Advances in Fishing Technology: Mitigating the Impacts of Fishing Operations on Coastal and Marine Environments

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Recently, a strong movement has taken place worldwide to minimize the impacts of fishing activities on coastal and marine environments, and put an end to the over-exploitation of the fishery resources. Many factors are held responsible for the current dismal state of the world's fisheries including excessive fishing effort and the exploitation of immature fishes that seek food and protection in shallow coastal areas. Likewise, the continued capture of unwanted fish (by-catch) is contributing to acute reduction of fish stocks. FAO has been working closely with SEAFDEC through its Training Department (TD) in promoting responsible fishing technologies and practices in the Southeast Asian region, specifically towards reducing by-catch and discards from fishing operations. Through such cooperation, TD has served as collaborating partner in the implementation of projects such as the Reduction of Environmental Impact from Tropical Shrimp Trawling through the Introduction of By-catch Reduction Technologies and Change of Management (REBYC-I), and the subsequent project that focuses on the Coral Triangle region of Southeast Asia (REBYC-II CTI). The successful implementation of the REBYC projects prompted FAO to organize in 2013 the annual ICES-FAO WGFTFB Meeting for the first time in Southeast Asia instead of convening it in the temperate regions. This article displays the advances in fishing technology that were presented and discussed during the meeting of WGFTFB which was organized on 6-10 May 2013 at the TD premises in Samut Prakan, Thailand.

In order to pave the way for addressing issues that impede the promotion of sustainable and responsible utilization of fishery resources, and minimizing the impacts of fishing activities on the environment, the Food and Agriculture Organization of the United Nations (FAO) and the International Council for the Exploration of the Sea (ICES) established in 2002 the Working Group on Fishing Technology and Fish Behavior (WGFTFB). Specifically, the Working Group aims to foster dialogue and collaboration among member states in addressing issues on fishing technology and fish capture for the sustainable utilization of the world's fishery resources. The WGFTFB Meeting convened by FAO and ICES in May 2013 in Thailand served as a forum for global synthesis of scientific knowledge on fishing technology and its effective use. The meeting explored the means of evaluating the role and potential for capture technologies and practices to reduce fishing impacts on the environment and energy use, and served as a medium to review and discuss advances in technology and analytical methods used to study these effects. Furthermore, the meeting provided 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, and means of fostering new partnerships between scientists and technology from developed and developing economies to minimize the impacts of fishing on the environment.

Advocating the Recent Advances and Future Direction of Fishing Technology

The ICES-FAO WGFTFB Meeting in May 2013 in Thailand was a significant event in SEAFDEC in view of its relevance to the sustainable development of small-scale fisheries in its Member Countries, and considering that SEAFDEC has been implementing various projects including "*Optimizing Energy Use and Improving Safety at Sea in Fishing Activities*" and "*Mitigating the Impacts of Fishing on the Environment: Fishing in Harmony with Nature*" with funding support from the Trust Fund of the Government of Japan. The Meeting provided information that enhanced the expertise of SEAFDEC in addressing various constraints that impede the sustainability of small-scale fisheries in the Southeast Asian region. The partnerships developed between countries in the region and with various stakeholders from other parts of the globe that was forged during the 2013 WGFTFB Meeting will help to build synergies for addressing regional and global challenges that hamper the Southeast Asian region. Development of sustainable fisheries for poverty alleviation and food security is the mandate for SEAFDEC and the ASEAN as provided for in the ASEAN-SEAFDEC Resolution and Plan of Action on Sustainable Fisheries for Food Security for the ASEAN Region Towards 2020 adopted in June 2011.

The May 2013 Meeting was attended by more than 150 fishing technologists, scientists, and other stakeholders representing 25 countries. It included a mini-symposia to discuss the effects of fishing on the environment which have been addressed through various initiatives and research studies undertaken not only in the temperate countries but also in the tropics, grouped into three main topics: (1) Low Impact and Fuel Efficient (LIFE) Fishing; (2) Use

Participants of the 2013 Annual Meeting of the Working Group on Fishing Technology and Fish Behavior

of Artificial Light as Behavioral Stimulus in Fish Capture (LIGHT Fisheries); and (3) Selectivity of Trawl in Multi-species and Crustacean Fisheries (SHRIMP Fisheries). These initiatives and research activities have recently led to significant advances in fishing technology, more particularly on sustainable fishing operations that minimize the impacts of fishing on coastal and marine environments.

Low Impact and Fuel Efficient (LIFE) Fishing

LIFE fishing means cost-effective next generation fishing technology through modifications and/or replacement of high-impact and fuel hungry fishing techniques and practices. As widely recognized, fishing activities can impact the environments not only due to over-exploitation of valuable aquatic species but also from direct physical contacts with critical habitats. LIFE fishing addresses these impacts and the heavy dependence of many capture fishing methods on fossil fuels. High consumption of fuel comprises a major constraint to the economic viability of capture fisheries and contributes to greenhouse gas emissions. Fishing gears can be designed and operated to cause less impact on the environment and to consume less fuel. Some pot, trap-net, hook-and-line fisheries are good examples. Currently, research in LIFE fishing has been focused on the creation of energy-efficient fishing vessel design and fishing operations that takes into consideration the associated policy and socio-economic aspects.

Once sustainably managed, the fishery sector could substantially decrease the negative impacts to aquatic ecosystems, reduce greenhouse gas emissions, and lower fuel costs by adapting technological improvements and adopting behavioral changes. LIFE fishing addresses the complex dynamic of energy consumption and environmental impacts while promoting economic viability and environmental sustainability of fishing operations, and enhancing the sector's contribution to food security.

