ISSN: 2347-5129
(ICV-Poland) Impact Value: 5.62
(GIF) Impact Factor: 0.352
IJFAS 2016; 4(2): 474-483

www.fisheriesjournal.com
Received: 07-01-2016
Accepted: 16-02-2016

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Fishing with Light: Ecological Consequences for Coastal Habitats

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Abstract
The use of artificial lights (metal halide lamp, incandescent lamp) for attracting fish and increasing catch is a common practice in the world fisheries and has been regarded as one of the most advanced, efficient and successful methods for capturing purpose as a result of our depleting fish stock resources, coral reef degradation, increased fishing input to low catch output and operational cost. This fishing aggregating method has been found to be environmental-unfriendly due to catching of immature stocks, overfishing, high rate of bycatch and discard and green gas emission. Therefore, there is an urgent need to develop an eco-friendly light fishing technology and fishing regulation in the near future. The purpose of this paper is to review some of the literatures on light fishing in relation to the impact on sustainable fisheries and proffered solutions to the problems.

Keywords: light fishing, incandescent, metal halide, environmental-unfriendly, sustainable fisheries, solutions

1.0 Introduction

The use of artificial light in fishing operations is a technique to attract and aggregate fish and eventually capture them using various fishing gears such as hooks, gill net, purse seine, beach seine, cast net or other means [17]. Light fishing involves the use of lights attached to structures above water or suspended underwater to attract fish to specific areas and facilitate harvesting. This method has been one of the most advanced and successful means employed in some types of fisheries in the world today. It is a form of optical bait used to attract and concentrate fish to a spot. Many commercial, traditional and recreational fishermen are seen putting on the light on board in the night to attract the fish around their boats [4]. This practice has been in existence since the olden days and described to be very effective in freshwater, brackish and marine ecosystems for catching and increasing landings of single and shoaling pelagic fish species such as sprat, herring and mackerel [8, 9].

Historically, the source of light has changed with the centuries. It began with artificial light in form of fire lit at the beach which has been used for thousands of years [8] when men discovered that some fish were attracted to light at the beach and they would silently enter the water with their family members, encircled the illuminated zone and dragged the fish to the shore with their legs and noise and killed them with stones, spears or clubs. The next development was the use of torches, being movable and made from coconut husk, split bamboo, carried by fishermen wading in water in the dark night to get the fish attracted, stunned and then captured with basket or spear. As time went on, the use of fuel oil; kerosene, gas and electricity, was introduced. [47] reported that Hawaiian and Philippine fishermen used to carry kerosene pressure tanks on their backs. Nowadays, the use of powerful incandescent, fluorescent, led lamps and metal halide, are common as the sources of light in commercial fisheries as shown in Figures 1 and 2. They are more convenient, safer, moved around, last longer but tend to be expensive, maintained and generate new problems such as increased competition among the commercial fishermen due to excessive level of light output [32], increased fuel cost, adverse environmental impact in terms of light pollution and green gas emissions e.g carbon(iv)oxide. If these are unchecked, could lead to overfishing, among other consequences. Many explanations have been offered to explain why fish respond to light whether attraction or repulsion. These include; avoiding predation or enhancing their feeding efficiency by locating their food source or prey (Figure 3) [45]. These types of responses depend on factors such as species, ontogenic development, characteristics of the light source, intensity, colour and wavelength [31]. It has been scientifically proven that fish and some of their food animals i.e prey have eyes sensitive to blue and green colour because the water where these aquatic animals live in is bluish or greenish in colour and their long wavelengths make them to penetrate deeper in water column (**Figures 4** and **5**).This tends to attract and concentrate the fish on the water surface. Therefore, the aim and objectives of this study are; to review the impacts of light fishing on sustainable fisheries and suggest some control measures.

