment, the adults are relatively sedentary and the live in burrows most of the time except for feeding and mating.

The trawl fishery for Nephrops is a mixed species fishery that also lands cod, haddock, whiting, monkfish, and megrim. This fishery has been substantially impacted by the EU's cod recovery plan. In Scotland, the cod recovery plan was addressed by the Scottish Conservation Credit Scheme which included measures to reduce cod discarding through the introduction of spatial/temporal closures, the use of CCTV cameras to ensure no discarding of cod, and the use of highly selective gears that reduced cod catch by 60 percent compared to standard gear. Nephrops fishermen however, also wanted to retain all Nephrops, as well as monkfish and megrim.

This presentation described the development of an industry-led gear programme that included initial gear design and trials by net makers and fishers, the use of industry observers (employed by the fishers' federation) to carry out more detailed trials, scientific trials of the most promising gears by Marine Scotland in collaboration with fishers, and a final report sent to the EU Commission for approval. Two gears were subsequently approved for use in the fishery and are currently being used by the fleet. One gear is the Flip Flap Grid trawl (FFG) and the other is Faithlie Cod Avoidance panel (FCAP), both of which involve the use of netting grids in the extension piece (Figure 31).

The FFG is comprised of a vertical panel of 200 mm square-mesh netting and the top half is sewn into the trawl from selvedge to selvedge while the lower half acts as a lead-weighted flap. There is a triangular fish outlet in the top panel of the net immediately ahead of the vertical panel that measures 26 meshes along the base and tapers along the bars to a point. There is also a 200 mm square-mesh panel (window) immediately ahead of the fish outlet hole that measured 8 bars × 10 bars. The FCAP 2 is a 300 mm square-mesh slightly inclined panel that has two escape holes ahead of the panel and a square-mesh panel behind the panel. (FCAP 0 and FCAP 1 were earlier versions of the FCAP that produced positive results, but did not achieve the 60 percent cod reduction target).



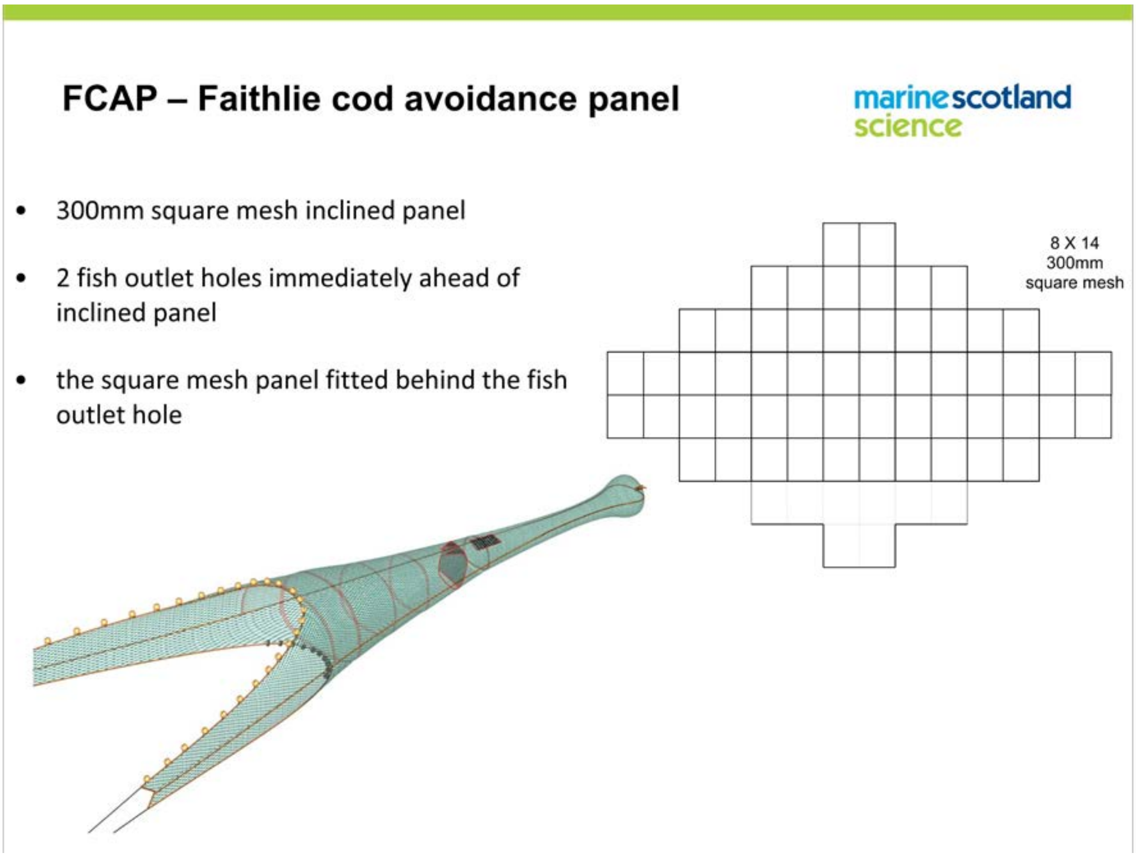


Figure 31: The two grids designed to reduce cod from Nephrops trawls

The escape holes were trapezoidal in shape measuring 28 meshes across the based, tapered along the bars, and nine meshes across the top. The base of the fish outlet holes covered over 50 percent of the circumference of the top panel.

Sea trials occurred in 2011 and 2012 using a twin trawl so that a standard (control) and experimental net could be tested simultaneously. The FFG reduced the catch of cod, haddock and whiting by 73 percent, 67 percent, and 82 percent, respectively, although larger individuals were more likely to escape than smaller individuals. The commercial catch of Nephrops, monkfish and megrim was reduced by 4 percent, 13 percent, and 11 percent, respectively. The FCAP 2 reduced the catch of cod, haddock, and whiting by 62 percent, 74 percent, and 66 percent, respectively and again larger individuals were more likely to escape than smaller individuals.

Both gears are now being used by fishers to meet EU requirements, in part because this was an industry-led process that had sufficient feedback mechanisms and flexibility to permit the development of an effective gear modification.

Development of sorting grids for Norway lobster fisherie *(by Niels Madsen, Rikke Frandsen, Jordan Feekings and Ludvig A. Krag)*

There are a variety of challenges facing fisheries in the Kattegat-Skagerrak area. In Kattegat, Norway, lobster is now the most important following a massive decline in the cod stock. In Skagerrak, Norway lobster is also most important although the fishery lands a variety of other species. Discard levels are commonly high and while the cod stock is healthy the quota is low. In this region, a discard ban will be introduced in 2014 in line with EU requirements.