Box 1. Papers presented during the Mini-symposium on LIFE Fishing

John Willy Valdemarsen and Petri Suuronen. 2013. **Low-Impact and Fuel-Efficient (LIFE) Fishing - Challenges, Opportunities and Some Technical Solutions**

Mobile Fishing Gear

Emilio Notti and Antonello Sala. 2013. **Propulsion System Organizations for Fuel Savings in Trawlers**

Shigeru Fuwa, Saeko Kude, Keigo Ebata, Hiroyasu Mizoguchi. 2013. **A Comparison of the Fishing Gear Efficiency on the Trawl with Knotted and Knotless Net Webbings**

Bob van Marlen. 2013. **The Development of Pulse Trawling in the Netherlands**

Keigo Ebata and Shinpei Teraji. 2013. **Reduction of Hydrodynamic Force Acting on Bottom Trawl Net**

Ulrik J. Hansen, Johan W. Nielsen and Jacob L. Rønfeldt. 2013. **Using Best Available Technology Drastically Improve Fuel Efficiency in Trawl Fisheries**

Leela Edwin and T.K. Srinivasa Gopal. 2013. **Initiatives Towards Development of Green Fishing Systems for Indian Waters**

Stationary Fishing Gear

Liming Song, Weiyun Xu, Daomei Cao, and Jie Li. 2013. **A Comparison of Two Catch Rate Calculation Methods: Application to a Longline Tuna Fishery**

Philip Walsh and Rennie Sullivan. 2013. **Comparative Baited Pots Trials to Harvest Northern Stone Crab (*Lithodes maja*) and White Hake (*Urophycis tenuis*)**

T. Arimoto, T. Kudoh, Y. Takashima, K. Ebata, A. Munprasit, T. Amornpiyakurit, N. Manajit, W. Yingyuad, A. Boutson, Yap Minlee, and S. Ishikawa. 2013. **Operation System Analysis of Set Net in Rayong, Thailand from the View Point of Cost-profit Simulation with Fuel Consumption Assessment**

Keigo Ebata, Anukorn Boutson, Isara Chanrachkij, Nakaret Yasook, Tanut Srikum, Takafumi Arimoto, Takatsugu Kudoh, Minlee Yap, and Satoshi Ishikawa. 2013. **Seasonal Variation in Fishing Operations and Fuel Consumption of Small-scale Fisheries in Rayong, Thailand**

Tools for LIFE Fishing

Chun-Woo Lee and Jihoon Lee. 2013. **Energy Saving Fishing Gears Design Using a Numerical Simulation**

Michael Pol, Steve Eayrs, Pingguo He. 2013. **GEARNET: A Bottom-up Approach to Gear Testing and Uptake**

Steve Eayrs and Christopher Glass. 2013. **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?**

Box 2. Findings from LIFE Fishing session

Employing various fishing techniques and types of fishing gear and practices has advantages and disadvantages, but the suitability of each gear type depends considerably on the operational conditions and on the species targeted. Moreover, the impacts of fishing gear on the ecosystems depend largely on the physical characteristics of the gear; the mechanics of its operation; where, when and how the gear is used; and the extent of its use. Nevertheless, there is still no single solution to increase the interest of fishers in new fishing gears and practices, as this depends on the fishery and individual circumstances. Suggestions, however, were offered such as providing incentives for participating fishers and encouraging them to take part in finding solutions to the problems that confront the fisheries sector. Considerations should also be given on how motivation and incentives, *i.e.* economic, regulatory, peer pressure, societal expectations, public perception and markets can drive fishers' uptake of such innovations and changes in fisheries development. Furthermore, there is also a need to make fishers understand the issues such as high-energy consumption and greenhouse gas (GHG) emissions that could occur after the catch is taken onboard fishing vessels as well as after landing (*i.e.* fish processing, cooling, packaging and transport).

Minimizing the impacts and energy consumption throughout the whole product chain is needed to reduce the overall environmental costs of fishing. For such reason, it is crucial that the fishing sector should lower its fuel consumption and decrease ecosystem impacts. Through technological improvements, gear modifications and behavioral change, the fishing sector can substantially decrease the damages that it inflicts to aquatic ecosystems, reduce GHG emissions, and lower operational costs without creating excessively negative impacts on fishing efficiency.

Box 3. Possible solutions that could address problems impeding the promotion of LIFE Fishing

Demersal trawl can be operated on many types of areas and grounds, in shallow and deep waters, by small and large vessels for a wide range of target species. Bottom trawling conducted in high-biodiversity environments is difficult to manage in terms of by-catch and habitat impacts although techniques and operational adaptations are available to reduce the drag and weight of the bottom trawl gear and reduce significantly fuel consumption and impacts on sea bed without marked decrease in the catch of the target species. Further work, however, is needed to improve the construction of the different components of the gear to minimize friction on the bottom and reduce the overall gear drag. For beam trawls, alternative gear designs are being developed to reduce the amount of tickler chains and to avoid excess weight in the beams, while the use of other stimuli (*e.g.* electric pulses) as alternative to chains is being tested to scare the target fish off the bottom and into the net. The use of acoustics, light or other additional stimuli to enhance encounters by target species within the catching zone of trawl nets has been explored. Electronic sea bed mapping tools and integrated global navigation satellite systems have been used to estimate the location of targeted fish and help in avoiding sensitive bottom habitats as well as minimize fishing effort and fuel consumption. The so-called smart trawling should be promoted to ensure that sea bed damages by bottom trawling are reduced.