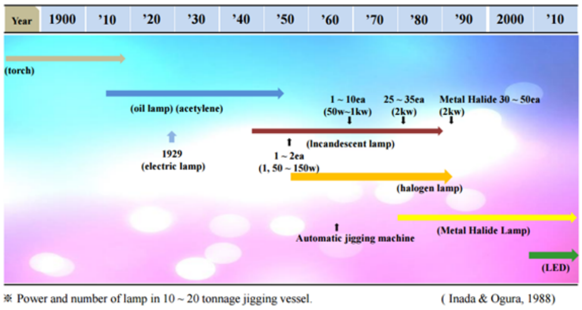

Fig. 1: History of artificial light used in fisheries [25]

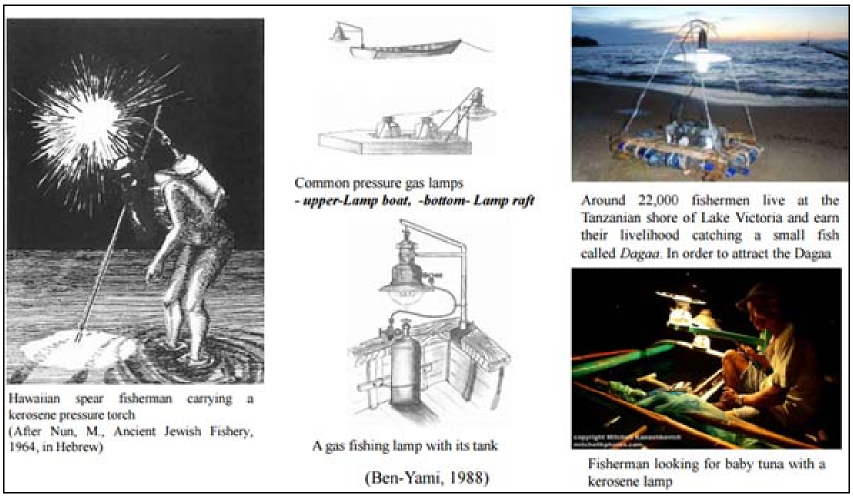

Fig. 2: Gas and Kerosene Light [9]

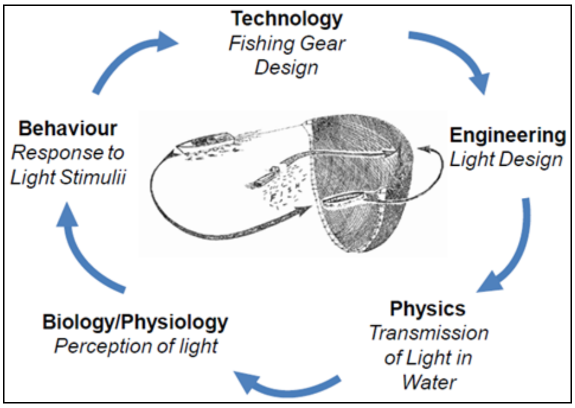

Fig. 3: Artificial Light Fishing [8]

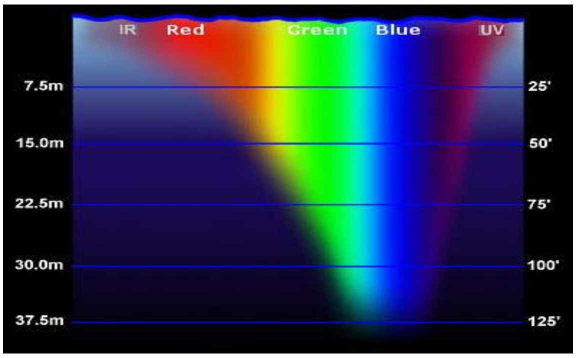

Fig. 4: The spectral transmission of light in the open oceans: demonstrating the attenuation of different wavelengths of light, with greatest penetration in the middle wavelengths (450–570nm; blue and green) in comparison to longer (>620nm; red) and shorter (<450nm; violet and ultraviolet) wavelengths **(***Reprinted from http://ultramaxincorp.com/?p2=/modules/ultramax/catalog.jsp&id=23; cited by 4]*.