Grids are widely used in the Kattegat-Skagerrak area by Swedish fishers, but they are not liked by Danish fishers due to handling problems and loss of Norway lobsters and other important species. Efforts were made to overcome these problems by bringing together net producers, makers and fishers. This included the development of a flexible grid to overcome problems winding rigid grids around net drums. Efforts also included increasing bar spacing from 35 to 45 mm, tests using a grid with horizontal bars and escape gaps at the bottom of the grid to minimize clogging of the grid by debris while retaining Norway lobster and flatfish (Figure 32).

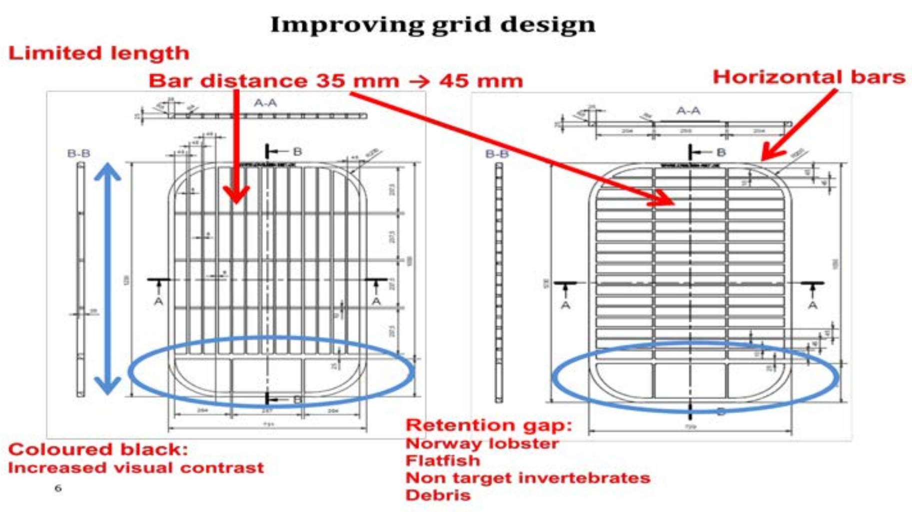


Figure 32: Modifications to the grid to improve performance (DTU Aqua, Technical University of Denmark)

This presentation described the results of tests with the horizontal grid and a vertical grid with and without a guiding panel ahead of the grid (Table 14).

The ability of Norway lobster to escape was found to be very dependent upon their orientation as they encountered the grid. While the handling concern was largely overcome by the development of the flexible grid, further improvement is needed to optimize grid performance. Consideration of adjustment in bar spacing and grid length is required, plus ways to manipulate Norway lobster orientation to the grid and reduce problems of clogging by animals and debris.

Table 14: Proportion of Norway lobster, cod and plaice that passed through the escape openings and each location of the grid, by grid type

Grid type	Location	Norway lobster		Cod		Plaice	
		<MLS (%)	>MLS (%)	<MLS (%)	>MLS (%)	<MLS (%)	>MLS (%)
Horizontal bars	Escape opening	5	24	88	83	59	77
	Upper grid	10	13	4	1	9	4
	Lower grid	38	19	3	2	11	4
	Escape gap	47	44	5	14	20	14
Vertical bars	Escape opening	17	25	85	89	79	92
	Upper grid	26	19	5	2	3	1
	Lower grid	27	22	3	1	1	1
	Escape gap	30	33	7	7	17	6
Vertical bars + guiding panel	Escape opening	6	13	50	53	35	46
	Upper grid	9	9	7	1	2	3
	Lower grid	21	12	5	0	6	2
	Escape gap	64	67	38	46	58	50

REBYC-II CTI Project – Strategies for trawl fisheries bycatch management in Southeast Asia and Coral Triangle region *(by Isara Chanrachkij (SEAFDEC) and Petri Suuronen (FAO))*

This presentation described a new four-year collaborative project involving Indonesia, Papua New Guinea, Philippines, Thailand, Vietnam and SEAFDEC. The project encompasses a region that includes much of the Coral Triangle region and a part of the South China Sea. Supported by GEF (Global Environmental Facility) and FAO, this project will attempt to mitigate problems associated with bycatch in fisheries in this region, in particular that by multispecies bottom trawling. It aims to promote sustainable fishing, encourage adoption of best fishing practices and provide a rational approach to delivering benefit from landed catch. The total budget for this project is US$11 million of which US$3 million is GEF funding with the remainder derived from the executing governments.

In this region, fisheries are highly important and provide employment and livelihoods, economic growth, and food security. Trash fish has become important for livelihoods as demand for feed in aquaculture operations and surimi products continue to increase. However, management of fisheries in this region is complex and includes issues such as the take of juvenile fish and poor fisheries management. This project has four main components:

1. The policy, legal and institutional frameworks component will strive toward the establishment of national or area specific trawl fishery management plans and building institutional capacity for their implementation.
2. The resource management and fishing operations component will develop more selective fishing gear and practice, provide a basis for implementation of fishing area zones and spatial-temporal closures, take steps toward a better understanding of fishing effort in the region and develop recommendations for fishing effort and capacity management.
3. The information management and communication component will include bycatch data collection, mapping of fishing grounds, establishment of socio-economic monitoring procedures, and means for communicating bycatch data and information. Standardized methods of bycatch data collection will be promoted across project countries.
4. The awareness and knowledge component will address trawl fisheries bycatch management issues and how they relate to sustainability and evaluate what measures are required to make fishing more responsible. Fishers, policy makers, fishery managers, officials, extension offices and NGOs will be offered training to enhance their knowledge on best management practices and responsible fisheries.

This project also aims to facilitate change by seeking a balance between environmental wellbeing and human wellbeing and the specific goals are:

- Minimizing the catch of juvenile fish and other animals.
- Minimizing the catch of species at risk from trawling.
- Minimizing discards.
- Avoiding the negative impacts of trawling on habitats.
- Improving the utilization of catch through value adding.
- Increasing the resilience of coastal livelihoods.