Bottom seining such as Danish, Scottish and pair seining is generally considered a more environment-friendly and fuel-efficient fishing method than bottom otter trawling since the gear is lighter and the area swept is smaller. The absence of trawl doors or heavy ground gear implies that there is less force on the sea bed. Therefore, the light gear used and low hauling speed could lead to significantly lower fuel usage than trawling operations. Although bottom seine nets have been regarded as having low impact on benthic invertebrates, the high by-catch of both undersized individuals of the target species and individuals of non-target species can be a problem in some seine fisheries.

Trap-nets are passive fishing gear usually set along the path of migrating fish in relatively shallow coastal waters. The leader-net herds and guides fish into a holding chamber. Modern trap-net fisheries can be energy efficient, flexible, selective and habitat-friendly, providing high quality catch still alive when brought onboard the vessels and allowing the operators with a greater number of options to add value to the catch. A recent innovation, the pontoon trap, offers various advantages compared with traditional trap nets because it is easy to transport, handle and haul, and adjustable in terms of size, target species and capture depth, as well as being predator-safe. Future developments may include large-scale, ocean-based fish traps with provisions to attract the fish. Designs and practices need to be improved to prevent the entangling of non-fish species in the netting and mooring ropes of the trap.

Pots are small transportable cages or baskets with one or more entrances designed to allow the entry of fish, crustaceans or cephalopods, but prevent their escape. Pots are usually set on the bottom with or without bait, and are extensively used in the capture of crustaceans such as lobster and crabs, and successfully used in fisheries targeting coral-reef species inhabiting areas where the use of active gear is banned or not practical. Compared with many other types of fishing gear, pots, like trap-nets, possess several appealing characteristics such as low energy use, minimal habitat impact, high quality, and delivery of live catch. However, lost or abandoned pots may continue to catch target and non-target species, known as ghost fishing, thus, contributing to marine debris with associated effects. Design features such as biodegradable materials may reduce ghost fishing, while the use of delayed surface marker buoys and location could promote the recovery of lost gear. Understanding fish behavior in relation to pots is essential in order to increase efficiency for those species that are currently not captured by pots in commercially viable quantities.

Hook and line refers to a gear to which fish, squid or other species are attracted and caught through the use of natural or artificial baits or lures placed on a hook. In view of its wide variations in term of configuration and their mode of operation, hook and line is an effective gear type for a wide variety of species. It is a versatile fishing method which is employed by a wide range of vessels from artisanal boats to large mechanized long-liners. Hook and line fishing is generally considered an environment-friendly but labor-intensive fishing method, with catches of high quality. Fuel consumption is comparatively low although it can increase significantly depending on the distance the vessels have to travel to and from fishing grounds (*e.g.* coastal hook and line fisheries versus high seas tuna long-lining). Long-line fishing may cause incidental mortality of seabirds, sea turtles and sharks, many of which are either protected or endangered. Bottom-set long-lines may also snag and damage benthic epifauna and irregular objects on the bottom. Nevertheless, long-line fisheries offer the potential of fishing without causing severe habitat damage provided it is done in a relatively energy-conscious manner.

Gillnetting using bottom-set gillnets, entangling nets and trammel nets have undergone improvements in materials and techniques, allowing the expansion of using these gears in deeper and rougher grounds (including wrecks and reefs). Gillnetting is a very versatile and flexible fishing method but can be labor-intensive. Except with trammel nets, size selectivity for fish is generally good, but species selectivity can be poor. Nevertheless, since fish are often injured and die during capture, catch quality is typically not as good as with pots, traps and long-lines, although gillnets may also give catch of good quality when the time the net is left in the water to fish is short. Gillnet fishing operations in general can damage benthic epifauna during gear retrieval at which time the nets and lead-lines are more likely to snag bottom structures. Abandoned, lost or otherwise discarded gillnets could continue to fish for long periods depending on their construction, the depth, and prevailing environmental conditions (ghost fishing). This can be addressed by increasing efforts to avoid losing gillnets and facilitating the quick recovery of lost nets.

During the Mini-symposium on LIFE Fishing, the scope of the presentations were broad and varied, *i.e.* on mobile gear fishing, stationary gear fishing, and tools for LIFE fishing, exhibiting a wide range of R&D on LIFE fishing conducted around the world. The papers presented and the findings noted during the Mini-symposium on LIFE Fishing are shown in **Box 1** and **Box 2**, respectively.

Furthermore, several activities were suggested that could address the issues that impede the promotion of LIFE fishing operations (**Box 3**). These include the practice of smart trawling and seining that reduce seabed damages, promotion of responsible passive gears, improvement of the use and recovery of gill nets, and conduct of R&D activities on energy-saving technologies. Changes from high-energy high-impact fishing methods or practices to practices with lower energy consumption and lower ecosystem impacts could offer opportunities for conserving fuel, preserving the ecosystems and improving food security.

However, it was noted that there are also barriers to the transition towards the use of LIFE fishing practices and gear. These include: lack of familiarity with cost-effective and practical alternatives; limited availability of suitable technologies especially in developing countries; incompatibility of vessels with alternative gear; risk of losing marketable catch; additional work at sea; concerns with safety at sea related to using unfamiliar gear or strategies; high investment costs; lack of capital or restricted access to capital; ineffective technology infrastructure support; inflexible fisheries management systems that include too rigid regulatory regimes. In inflexible management systems, regulatory regimes could be too rigid creating a new set of problems and denying fishers the flexibility to innovate and adopt new technologies. Making stakeholders an integral part of the management process could address these concerns, especially when amendments to legislations are under consideration. Changes from high-energy high-impact fishing methods or practices to practices with lower energy consumption and lower ecosystem impacts could offer opportunities for conserving fuel, preserving the ecosystems and improving food security.