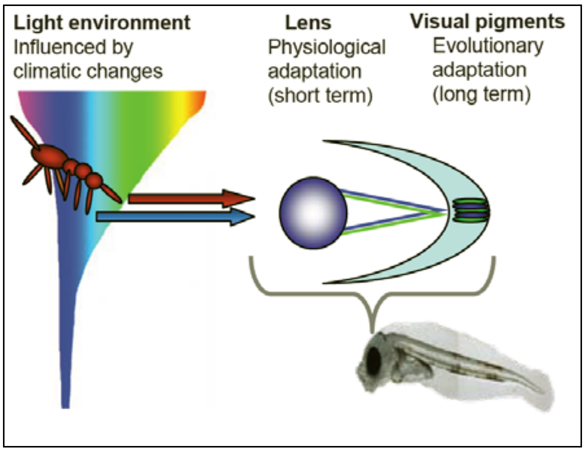

Fig. 5: Visual detection in fish, which is influenced by the ambient light environment, short term physiological adaptations (e.g. in the structure of the lens) and long-term evolutionary adaptations (e.g. in the composition of visual pigments in the retina). Figure by Jon V. Helvig, Dept. of Biol., Univ. of Bergen.

2.0 Overview of the use of Fishing with Light in the World Fisheries (Case Studies)

2.1 Indonesia

Due to the introduction of the electric lamps, the light fishing has been widely spread to the offshore fisheries to the large-scale commercial level for the boat seine, purse seine, Bagan (platform lift-net), by using electric lamps such as incandescent, fluorescent and mercury lamps. As the typical characteristics of the tropical fisheries in Indonesia, there are many types of fishing gears for a certain target species, and variety of catch species for a certain type of gear, for identifying the multi-species and multi-gear fisheries (Figures 6a, b). South Sulawesi is one of the famous regions in

Indonesia with the intensive fishing activities with light, with the specialized development of Bagan Rambo (Large scale lift-net operated from the platform raft) in Barru regency, and the purse seine in Jeneponto regency [21]. *Bagan* is a lift net formed of box-shaped net with fine mesh size of 0.5 cm, operated with lamp for attracting pelagic species. The small pelagic fisheries in the South China Sea and Andaman Sea have been exploited since 1970s. The dominant species caught are scads (*Decapterus spp*), Indian mackerel (*Rastrelliger spp*) and sardines (*Sardinella spp*).Currently, the maximum sustainable yield of the small pelagic fish resources in the South China Sea of Indonesia has been estimated to be around 621,500 MT/year, whereas for the Malacca Strait, including the Andaman Sea reaches 147.300 MT/year [46]. The pelagic fish species make small school, usually shelter around Fish Aggregating Devices (FADs), and are attracted to light at night. With this characteristic, to catch fish by purse seine easily, most of the fishers using FADs and light to aggregate fish before the fish being caught. The use of FADs and lamps is able to improve fishing efficiency such that the ability of purse seine to catch fish increased [46]. The increased catchability of purse seine may result in over exploitation in certain waters.

2.2 Ghana

[6] reported that light fishing is commonly practised in three coastal areas in Ghana, namely; Tema, Mumford & Elmina and Sekondi regions because they have port facilities for landing their catches operated by large inshore vessels using purse seine predominantly using light attraction. Currently, there are over 250 registered of such inshore vessels in the country whose size is 39-60 feet but only small fraction are still operating due to problem of spare parts and operation cost. Light fishing operation in Ghana usually operates using purse seine gear with small size generator for powering the incandescent lamp. They also make use of fish finders, a two-way radio communication gadget and diesel-driven winch drum to facilitate fish searching and catch hauling. Most of the targeted species are of herring group such as herring, sardines and anchovies. Others are horse-mackerel, bonitos and cephalopods (squids) which are caught using light attraction. These small pelagic fisheries are dominated by canoe fishery which lands 80% of the total catch in Ghana while the remaining 20% is covered by the inshore fishery. This outcome has forced the inshore fishery to adopt advanced light fishing as a means of realizing economic returns through intense capitalisation as a result of poor landings (Figure 7a). This development has generated some conflicts between the inshore and canoe fishers. The canoe fishers complained about their poor landings and accused the inshore counterparts of their light as the reason for their declining catches. They reasoned that the light detains the fish further off-shore thus preventing the fish from coming to their area of operation.