Key challenges to the success of this project include sufficiently motivating fishers to take steps to protect and manage fishery resources. The private sector, including fishers, processors, retailers and other stakeholders, is expected to participate in this project and aid in the development and adoption of best practices, the creation of adequate incentives and the promotion of responsibly harvested seafood from trawl fisheries. Project outcomes are expected to include:

- Critical barriers for executing responsible fishing activity understood and addressed through appropriate community support measures.
- Incentives for fishers to change defined and implemented.
- Institutional arrangements and processes for public and private sector partnership in place.
- Appropriate harvest strategies available.
- Cost effective measures adopted to reduce the catch of species of concern by 20 percent.
- Improved data on catch composition and the condition of sensitive fishing grounds collected through standardized methods across all project countries.
- Agreed regional trawl management plans.

Introducing a RIHN project (Coastal area capability enhancement in Southeast Asia) *(by M. Yap and S. Ishikawa)*

Conservation International has identified 34 global hotspots, many of which are located in sub-tropical and tropical latitudes. They cover only 2.3 percent of Earth’s land surface, but more than

50 percent of the world's plant species and 42 percent of terrestrial vertebrate species. Furthermore, coastal waters cover 8 percent of the total marine area, but accounts for one-third of total marine productivity and Southeast Asia holds the greatest marine biodiversity. In this region, millions of people rely upon local productivity and biodiversity. However, misuse of habitats, overexploitation, illegal activities, ineffective use, and pollution are current issues that limit full value being derived by local ecosystem services. The imbalance between limited habitats and resources and the complexity of coastal activities has led to a mismatch between ecosystem features and current management. In short, a new ecosystem evaluation methodology and governance model is necessary based on coastal area capability (Figure 33).

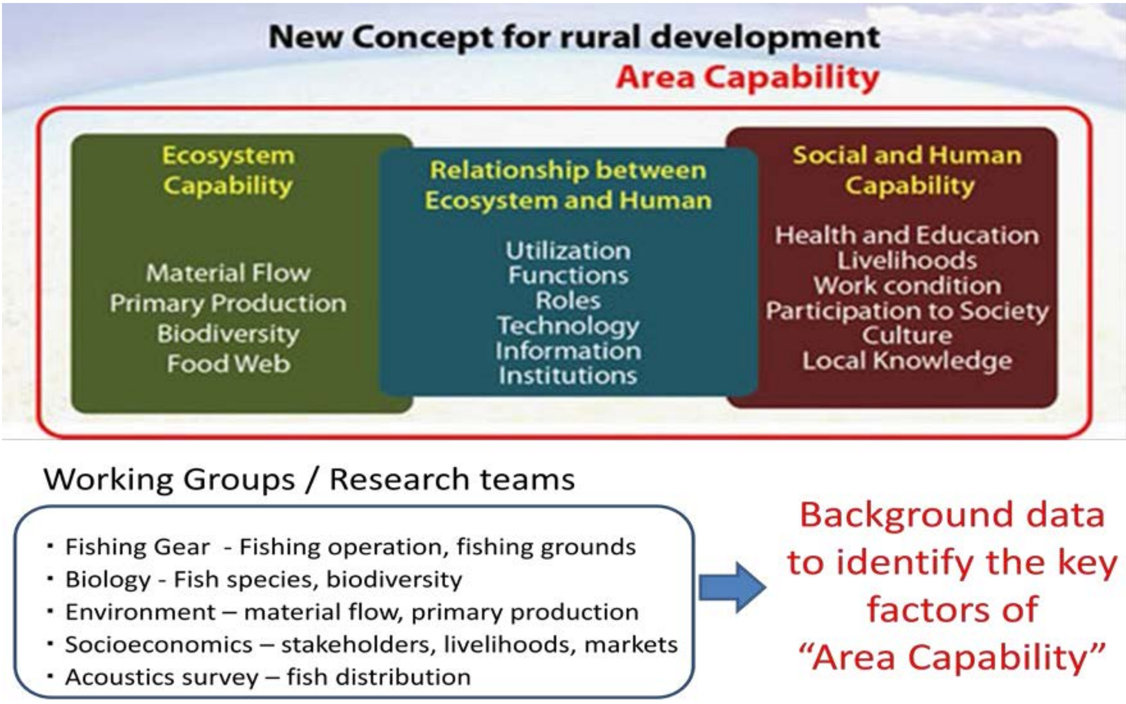


Figure 33: The ecosystem evaluation methodology and governance model

Coastal area capability is about linking and valuing the link between ecosystem capability and social-human capacity. This presentation described planned efforts by about 100 researchers from Japan, Thailand and the Philippines to achieve the goal of identifying local issues, constraints and potential of tropical coastal regions and finding opportunities to enhance area capability for local communities and government institutions. To identify the key factors of area capability a number of working groups and teams have been established. For example, the mission of the fishing gear team is to establish a database of fishing gear, boats, and operations, compare set-net and non set-net fishers and to analyse the relationship between fishing operations and weather conditions. A variety of methods will be used including interviews with fishers, log-book analysis, GPS records of fishing boats and analysis of weather data.

The next step is to adapt area capability into governance involving both local communities and governmental institutions and several case studies have been selected to evaluate the potential to achieve this outcome. The community based set net fishery in Rayong, Thailand is one important case study and the ideal coastal management framework involves strong linkage, dialogue, and information exchange between stakeholder groups (Figure 34).

The assessment and success of this project will be based on a blend of outcomes that characterize ecosystem health, human capabilities, social capital, and utilization of ecosystem services. Elements of each characteristic will be selected but it remains unclear at this time which elements will be important or used to describe the success of the project.