The transition from using one gear type to another is not always easy or practical because there are often limited possibilities for changing the size and design of existing fishing vessel including machinery and equipment. Secondly, fishing gear, fishing vessels, operations, and practices have been adapted to specific fishing grounds and the behavior of target fish species over a considerable period of time. Accordingly, the evolved fishing gear and practices are "*tailor-made*" to catch specific target species or species groups in a manner that is often perceived to be optimized to the best technical and economic scenarios that will be encountered during fishing. Moreover, where fishing practices are rooted in tradition there is a strong resistance to change. Nevertheless, fuel consumption and ecosystem impacts can often be reduced through simple modifications in operational techniques and gear design without drastic changes in the gear and operational practices. This approach has shown promising results in many cases and is often preferred by the fishing industry over transitioning to a completely new gear type and fishing practice, an alternative that has many uncertainties with high economic risks. R&D on energy-saving technologies carried out by designers of machinery and fishing vessels and gear, point towards the signs that the fishing industry has begun to improve its fuel efficiency. However, refinements to fuel quality, *i.e.* lowering the content of sulfur oxide and particulate matter, could lead to even higher fuel and lubricating-oil costs. This would have greater impact on the fishing industry in developing countries where mechanization continues to increase since fuel continues to be the major cost of operation in capture fisheries, although it will also strengthen the advocacy for fuel efficiency.

Use of Artificial Light as Stimulus on Fish Behavior in Fish Capture (LIGHT Fisheries)

Fishing attractor makes use of lights attached to structures above water or suspended underwater to attract fish to specific areas and facilitate harvesting. While fishers seek conditions where the chance of catching fish is optimized, fish seek the areas where the chance of finding their food is optimal. Most fish seek waters that are rich in food such as smaller fish, insects or shrimps, and congregate where their food is most concentrated. Scientific research shows that fish and some of their food animals have eyes sensitive to blue and green color because the water where these aquatic animals live in is bluish or greenish in color. Water, containing little particulate matter, scatters light in the blue

region of the spectrum. Meanwhile, water which is rich in nutrients and contains photosynthetic micro-organisms and plants preferentially absorb red light. The remaining, unabsorbed light is transmitted and scattered, thus giving the water a greenish appearance. If water contains a lot of organic materials from decaying plants or suspended sediments, it may take on a yellowish brown color.

Fish and some of their food animals have color receptors in their eyes that could optimize the light of their "space", see a single space color, and detect changes in light intensity, equivalent to a world in black, white and shades of gray. In its simplest level of visual information processing, an aquatic animal can recognize that something is different in its space, *i.e.*, there is food or predator "over there". Most animals living in a lighted world have an additional visual resource: color vision, which means that they have color receptors containing at least two different visual pigments. To efficiently perform this function in water illuminated with light, an aquatic animal would have visual pigments sensitive to the background "space" color and one or more visual pigments offset from this blue-green region, especially in the red or ultraviolet region of the spectrum. This produces a clear survival advantage for these aquatic animals because they can detect not only changes in light intensity but also contrasts in color. Many fish, for example, have two color receptors, one in the blue region of the spectra (425-490 nm) and the other in the near UV (320-380 nm). Insects and shrimps which are members of the fish food chain, have blue, green (530 nm) and near UV receptors. Some aquatic animals have up to ten different classes of visual pigments in their eyes. By comparison, humans have three with maximum sensitivities in the blue (442 nm), green (543 nm) and yellow (570 nm). It is the differential responses of these receptor cells that enable the color vision.

The best color for a light attractor is still an open question, but based on the biology of visual receptors, the light should be blue or green — the space colors of fish and members of their food chain. However, while blue or green light is desirable it is not essential. Even if the eyes of fish or members of its food chain have color receptors most sensitive to the blue or green, these same receptors have a broad but decreased sensitivity to other colors. So, if a fishing light source is intense enough, other light colors will also attract fish. For example, a sodium vapor light with its characteristic yellow color will attract fish — if intense enough. A fishing light attractor can also be white light because a portion of its total energy is in the blue to green region. Nevertheless, the perfect fishing light could have the following properties: (1) high intensity, (2) emit light in a color similar to the fishes' space (blue

Box 4. Papers presented during the Mini-symposium on LIGHT Fisheries

Mike Breen and Amit Lerner. 2013. **An Introduction to Light and Its Measurement when Investigating Fish Behavior**

T. Arimoto. 2013. **Fish Behavior and Visual Physiology in Capture Process of Light Fishing**

Physics & Engineering

Yoshiki Matsushita and Hisayuki Arakawa. 2013. **Marine Optics - Essential Elements for Fishing Technology and Fish Behavior**

Ja Soon Jang. 2013. **Review of Technological Design: LED Packaging and Lighting**

Heui Chun An. 2013. **Research on Artificial Light Sources for Light Fishing**

Sugeng Wisudo. 2013. **Light Output Arrangement in Light Fishing Through the Use of Simulation Model of Underwater Illuminance Distribution**

Dan Watson. 2013. **Novel Power Supply Technologies for Artificial Lights on Fishing Gears/Energy Harvesting in the Trawling Environment**