2.3 East Africa (Lakes Victoria and Tanganyika)

Lake Victoria: It is the world's third largest but Africa's largest lake with an area of 68,800 square kilometres and average depth of 40metres.It is bordered by Tanzania, Uganda and Kenya. The first night fishing was recorded dated back to 1960s [20] and fishing techniques differ among locations (Figure 7b). Canoe fishery predominates in the Lake Victoria with average canoe-size measuring 4m long and 1.5m wide and fishermen occur in crew of four. The kerosene lanterns are tied to the small wooden floats (60cm by 60cm), each float carries one light. The floats are usually four in number with each carrying a piece of kerosene lantern. This means that there are four lanterns per boat. The floats are anchored to a stock (rock) to prevent it from being swept away. The fishermen would then encircle the float with net forming a diameter of about 30 metres, with the float and light at the centre. Then, they begin to haul and close the net through hauling operation. The fish targeted and landed on-board are usually Dagaa (a small pelagic spp belonging to sardine family). The fishermen usually work between 14-21 nights per month for eight to twelve hours per night. At both Lakes Victoria and Tanganyika, the night fishermen have their own fishing camps which vary in size from beaches with few boats to a large camp containing 200 boats [43]. They are registered as Beach Managing Units (BMUs) which is a co-management institution whose mandate is to manage, regulate and monitor fishing activities and ensure socio-economic development of its members. The fish traders who often visit the lake to buy fish provide and supply the necessary equipment and fuel to these camps. Over 175,000 fishermen are working as full-time operators around the lake. Out of this number, 31,891 fishermen with 8272 vessels are engaged in night fishing especially for Dagaa [29]. It is important to know that there have been a decline in the fish landings over the years and this has resulted to the seasonal migration of fishermen to different sites in searching for a better fishing conditions and prices. [44] cited by [19] conducted a survey and found out through interview that half of the fishermen interviewed in 2007 stated to have moved their fishing sites to a better location.

Lake Tanganyika: It is the second deepest lake in the world and second largest in Africa in terms of surface area. It is bounded by four countries namely, Burundi, Zambia, Tanzania and Congo Democratic Republic. Over 10 million people depend on the lake for their livelihoods as it offers vital resources including fish, domestic water and serves as a means of transportation [39]. The lake is famous mostly for two commercially important pelagic, non-cichlid species, which are clupeids; *Limnothrissa miodon* (Boulenger, 1906) and *Stolothrissa tanganicae.* Most of the fishing operations are done in the night using different gears such as purse-seine net, lift net, and rely on clupeids attracted to light. Most night fishing operations cease every month during the period of full moon. Three types of fisheries are found in the Lake, these are; (1) Artisanal Fishery characterized by 6-7m long wooden plank hulls, lift net, 6-7 lamps and 4-7 fishers. (2) Traditional or subsistence fishery characterized by using gears such as gill-net, hook and line, scoop net which are less efficient than artisanal. (3) Semi-industrial fishery are characterized by the use of purse seine net, 16-20m long steel vessel, auxiliary steel boat, 5 lamps and a crew of 30-40 fishers.

There has been a decline of the catch per-unit-unit-effort (CPUE) recorded over the last ten years for the semi-industrial as well as the traditional fisheries within Burundi waters. The average CPUE/night for the semi-industrial fishery in Burundi decreased from 1173 kg/night/unit in 1983 to 150 kg/night/unit in 1993 and now appears to be unprofitable. However, the artisanal lift-net fishery, due to the use of bigger nets, better fishing lamps and the choice of more productive fishing grounds, manages to maintain its CPUE at a profitable level.

In addition, [7] showed the number of fish species caught in different regions of the world using artificial light fishing operations (Figure 8).

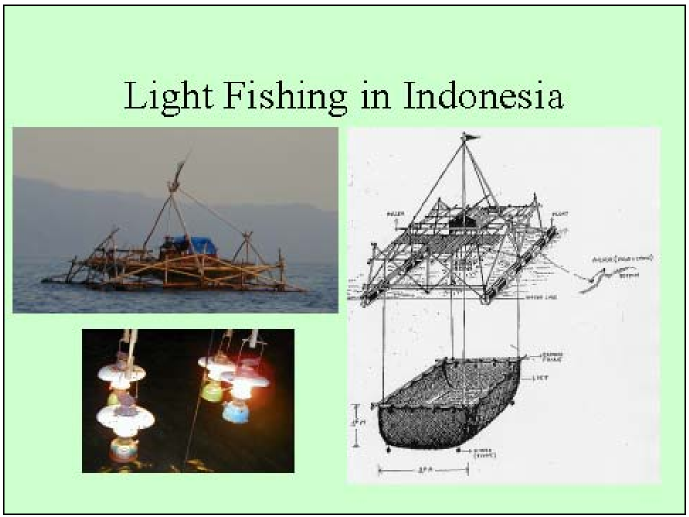

Fig. 6a: Light fishing gear types used in Indonesia (http://www.soi.wide.ad.jp/class/20020017/slides/02/102.html)