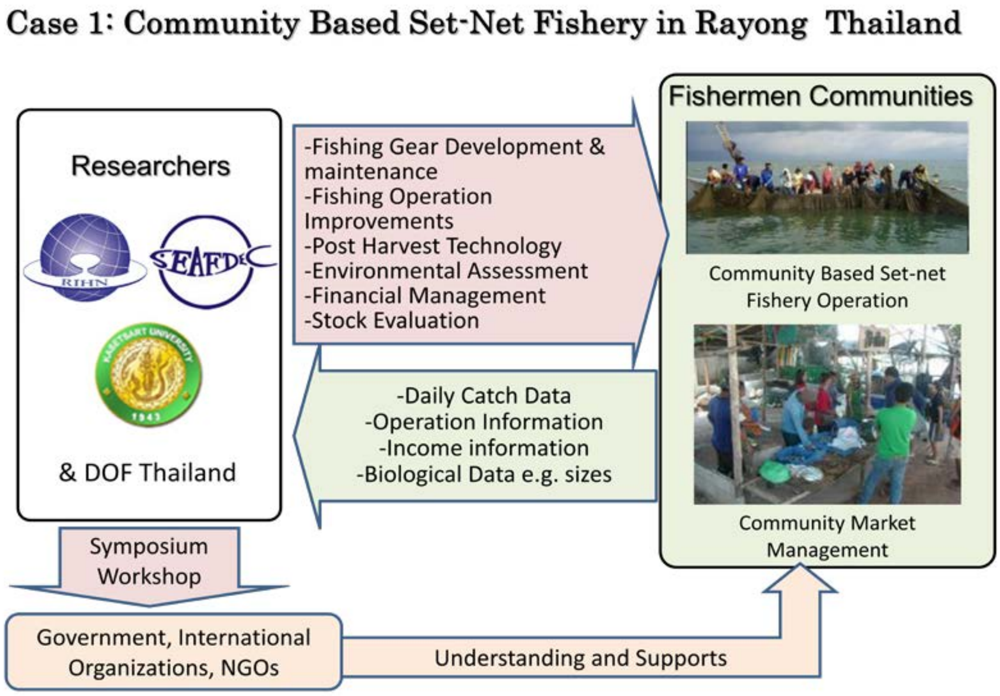


Figure 34: Proposed coastal management framework

3.4. FTFB OPEN SESSION

Understanding size selectivity in diamond mesh codends based on flume tank experiments and fish morphology: effect of catch size and fish escape behaviour *(by Junita D. Karlsen, Ludvig A. Krag, Bent Herrmann and Kurt Hansen)*

Size selectivity is influenced by mesh geometry, fish morphology, and fish behaviour, and has been found to be positively correlated to codend catch size, primarily due to changes in mesh geometry. Once inside a trawl, selectivity of fish occurs primarily in the codend, with relatively few individuals escaping through meshes elsewhere in the trawl. As catch increases codend shape changes and meshes in some located in the codend are widened. However, further forward, mesh geometry narrows for a given catch weight. The selection of fish from a codend can be found by:

$$A_s = P_s \times F_b$$

Where A_s (actual selection) is the proportion of fish that escape through codend meshes, P_s (potential selection) is the proportion of fish that are morphologically capable of penetrating a mesh and do penetrate the mesh and F_b (fish behaviour) is the proportion of fish that could have escaped but are found in the catch. Hence, by utilizing this expression it is possible to evaluate fish behaviour in the codend and exploit this behaviour to improve selectivity.

The aim of the study was to quantify size selection in three dimensions along the codend and describe plausible fish behaviour in the codend based on size selection data. Data was collected from tests in a flume tank and fieldwork at sea.

Codend mesh geometry was measured in five different positions in a flume tank over a range of simulated catch weights (0 kg, 350 kg, 700 kg). Morphological data were collected based on the cross section of cod and penetration simulations using the FISHSELECT software permitted the calculation of L50 values at selected positions along the codend. Linear interpolation was used to describe fish size selection for catch weights not tested in the flume tank. Testing was achieved based on two behavioural scenarios: (i) that there is uniform escape rate in all directions along the codend; and (ii) most fish escape ahead of the accumulated catch. A covered codend experiment was then performed in Skagerrak in a commercial setting. Codend mesh size was 90 mm and a total of 13 hauls were completed at 2.8 knots.

When catch weight was 350 kg and 700 kg, flume tank and fish morphology results indicated that mean L50 decreased as distance from the aft end of the codend increased (toward the trawl mouth) (Figure 35). There was little difference in mean L50 values between these two weights at any given measured position along the codend. There was little difference in mean L50 values at any position when catch weight was 0 kg. The greatest measured difference in mean L50 between any weight was at the position closest to the catch.

Based on results from the covered codend experiment the relationship between mean L50 and catch weight is described by a curve that reaches an asymptote when catch weight was around 300 kg (Figure 36). The line describing this relationship based on scenario: (i) and the flume tank and fish morphology model poorly fit the fieldwork data and substantially underestimated this relationship, although testing scenario; (ii) indicated a better fit. Testing the model at lower catch weights (100–200 kg) indicated a better fit to the fieldwork data. The key implication of this work is that catch weight has significant implications for size selection and that measurements based on lower catches compared to those in the commercial fishery can seriously underestimate size selection in the aft end of the codend.