Biology & Behavior

Ronald Kröger. 2013. **The Biology of Underwater Vision**

Amit Lerner. 2013. **Polarization Vision in the Sea**

Kyounghoon Lee. 2013. **Attracting Effects on Swimming Behavior Patterns of the Chub Mackerel (*Scomber japonicus*) and Common Squid (*Todarodes pacificus*) by LED Luring Lamp**

Daniel Aquilar-Ramerez, S. Hoyt Peckham, Jesse Senko, John Wang, Luis V. González-Ania and Santa L. Ganelón-Leon. 2013. **Effects of LED Illuminated Gillnets on By-catch of Loggerhead Turtles in Coastal Mesh Net Fisheries at Baja California Sur, Mexico**

Hyeon-Ok Shin and Jin-Wook Jung. 2013. **Visual Threshold of Rockfish (*Sebastes inermis*) Response to Different Wavelength of LED Lamp**

Kazuhiko Anraku and Tatsuro Matsuoka. 2013. **Development of the Evaluation Method on the Effect of Artificial Fishing Light**

Light Fishing

Weiguo Qian and Yingqi Zhou. 2013. **Review on Squid Jigging with Lights of Chinese Fishing Fleets**

Young-Il An and T. Arimoto. 2013. **Fishing Efficiency of LED Fishing Lamp for Squid Jigging and Hair Tail Angling in Korean Waters**

Daisaku Masuda, Shuya Kai, Taisei Kumazawa and Yoshiki Matsushita. 2013. **Application of the Low-power Underwater Light to a Large Scale Fish-trap Fishery**

Grant Murphy and R. Sullivan. 2013. **Modifying Baited Cod Pots to Capture Flatfish Species While Excluding Snow Crab**

Box 5. Findings from the Mini-symposium on LIGHT Fisheries

The discussions centered on the physics, properties, and characteristics of light including the tools to measure light and clarification of the myriad of units used in light measurement. The use and development of artificial light in squid jigging operations and the importance of understanding fish vision, its influence on fish response to visual stimuli, and research methods and techniques to investigate fish vision and functions such as visual acuity, maximum sighting distance, and spectral sensitivity were also examined. Likewise, the development and engineering of LED lights, and harvesting renewable energy sources from the fishing processes and ocean environment using innovative technologies and techniques to develop self-powered underwater lights. Measurements of the underwater light field and the behavior of squid and fish in response to artificial illumination onboard fishing vessels or underwater, and the importance of polarized light to some fish and invertebrates particularly in prey detection were also described. Finally the benefits of LED lights compared to other sources of illumination including their effect on catch rates and fuel consumption, as well as the relative performance of LED lights of different color were also discussed. The question on why light fisheries have been popular in the east and less so in the west, was explained in terms of the abundance and schooling behavior of fishes in the eastern hemisphere. However, the aspect of why fish are positively phototactic is still not well understood and remains an area for future research. Although Light Fisheries could be less harmful to the environment and overfishing is seemingly lessened than in using other gear, in some fisheries light can create conflict between the fishery and fishers which is difficult of control and regulate.

Lights used in fishing could be classified into two groups: portable and permanently mounted. Portable lights which are powered by batteries, sets practical limits to the kind of light used in fishing. Most portable light sources are relatively low in light intensity and have short operating times. A 12 volt automobile incandescent headlight mounted on a styrofoam float ring is probably the least expensive and lasts for a few hours before the battery is discharged. Battery-operated fluorescent lamps are three times more efficient in converting electricity to light. Therefore, comparing lamps of similar brightness, these lamps can be operated about three times longer before the battery is discharged. Also, the operating lifetime of fluorescent lights are about ten times longer than incandescent lights. Commercial portable fishing lights based on fluorescent lamps vary widely in intensity. The best use 25-40 watt lamps that emit about 1000–3000 lumens per tube cost $160–$200. Lights made up of LED lights are an up-and-comer but to date are 10 to 100 times less brighter than a fishing light using a standard 25-40 watt fluorescent lamp. LEDs are extremely efficient in converting electrical energy to light, and as the cost of LEDs decrease and their brightness increases, functional fishing lights consisting of large arrays of LEDs could be promising. Permanent lights are typically powered with 115 volt house current, placed on poles at the end of a dock or pier, and are the least expensive lights for outdoor use for security purposes. Flood lights that make use of mercury vapor, high pressure sodium vapor, metal-halide discharge or fluorescent bulb cost US$25-100. While the lower cost 115 V AC outdoor flood lights using standard tungsten (incandescent) or tungsten-halogen (quartz) bulbs can also be effective as fish attractors and are energy inefficient. While it takes about five 100 watt tungsten lamps to deliver the light equivalent of one security lamp, the fixture includes a photocell controller for automatic dusk-to-dawn operation and comes complete with an appropriate bulb. These lights are very bright (6-8 thousand lumens), efficient in converting electricity to light (operated daily for 8 hours, electrical supply costs US$40–100 per year), have long bulb lifetimes (24,000 hours) and stand up well to outside weather conditions. When used as fishing light, its light output can be redirected towards the water by installing a 5”x10” piece of aluminum flashing or heavy foil bent into a half circle and placed next to the lamp’s circular acrylic lens. Stadium spot lights are energy efficient and their superior brightness illuminates a large area of water. Sorted in 250, 400, 1000 and 1500 watts, the high intensity discharge lamp, parabola-shaped reflector and light ballast are each sold separately, so that a complete light fixture and lamp would cost about $400–$500. The cost of lamps with different wattage ratings is similar, so one can choose higher wattage lamps. The bulbs in these lamps can emit white, blue-green, green or yellow light. For most fishing waters, the lamp color of choice is green but it would take two people to install these big lamps and the installation may also include a switch, timer, heavy gauge wiring and circuit breaker, thus adding to the cost. However, a significant fraction of the light shining on the surface of the water is lost by reflection and, thus, will not be available to attract fish and members of their food chain. Security lights can be modified to operate when submerged in water, because positioning the bulb underwater delivers approximately twice as much light to attract fish. Modification must be done professionally as high voltage that powers these lamps can be lethal. Therefore, the power ballast and lamp housing should be mounted on a pole in a dry location while the lamp, potted in a waterproof housing, is connected to the ballast through a waterproof cable. Floating like a fishing line bob, the lamp is positioned underwater by weights on its submerged power supply cord. The bulb is fragile so some manufacturers offer protective covers and hard lenses. One unique feature of the submerged, unprotected bulb is that its outer glass envelope could get hot enough to prevent establishment of marine growth. When the bulb has a protective cover or is not operated daily occasional cleaning is required. A permanently fixed fishing light attractor is most effective if it is operated every night. It takes a week or two for larger fish to discover the increasing concentration of bait fish attracted to the light. Once discovered, the fish return regularly, often arriving at predictable times of the evening.