Fig. 6b: A fixed bagan platform in Indonesia(http://www.google.de/imgres?imgurl=http://c8.alamy.com/comp/CBCGMN/fishing-platform-called-bagan-cenderawasih-bay-west-papua-indonesia-CBCGMN.jpg&imgrefurl=http://www.alamy.com/stock-photo-fishing-platform-called-bagan-cenderawasih-bay-west-papua-indonesia 41458501.html&h=447&w=640&tbnid=mqBhAb_hWGAdIM:&tbnh=135&tbnw=194&usg=__4tQU4TKLpGxJzsiwxyYY-qFZaMg=&docid=xWeQvuSmwoRyM&client=opera&sa=X&ved=0CCYQ9QEwAWoVChMI1d6bxMKqxwIVQlwUCh0S1wi0)

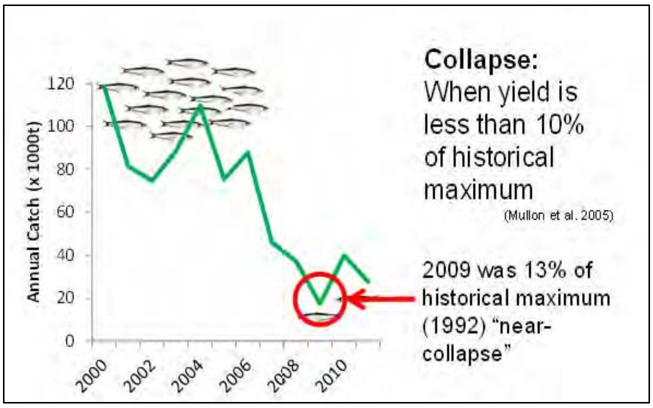

Fig. 7a: Ghanaian canoe catch of *Sardinella spp.*

(Source credit: Proceedings of the 3rd National Fisheries Dialogue: World Fish)

Fig. 7b: Fishing technique at Lake Victoria [19]

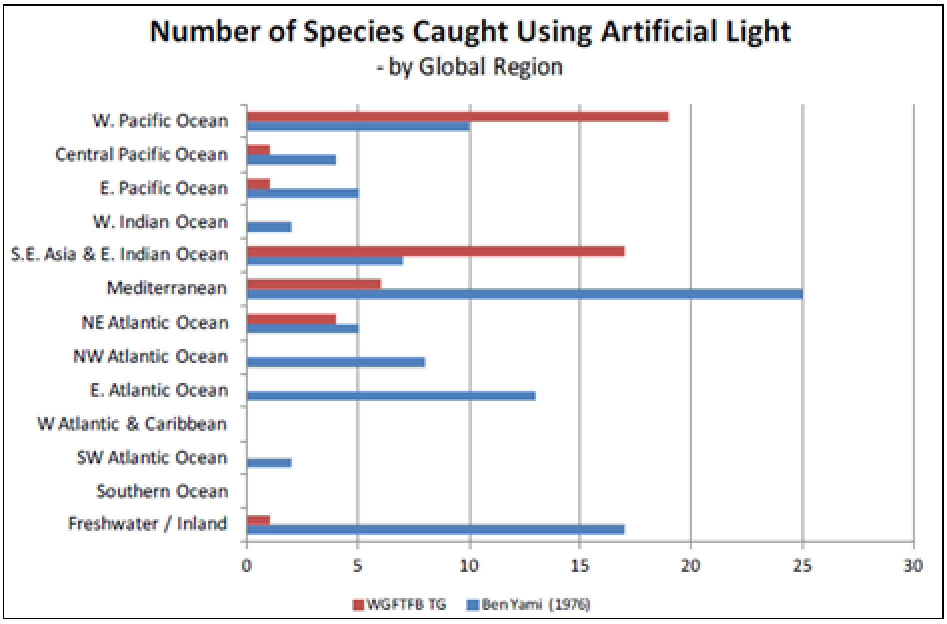

Fig. 8: Overview of number of species using artificial light by global region [7]