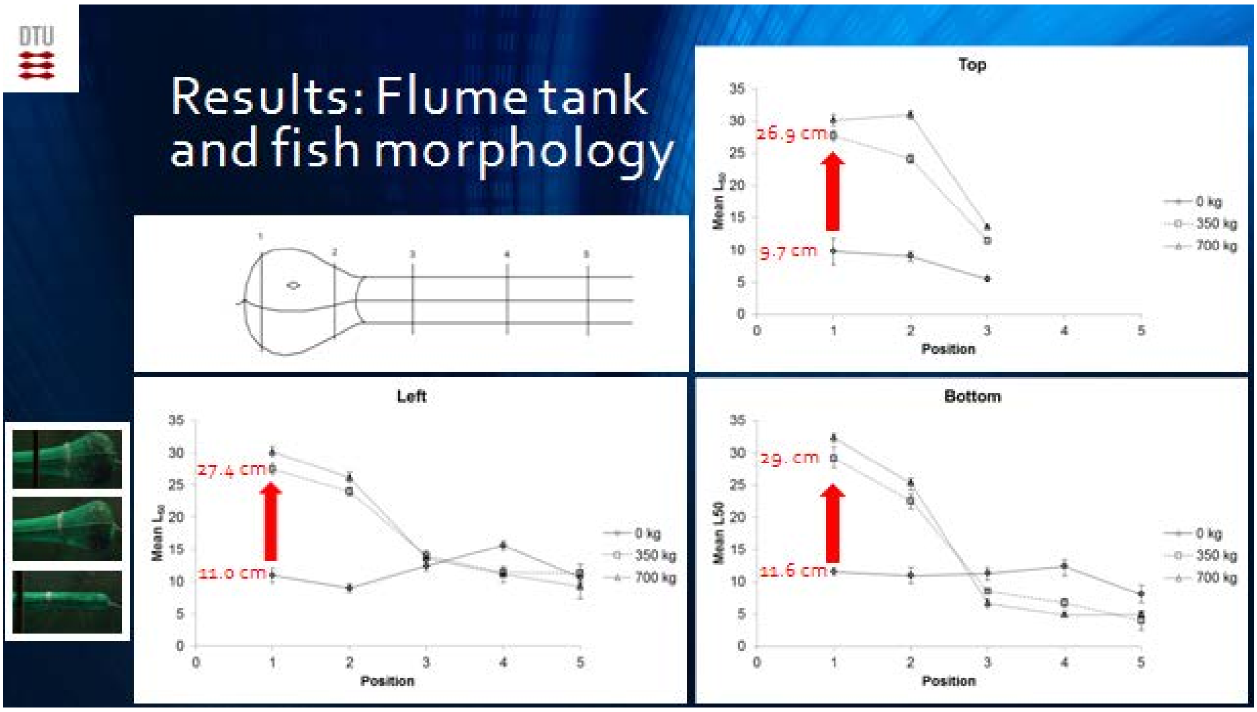
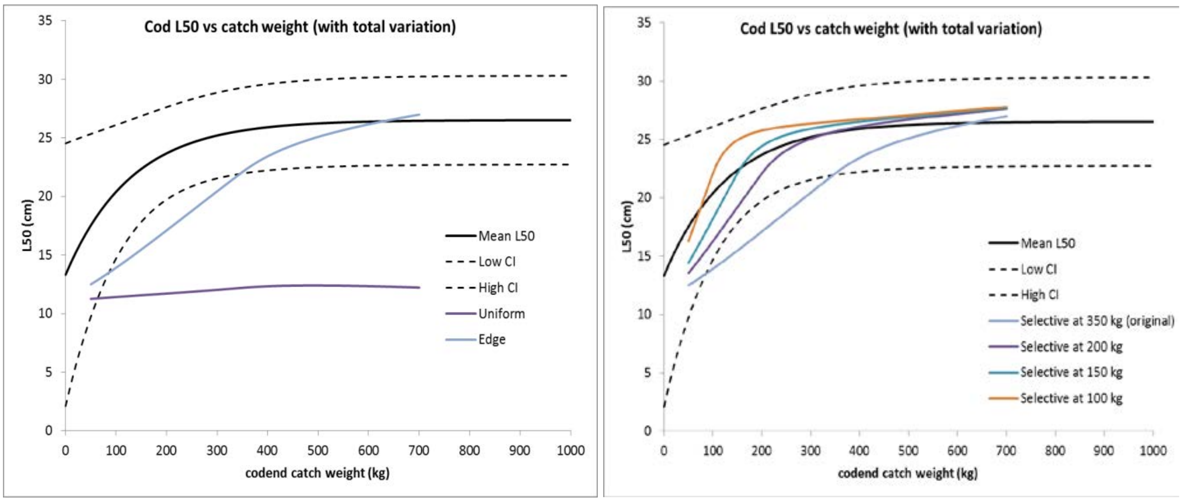


Figure 35: Mean L50 values for 5 positions along a codend for three simulated catch weights



(a) (b)

Figure 36: (a) Cod L50 values based on fieldwork catch data (black curve) and flume tank and morphological data. The mean L50 values are based on assuming escape in all directions (uniform) or from immediately ahead of the accumulated catch (edge); (b) Mean L50 values based on interpolated data.

Observations of fish behaviour during trawling operations in the Eastern Mediterranean *(by Yeliz Doganyilmaz Ozbilgin, Ebrucan Kalecik, Adem Bozaoglu, Ahmet Raif Eryasar, Gökhan Gökce and Huseyin Ozbilgin)*

A recent project in Turkey focused on: (i) quantifying catch and discards during trawl operations; (ii) fish behaviour in response to trawl stimuli; (iii) methods to improve size and species selectivity;

and, (iv) outreach of results to stakeholders. In an effort to improve understanding of fish capture and selection underwater video cameras were used to observe fish behaviour. This also included capturing images of behaviour in response to a super shooter grid and a fisheye BRD.

Over 100 days data from 224 hauls was collected in depths from 3–100 m. Approximately 637 hours of video was recorded. A variety of camera systems were used, in particular GoPro cameras given their size and image quality at depths up to 45 m.

Video images of trawl gear and fish behaviour were demonstrated. An important image was that of tracks from trawl doors from an earlier tow. A point was made that camera use requires time and patience, and that often many hours of footage are taken for only a few minutes of usable footage.

Can we save toothfish, killer whales and fishermen together? *(by Gerard Bavouzet, Fabien Morandeau, Sonia Mehault and Jean Roullot).*

This project brought fishers, scientists, and NGOs together to tackle the problems of opportunistic depredation by killer whales and sperm whales of baited longline hooks and to control bird mortality linked to longlines, while preserving the Patagonian toothfish resource. To achieve these goals efforts were taken to test a variety of conical, rectangular, floating, and bottom tending fish traps in a flume tank and then in coastal waters. Tests were then conducted on commercial fishing grounds near the Crozet Islands in the southern Indian Ocean. Depth sensors were attached to the pots and low light cameras to observe pot performance and fish behaviour.

A total of 985 toothfish were landed (Figure 37) weighing just over 12 000 kg from 3 244 pot hauls. However, crab bycatch numbered over 26 000 individuals (approximately eight per pot haul). The foldable fish pot demonstrated promise by catching more toothfish than the rigid pot. Importantly, there was no bird mortality or whale depredation of catch while using the pots.

Figure 37: Toothfish caught in a test pot

Swimming performance of fish in capture process simulation examined by EMG/ECG monitoring and muscle twitch experiment *(by Mochammad Riyanto and Takafumi Arimoto)*

The swimming performance of fish during the trawl capture process is a function of their swimming endurance and speed. In turn, these affect the catchability of fish and the selectivity of the trawl. Electrocardiogram (ECG) and Electromyogram (EMG) monitoring, respectively provides an opportunity to evaluate the change in heart rate and muscle power output of a fish over a range of swimming speeds. Collectively, this information provides an insight into the physiological condition of fish at a range of towing speeds. Muscle twitch experiments can also be used to evaluate the maximum swimming speed of fish and their potential ability to escape capture.

This presentation reported on an experiment that included holding jack mackerel in a tank for one week. Anaesthetized individuals then had two copper electrodes inserted in the pericardial cavity to enable ECG monitoring. An electrode was also inserted in the white muscle to enable EMG monitoring. These individuals were then placed into a swimming flume tank and water speed was systematically increased every ten minutes from 1.6 to 6.2 fork lengths/second (FL/s) in increments equivalent to 0.8 FL/s. A high-speed video camera was used to observe swimming behaviour and tailbeat frequency.