or green), (3) powered by a portable electrical supply, and (4) submersible. The last attribute is desirable because significant amounts of light energy from land- or boat-mounted lights are lost through the reflection off the surface of the water.

However, no commercial light has so far satisfied all four of the abovementioned criteria. For example, high intensity lights such as tungsten-halogen (incandescent), medium pressure mercury or metal-halide discharge lights are so power hungry that they can only be operated for very short periods of time with a battery, thus compromising convenience and portability. While LEDs and fluorescent lights use much less electrical energy, these are mostly not very bright. Furthermore, many of the abovementioned lights cannot be submerged in water without risks of electrical shock or damage to the lighting system. The Mini-symposium on LIGHT Fisheries therefore, focused on the physics and engineering aspects of artificial light in water; biology of vision and behavioral responses of fish to artificial light; and novel and innovative approaches in LIGHT fisheries

More specifically, the papers presented have pointed towards significant technological advances in LIGHT Fisheries such as the adoption of LED lights in favor of incandescent, halogen, and metal halide illumination. These technological advances have shown to be similarly effective compared to many of the older sources of illumination with the added benefit of requiring considerably less energy, hence, consumption of fuel and greenhouse gas emission are significantly reduced. The papers presented and additional findings from the Mini-symposium on LIGHT Fishing are shown in **Box 4** and **Box 5**, respectively.

Selectivity of Trawl in Multi-species and Crustacean Fisheries (SHRIMP Fisheries)

A range of tools to manage by-catch and reduce discards, including technological measures to improve the selectivity of fishing gear, has recently been promoted worldwide. As a result, decline in by-catch and discards have been attained in many fisheries through the introduction of effective gear modifications and by-catch reduction devices. Species selectivity is aimed at reducing unwanted species while size selectivity aims to reduce the catch of undersized fish. The coastal shrimp trawl fisheries in the Southeast Asian region can be characterized as highly multi-species fishery. Thus, it might not be possible to catch all species in an optimal way. Tropical shrimp trawl fisheries should be allowed some by-catch taking into consideration social and market implications, although "shrimp" trawling with no retention of any other species may not be a practical objective, because selective fishing may not necessarily equate to better conservation.

More specifically, the papers presented during the Mini-symposium on SHRIMP Fisheries emphasized on the challenges associated with the development, testing, uptake, and regulatory compliance associated with turtle excluder devices (TEDs) and by-catch reduction devices (BRDs). The high ratio of shrimp to discards and the ongoing practice of landing significant numbers of undersized fish for commercial purposes were also reported. Another issue raised was the loss of shrimp and other commercial species from both TEDs and BRDs, often described as the result of poor TED or BRD design or clogging of the TED by sawfish, tree limbs, and other debris. The papers presented and main findings from the Mini-symposium on SHRIMP Fisheries are shown in **Box 6** and **Box 7**, respectively.

Box 6. Papers presented during the Mini-symposium on SHRIMP Fisheries

David Brewer and S. Griffiths, S. Zhou, S. Eayrs, I. Stobutzkic, R. Bustamante & C. Dichmont. 2013. **Understanding and Managing Impacts on By-catch in Australia's Northern Prawn Fishery**

Petri Suuronen and Daniela Kalikosk. 2013. **Incorporating Human Dimension in the By-catch Management of Shrimp/Bottom Trawl Fisheries**

Ari Purbayanto, Ronny I. Wahyu, and Joko Santoso. 2013. **Research on By-catch of Shrimp Trawl Fishery in Arafura Sea: Volume, Reduction Devices, and Utilization of Discarded By-catch**

Adna Tokaç, Hüseyin Özbilgin and Hakan Kaykaç. 2013. **Selectivity of Five Different Codend Designs to Improve Size Selectivity for Deep Water Rose Shrimp (*Parapenaeus longirostris*) in the Aegean Sea**

Gökhan Gökçe, Ahmet Eryaşar, Yeliz Özbilgin, Adem Bozaoğlu, Ebrucan Kalecik and Hüseyin Özbilgin. 2013. **Discard Ratios of Fish and Shrimp Trawls in the North Eastern Mediterranean**

Pingguo He. 2013. **A Decade of Systematic Research to Minimize Discards in Northern Shrimp Trawls**