3.0 Description of light fishing techniques – industrial and artisanal

The origin of jigging dates back to antiquity in many parts of the world. The use of artificial light combined with jigging has been found to be highly successful for attracting and concentrating squid at night and several important squid fisheries have been established in recent years. Jigging for squid is perhaps one of the oldest methods used in Japan and other countries including Norway, United Kingdom and some Pacific Islands as shown in Figures 9 and 10 [48]. Almost all aspects of jigging fishery have undergone rapid changes within past few decades [50]. Automatic squid jigging and computer operated automatic jigging machines were introduced and developed in 1965 and late 1980s respectively. [28, 13] reported that about 70% of squid's landings in Japan are captured by jigging method which makes use of overhead bright light in the night to attract squids to the surface. The squids attack the jigs, which are lures, arranged and separated at intervals of 90cm on a microfilament, and their tentacles become hooked. The jigs are then reeled aboard and squids disengaged in the process. Squid jigging boats in Japan are classified into three based on their capacity in tonnage; small scale (1-30 ton), medium scale (30-100 ton) and large scale (100-500 ton). Small boats are made of either wood or ferro-reinforced plastic while large boats have steel hulls. Squid's landings made by these boats are in proportion to their capacities/sizes and focus from coastal to offshore waters. For instance, over 50% of the total landings are made by the large scale boats because they are well equipped with powerful electric generators which provide highly demanding squid-attracting lights of over 300kW and have larger freezing or cold storage facilities of 10-17 tons per day. Although, squid jigging fishery was not regulated until 1969 because there was glut of the resource before then, but with decreasing CPUE over time, there have been serious competitions among the large number of boats posing a big problem for the fishery.

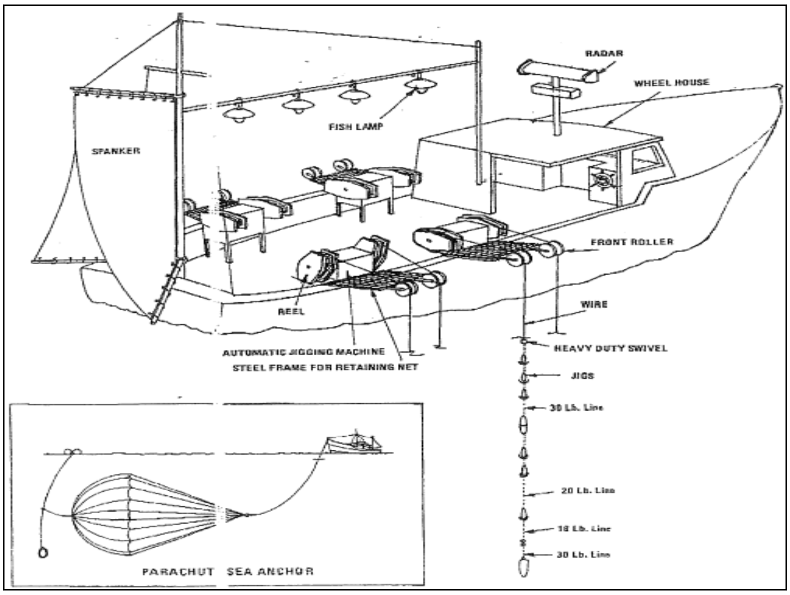

Fig. 9: A typical small squid fishing boat (Adapted from [48])

Fig. 10: Commercial Squid fishing boat, Obama, Japan) (http://www.aslo.org/photopost/showphoto.php/photo/2141/title/commercial-squid-fishing-boat-2c-obama-2c-japan/cat/506)

4.0 Ecological Impacts of Fishing with Light

4.1 Overfishing/Undersized or Immature target fish species/Catch trend/Size Composition of Main Species

The use of purse seine and lift net has prevailed in the coastal fisheries for pelagic fish around Flores Sea in Indonesia. These two fishing gears are characterised by different catches per trip in the region. Most of the purse seine used in the region are of mesh size of 2.5mm. [37] experimented and reported the diversity of the various fish species which were caught using light attraction in Flores Sea. The result showed that most of the species caught were of small size and of immature gonads (Table 1).This means that the spawning, reproductive activities and most especially population dynamics (low recruitment) of the species concerned would be adversely affected in the following season. Therefore, it is necessary to ensure sustainability of the pelagic species concerned by regulating the mesh size of the fishing gear [33, 54].