In the case of a jack mackerel measuring 19.8 cm FL, heart rate was steady up to a swimming speed of around 3.0 FL/s and little different to the resting heart rate of 40 beats/minute. At higher swimming speeds the heart rate reached 100 beats/minute at just over 4.0 FL/s and peaked at a little below 130 beats/minute at 5.0 FL/s. The white muscle was activated at just over 4.0 FL/s and peaked at just over 100 pulses/minute at around 5.0 FL/s. At higher speeds both heart rate and EMG pulse decreased, indicating that peak swimming performance (maximum sustained swimming speed) had been reached. During the recovery phase (zero speed) it took 300 minutes for heart rate to return to the initial resting heart rate. Similar changes in heart rate and EMG were recorded for other individuals, indicating that heart rate change and EMG change can be useful indicators of maximum performance. After testing a range of individuals the maximum sustained swimming speed was found to be around 4 FL/s. Observations with the video camera indicated that this corresponded to a tail beat frequency of around 6 Hz.

A muscle twitch experiment was conducted on jack mackerel at temperatures of 10, 15 and 22 degrees Celsius (Figure 38). A strain gauge was inserted into the musculature and electrically stimulated by a 3 volt, 2 ms pulse. An oscilloscope was used to record the muscle contraction time which is the duration between the stimulus pulse and the peak muscle contraction time. This was repeated at five longitudinal locations along the length of each fish (Figure 39). From this data, the maximum swimming speed could be determined.

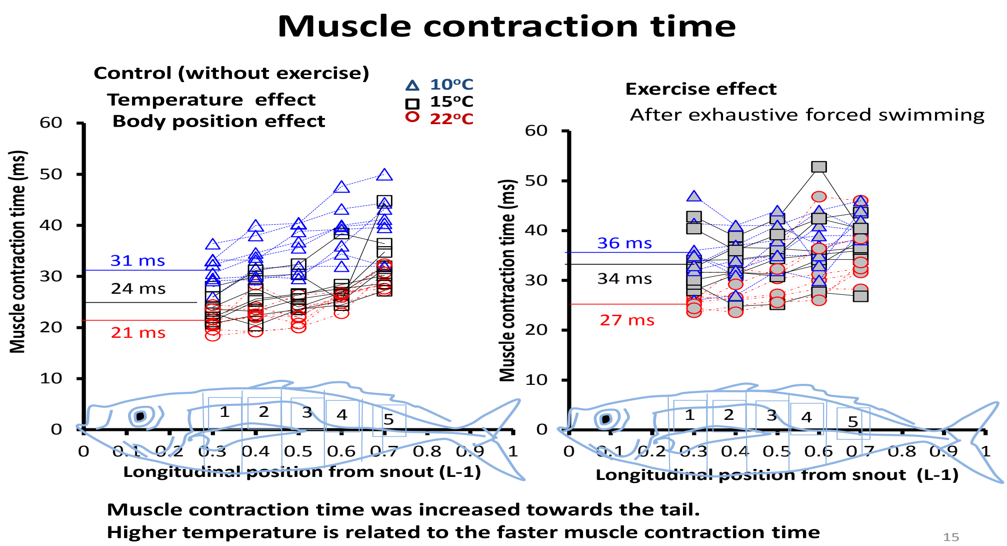


Figure 38: Muscle contraction time for jack mackerel at different water temperature

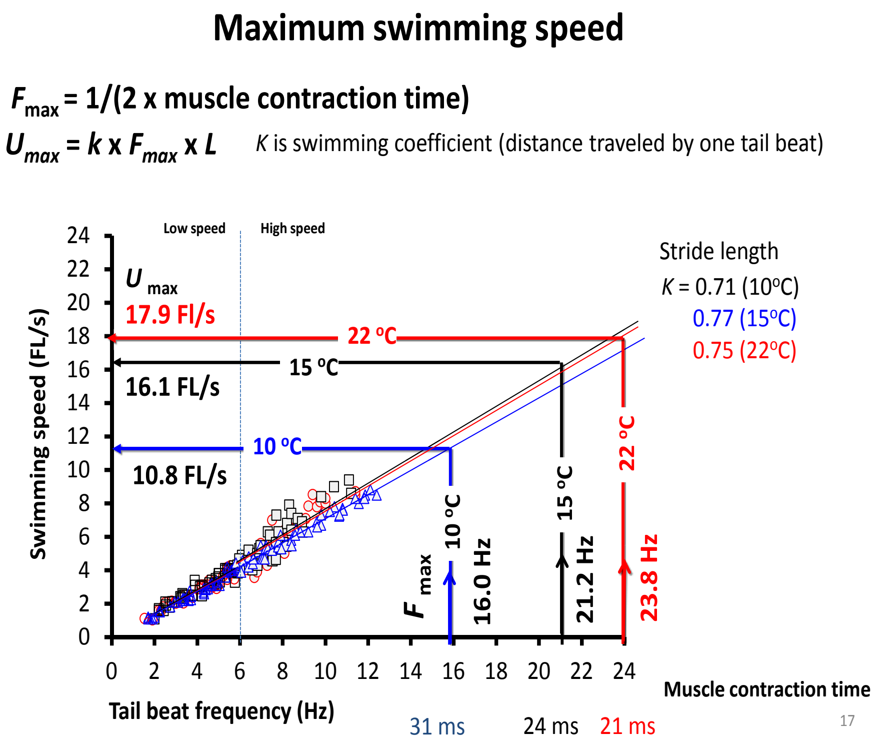


Figure 39: Maximum swimming speed (U_{max}) by maximum tail-beat frequency (F_{max}) for jack mackerel at different water temperature (in control)

Improvement of size selectivity and short-term commercial loss in the eastern Mediterranean demersal trawl fishery *(by Huseyin Ozbilgin, Ahmet Raif Eryasar, Gökhan Gökce, Yeliz Doganyilmaz Ozbilgin, Sezai Bosaoglu and Ebrucan Kalecik)*

A recent project in Turkey focused on: (i) quantifying catch and discard; (ii) fish behaviour to gear; (iii) methods to improve size and species selectivity; and (iv) outreach of results to stakeholders. In an effort to improve trawl selectivity, an experiment tested four different codend types. These included a 44 mm diamond mesh codend (D44), a 50 mm diamond mesh codend (D50), a 40 mm square mesh codend (S40) and a new and increasingly popular, loosely twisted, hand-knitted 44 mm diamond mesh codend (CD44).