Truong Nguyen, Paul Winger, George Legge, Earl Dawe and Darrell Mullowney. 2013. **When Shrimp Trawling Collides with Crab Fisheries: A Case Study from Newfoundland, Canada**

Eduardo Gramaldo, Jørgen Vollstad and Roger B. Larse. 2013. **Trawling for Shrimps and Simultaneously Retaining Cod**

Suppachai Ananpongsuk. 2013. **The Promotion of Responsible Trawl Fishing Practices in Southeast Asia Through the Introduction of Juvenile and Trash Excluder Devices (JTEDs)**

F.G. O'Neill, R.J. Kynoch, J. Drewery, A. Edridge, and J. Mair. 2013. **Netting Grids in *Nephrops* Trawls to Reduce the Capture of Cod in the North Sea**

Niels Madsen, Rikke Frandsen, Jordan Feekings, and Ludvig A. Krag. 2013. **Development of Sorting Grids for Norway Lobster Fisheries**

Petri Suuronen and Isara Chanrachkij. 2013. **Trawl Fisheries Management in Southeast Asia and Coral Triangle Region**

Minlee Yap. 2013. **Introducing RIHN Project: Coastal Area Capability Enhancement in Southeast Asia**

Other Issues

Papers were also presented during the Open Session (**Box 8**) that discussed other relevant issues. Understanding size selectivity in diamond mesh codends and fish morphology was discussed, where the codend mesh geometry could be measured in 5 locations in a flume tank over three simulated catch weights. Morphological data based on the cross section of the cod, could be used to calculate the L_{50} values at these and other selected locations along the codend, and a curve presenting L_{50} values over a range of catch weights could be compared against the data collected in the field. When the calculated data fitted poorly to field data, this could mean that catch weight has significant implications for size selectivity, particularly when catches are low. Efforts to use underwater video cameras were

Box 7. Findings from the Mini-symposium on SHRIMP Fisheries

During the discussion, the issue on blocker of clogged grids was raised and options were discussed to overcome the issue which often negatively impact the level of enthusiasm by fishers to use these devices because of associated shrimp loss. Reducing this effect includes the use of a well designed and maintained grid operated at correct angle. The use of large grid could increase the filtering area and also the likelihood that the 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 while the distortion of the codend by a large grid helps ensure that the escape cover is held over the escape opening by water pressure. However, ensuring that the escape cover can be readily pushed aside by escaping large animals and thus promoting readily acceptance by fishers to use grids, such as the large ones, could be difficult given fishers' concerns for shrimp loss and the impacts of cumbersome grids on fishing operations. Regarding the notion that a successful trial of fishery could be quickly replicated in another location, it was argued that this is not always the case as time and patience are required to tune and optimize the devices, which could take several weeks longer. Utilization of by-catch was seen as an attractive option which could provide additional income to fishers. However, the sustainability of this activity has always been questioned and thus, should not be seen as quick response to the issues and concerns. Alternative tools to managing by-catch should therefore be considered, with the possibility of getting producers and supplies involved in developing incentives for adopting change.

Box 8. Papers presented during the Open Session to discuss other relevant issues

Juanita D. Karlsen, Ludvig Ahm Krag, Bent Herrmann, and Kurt Hansen. 2013. **Understanding the Size Selectivity in Diamond Mesh Codends Based on Flume Tank Experiments and Fish Morphology: Effect of catch size and fish escape behavior**

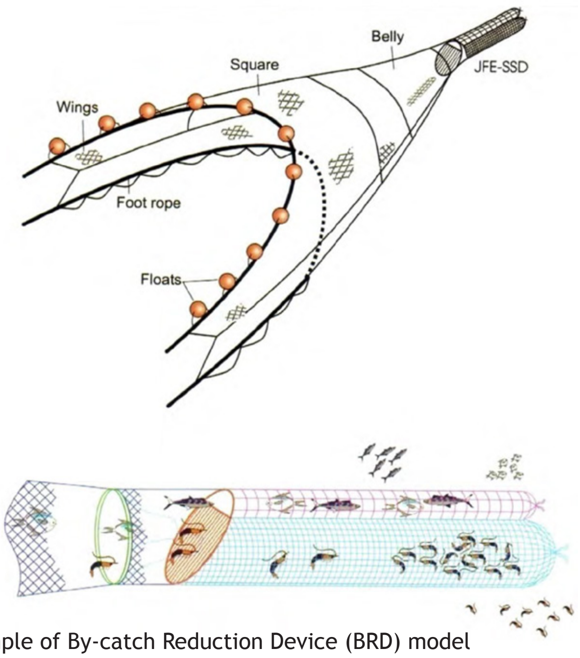
Yeliz D. Özbilgin, Ebrucan Kalecik, Adem S. Bozaoğlu, Ahmet R. Eryaşar, Gökhan Gökçe, and Hüseyin Özbilgin. 2013. **Observation of Fish Behavior during Demersal Trawling Operations in the North Eastern Mediterranean**

Mochammad Riyanto and Takafumi Arimoto. 2013. **Swimming Performance of Fish in Capture Process Simulation Examined by EMG/ECG Monitoring and Muscle Twitch Experiment**

Hüseyin Özbilgin, Ahmet Raif Eryaşar, Gökhan Gökçe, Yeliz Doğanyilmaz Özbilgin, Adem Sezai Bozaoğlu, and Ebdrucan Kalecik. 2013. **Improvement of Size Selectivity and Short Term Commercial Loss in the Eastern Mediterranean Demersal Trawl Fishery**