On the other hand, the research conducted by [59] in Singapura strait showed that Bagan Rambo also tends to be environmentally unfriendly to four dominant pelagic species (anchovy, Russell's scad, Indian mackerel and sardine) which were caught within the size range of 5.7-9.2cm. He found out that the standard length for anchovy at 5cm is considered as the first maturity stage. [55] found out the same result for Russell's scad and Indian mackerel in Makassar Strait as the size of the species caught were small and immature as shown in Figures 11a, b, c.

[30] also reported the small size and immaturity of the pelagic

species caught during their experiment using Bagan Rambo and [27] reported the same finding during his experiment in Bone Bay South Sulawesi. [41, 40] have also measured fish lengths for the four dominant catch in their experiment for anchovy, scad, *Rastralliger* and sardine in Makassar Strait.

In regards to overfishing/catch trend, the result of the hauling experiment conducted by [55] using Bagan Rambo indicated that the catch of the pelagic species tend to decrease in weight with time as more than 22% of the catch fall within the range 0-400kg as shown in Figure 12. [56] reported that in Bone Bay (Sinjai water) total fishing effort using Bagan Rambo increased over 8 years, total production and catch per unit effort decreased over the same period as seen in Figure 13.

Table 1: The Fork length and Gonad Maturity of fish catch by purse seine in Flores Sea [37, 38]

		(mm)	Maturity	
			Immature	Mature
1.	Frigate mackerel *(Auxis tahazard)*	192-363 [b)]	97.5 %	2.5 %
2.	Indian mackerel *(Rastrelliger kanagurta)*	110-220 [a)]	79.0 %	21.0 %
3.	Scad mackerel *(Decapterus ruselli)*	110-230 [b)]	76.0 %	24.0 %
4.	Sardine *(Sardinella fimbriat)a*	104-176 [b)]	34.8 %	65.2 %

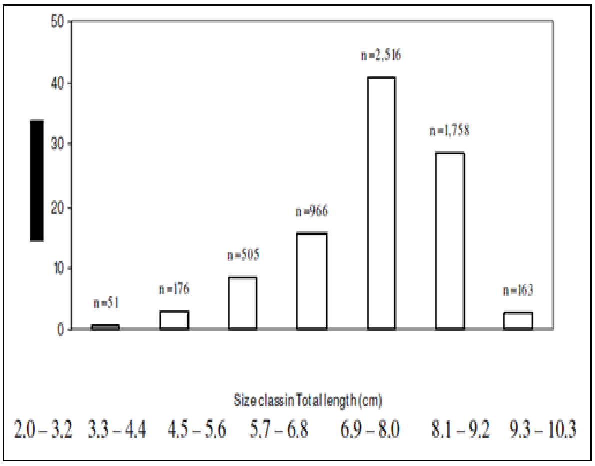

Fig. 11a: Length frequency distribution of anchovy caught by Bagan Rambo [55]

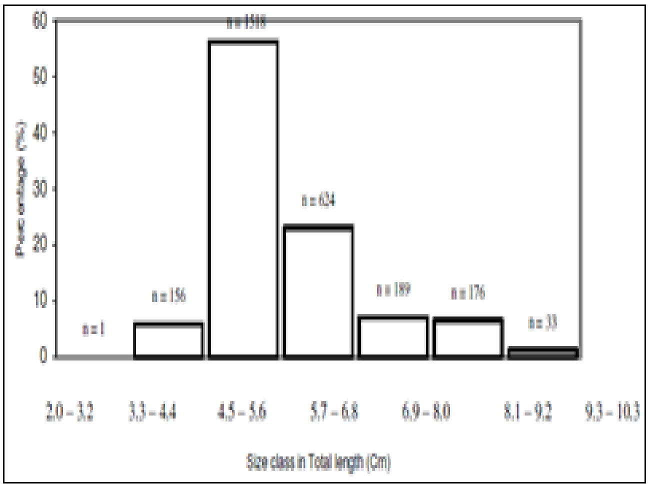

Fig. 11b: Length frequency distribution of Russell's scad [55] caught by Bagan Rambo.