Catch data was collected from a total of 87 valid hauls in depths from 15–141 m. Tow duration was between 80 and 220 minutes and towing speed was 2.3–2.8 knots. A covered codend was used to collect animals that escaped through the meshes of each codend.

Data were pooled for each codend type. Total length was recorded for fish and carapace length for shrimp. A total of 91 species were landed, of which 31 are marketable species. In all instances the use of the square mesh codend resulted in the loss of commercial landings compared to the hand knitted diamond mesh codend although L50 values when using square mesh either approached or surpassed the MLS for each species. The use of larger diamond meshes in the codend increased the L50 value of tiger prawns and speckled shrimp; the use of square-mesh did not improve the L50 of tiger prawns (Table 15).

Table 15: L50 values for common species retained by each codend, with minimum landing size indicated. There is no MLS for prawns or shrimp although length at first maturity is 3.6 cm and 2.1 cm for tiger prawns and speckled shrimp, respectively.

Species	**MLS (cm)**	**L50 (cm)**			
		CD44	**S40**	**D44**	**D50**
Red mullet	13.0	8.24	13.94	8.66	12.24
Lizardfish	16.0	7.83	24.50	24.16	29.69
Common pandora	15.0	7.90	13.00	11.29	14.59
Goldband goatfish	10.0	5.37	16.34	12.13	-
Threadfin bream	-	6.11	14.50	12.04	11.61
Tiger prawn	-	-	2.14	2.19	2.72
Speckled shrimp	-	1.54	2.19	1.85	2.20

An evaluation of the relative income using each codend indicated that the landed value of the S40, D44, and D50 codends was reduced by 17 percent, 9 percent and 21 percent, respectively compared to the knitted codend. While the other codends significantly improve selectivity they resulted in short-term loss of income and are not favoured by fishers and attempts to introduce these codends may require fishers to be compensated for the loss.

Test of the rope separator haddock trawl on Georges Bank, Northeast US *(by Chris Rillahan, Pingguo He and Vincenzo Russo)*

The classic behavioural model of cod and haddock is based on cod remaining near the seabed when approached by a trawl while haddock rise upwards. With the addition of a horizontal separator in a trawl it is conceivably possible to separate each species, thus, retaining one while allowing the escape of the other.

There is currently little uptake of this type of gear in the fishery. However, interest in such gear is changing primarily because of changing groundfish allocations as allocations of pollock, cod, and winter flounder have decreased substantially is recent years. Allocations of haddock have also done likewise although the percentage of haddock landed by fishers in the 2012–13 fishing year was only 4 percent of the total allocation. In this environment, a move to use fishing gear to avoid catches of pollock, cod and winter flounder while maintaining catches of haddock is an increasingly desirable option.

Using a flume tank, a rope separator trawl was developed with large openings in the bottom panel to facilitate escapement of bottom dwelling fish. The ropes extended horizontally between seams of the trawl in the trawl mouth (Figure 40). The ropes were used for ease of use and to avoid meshing of fish in netting panels.

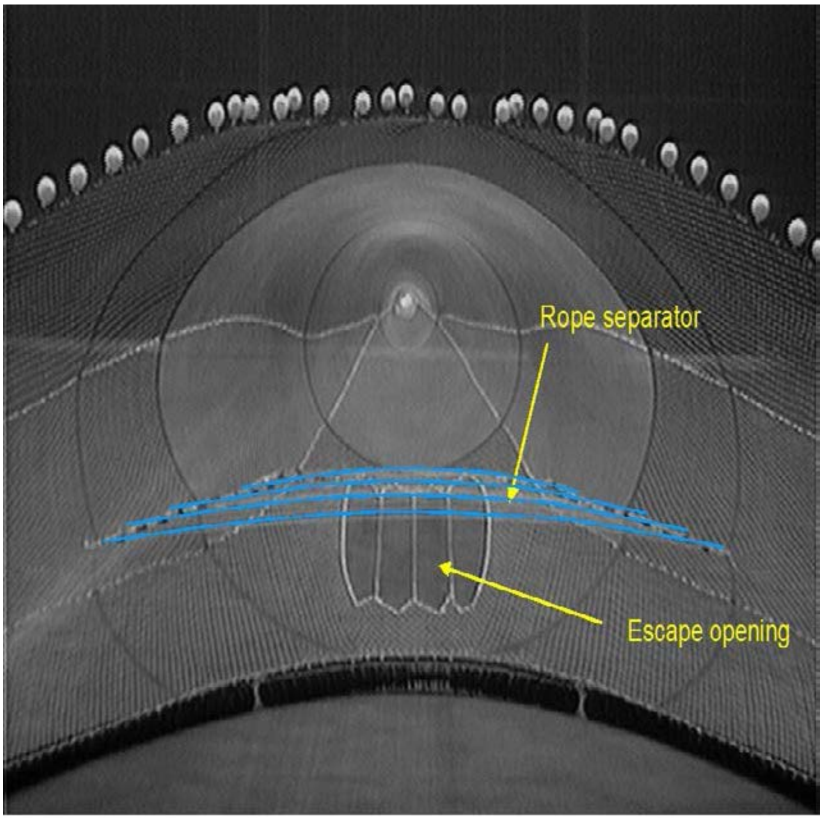
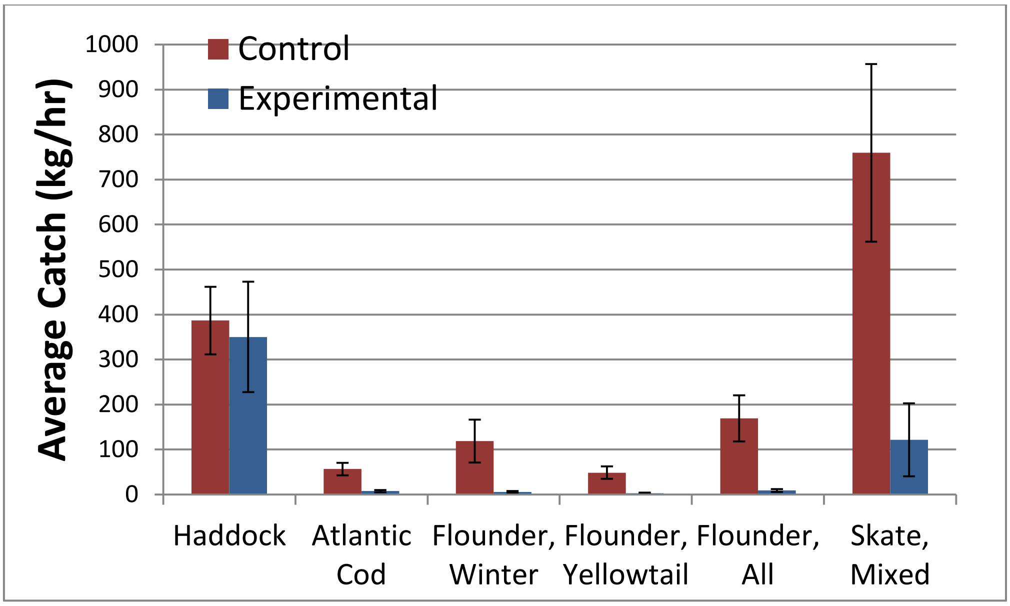