Limin Song. 2013. **A Comparison of Two Catch Rate Calculation Methods: Applicaion to a Longline Tuna Fishery**

Chris Rillihan. 2013. **Test of Rope Separator Haddock Trawl on Georges Bank**



Example of By-catch Reduction Device (BRD) model

also presented as means of evaluating qualitatively fish behavior during the capture process, especially in TEDs and BRDs. The footages presented useful observation and improved the understanding of trawl performance, TED and BRD performance, as well as the sources of blockage and loss of catch, and also demonstrated the fact that these trawl gear could cause mortality associated with using such gear. Moreover, efforts to evaluate the physiological condition of fish over a range of towing speeds were also reported, which involved the use of electrocardiograms and electromyograms in jack mackerel to evaluate the changes in heart rates and muscle power output over a range of swimming speeds. For example, while the peak swimming performance of jack mackerel was found to be around 5.0 fish lengths per second and the maximum sustained swimming speed was 4.0 fish lengths per second, the recovery time was found to be 300 minutes.

Results of a codend selectivity study were also described, where four different codends were tested in a covered codend experiment, while the selectivity of 5 common fish species and 2 species of shrimps was described. An evaluation of the impact of each codend on the income of fishers was also discussed, considering that several attempts to promote various codends had met resistance as these had reduced incomes of and uptake by fishers. Furthermore, efforts to develop and test a rope separator trawl to reduce catch of cod were also presented. Following a model tested in a flume tank, sea trials with a full sized separator trawl showed promise with significant reductions in cod, flounders, and skates compared to a control trawl. The impact of this trawl on catch of haddock was difficult to evaluate due to low and variable catch rates at the time of the experiments, although catch rates were only slightly less when the experimental trawl was used.

Conclusion and Way Forward

While fishing operations are exposed to the rising fuel prices with little or no significant price increases at the first sale of catch, capture fisheries will probably continue to suffer declining profitability in case necessary actions are not taken. If resource abundance remains static and operation costs are increasing, some bottom trawl and dredge fisheries may no longer be economically viable although passive gear and seine net fisheries may be less affected. Demersal trawl fishing, however, accounts for a significant part of the total catch for direct human consumption. Dramatically reduced trawling activity could adversely affect global fish supply and food security, at least in the short term. With medium-term forecasts indicating high likelihood of further increases in fuel prices (**Fig. 1**), sustainability of the fishing industry in the future becomes very challenging.

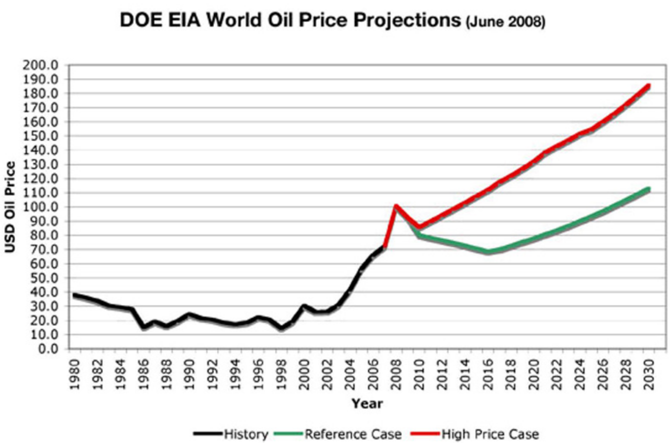


Fig. 1. Oil price projections until 2030

Thus, the fishing sector should strive to lower its fuel consumption, reduce carbon footprints, and decrease ecosystem impacts. Although the implementation or expansion of fuel subsidies as the case may be, would reduce immediate operating costs, this is often less accepted in many developing countries. Therefore, in order to help the fisheries sector achieve significant and permanent cost reductions, governments should strengthen their fisheries sector energy policy and create an enabling environment for fishing industries to rapidly and comprehensively adopt low-impact and fuel-efficient (LIFE) fishing technologies and practices. The development and adoption of such fishing techniques offer a range of aspects for maintaining the long-term profitability and sustainability of capture fisheries worldwide.

With fossil fuels remaining as the dominant energy source, pursuing energy efficiency in capture fisheries could generate benefits by reducing operating costs, controlling GHG emissions, and minimizing environmental impacts of fishing on the aquatic environments. Success of this transition will depend heavily on the response of governments to the implementation of international conventions together with positive reactions from the engine manufacturing sector, fuel-oil and lubricating-oil producers, and the fishing industry including the manufacturers of fishing gear. This could lead to the development and application of suitable and acceptable measures to conventional fisheries and create an appropriate catalyst for change in behavior of fishers. Furthermore, developing initiatives such as pursuing the modification of existing gear types and the development of low-resistance towed fishing gear with minimal impact in the aquatic environment is also equally important. In some cases, it may be necessary to switch to completely new gear types or practices in order to adopt LIFE fishing practices, thus, close cooperation between the fishing industry, scientists, fisheries managers, and other stakeholders will be fundamental to the development, introduction and acceptance of LIFE fishing technologies.

In general, in order to be effective, global R&D priorities should be established and pursued in support of the development and adoption of LIFE Fishing. The R&D priorities could include: promotion and funding of studies of cost-effective gear designs and fishing operations, including the establishment of technology incubators and other public-private sector initiatives to commercialize economically viable, practical and safe alternatives to conventional fishing methods; analysis and review of best practice operations across fisheries; improvement of technical ability among fishers; establishment of appropriate incentives; industry compliance with international conventions; and execution of robust but flexible fishery policies that support the transition to alternative technologies.

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