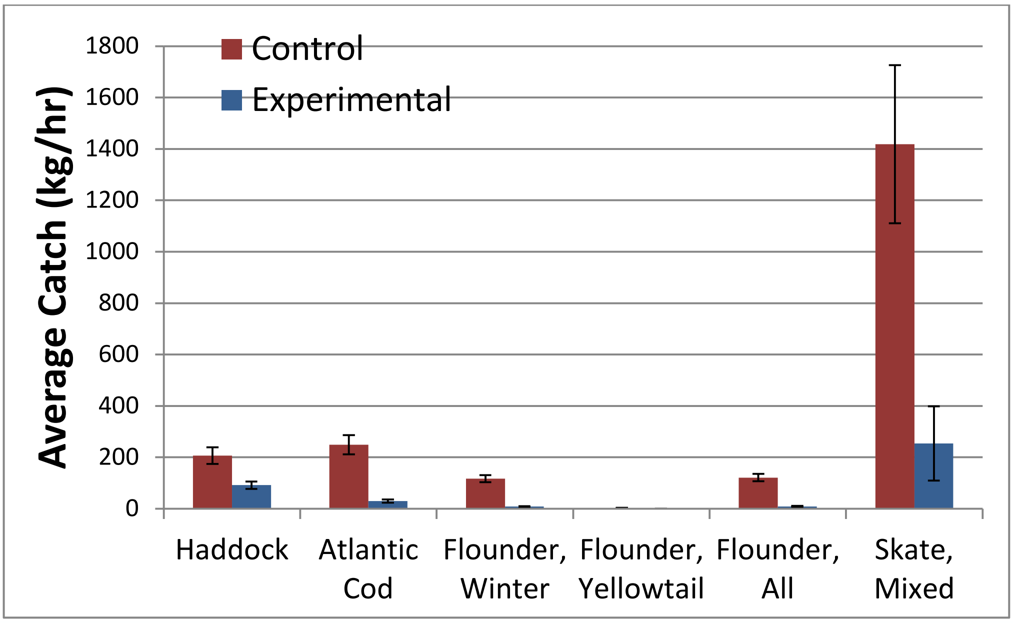
Figure 40: The rope separator haddock trawl

Three fishing trips were completed between May 2011 and 2012 and an alternate haul technique was used comparing the separator trawl against a standard, control trawl over a total of 16 days. The experimental trawl had slightly higher headline height and door spread. Separator height was 1.8 m. The experimental trawl performed well although the catch was dominated by skates (Figure 41).

The large haddock reduction in 2012 compared to 2011 was primarily due to a significantly greater proportion of undersized haddock in the catch in 2012. There was no significant reduction in legal sized haddock, but there was in sub-legal haddock. Non-target catch was reduced by 84 percent while catches of cod, flatfish, and skates was reduced by 88 percent, 93 percent and 82 percent, respectively. The captain and crew had little problem using the trawl.



% reduction	9.5%	86.5%	95.1%	94.0%	94.7%	84.0%
p-value	0.146	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001



% reduction	55.7%	88.1%	93.2%	89.4%	92.8%	82.1%
p-value	0.0183	<0.0001	<0.0001	0.005	<0.0001	0.003

Figure 41: Catch results in 2011 (upper) and 2012 (lower)

3.5. CONCLUDING REMARKS

A primary objective of the ICES-FAO Working Group on Fishing Technology and Fish Behaviour (WGFTFB) is to provide stimulus and to foster dialogue and collaboration between the countries and various actors to address key aspects of fish capture technology and contribute to the sustainable exploitation of global fisheries resources. This work takes great advantage of synergies resulting from the global nature of the working group.

The WGFTFB meeting and mini-symposia held on 6–10 May 2013 at the Southeast Asian Fisheries Development Center (SEAFDEC) in Thailand was a significant step in expanding the coverage of the global network of fishing scientists and technologists and in discussion of problems associated with achieving sustainable exploitation practices of fishery resources. The presentations and discussions demonstrated that a significant body of research and development is being dedicated to the development of responsible and sustainable fishing technologies around the world and major advances are being made across a variety of fishing gear types and propulsion systems in both developed and developing countries to reduce the environmental impacts and fuel consumption of fish capture processes. Alternative gears and practices, as well as fish stimulation through light and electricity offers great potential for a change.

The poor uptake of sustainable fishing practices was identified as one of the major issues that have to be addressed more effectively. Better understanding is needed to understand what motivates people to a change and how to trigger these changes in behaviour. We need to better understand the motivation for change and how to make the change permanent. We have to accept that better outreach opportunities are required and that successful gear development project should extend to the uptake by fishermen. Win-win solutions and outcomes for the environment and fishermen will have to be found.

This document contains the report of the Symposium on Impacts of Fishing on the Environment arranged by the ICES-FAO Working Group on Fishing Technology and Fish Behaviour (WGFTFB) held in Bangkok, Thailand, from 6 to 10 May 2013. The Symposium was attended by more than 130 fisheries experts from 25 countries, and it provided an opportunity for fishing technologists and others from ICES member countries to exchange knowledge and ideas with contemporaries from around the world, especially Asia. The symposium comprised three one-day sessions: (i) low-impact and fuel-efficient fishing gear (LIFE); (ii) use of artificial light as a stimulus on fish behaviour in fish capture (LIGHT); and (iii) selectivity of trawls in multispecies/crustacean fisheries (SHRIMP). This report summarizes the presentations of the Symposium and concludes the main discussions. This report also summarizes presentations from the open session of the annual WGFTFB meeting.

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