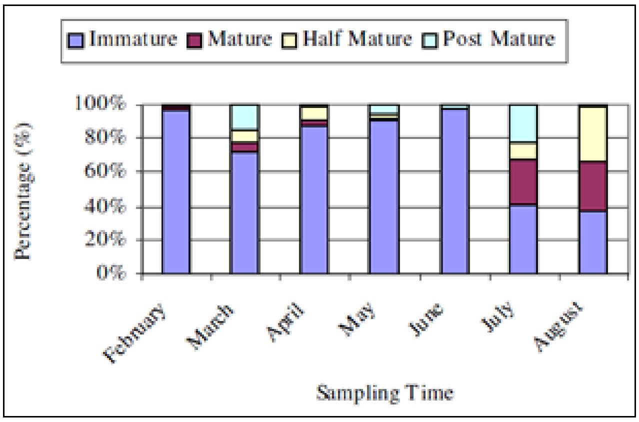

Fig. 11c: Gonad maturity stage caught by bagan Rambo ín Makassar Strait (sample size=2777 individuals) [55]

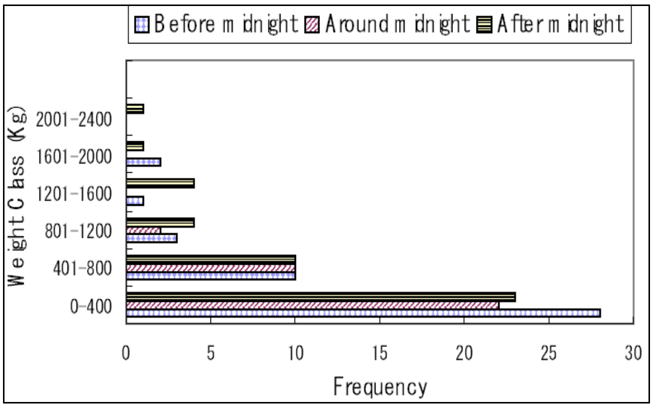

Fig. 12: Catch trend of landings [55]

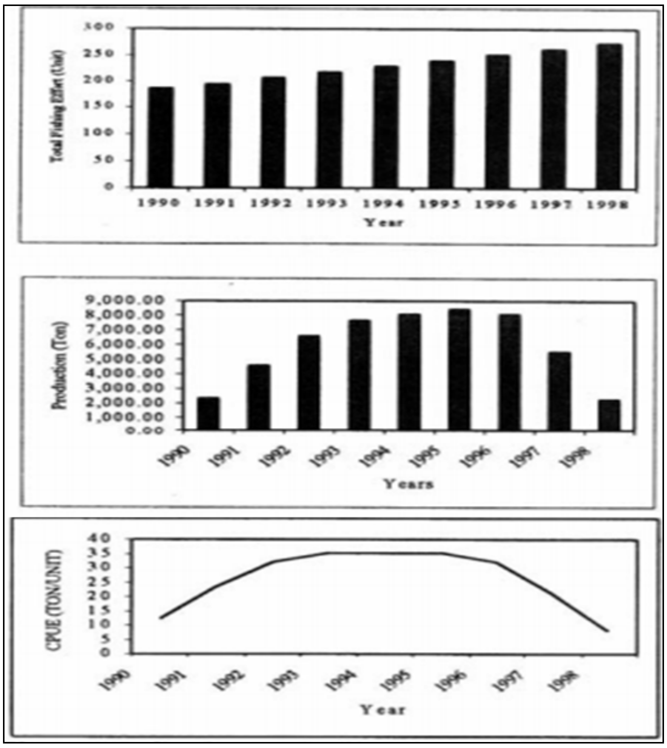

Fig. 13: Total Fishing Effort, Total Production and CPUE in Sinjai Waters [56].

4.2 Increased By-Catch and Discard Rate

The issue of By-catch in global fisheries has become a conservation concern especially in areas where ecosystems are seriously degraded [24]. Bycatch is regarded as the incidental catch of non-target species which are often discarded due to their unmarketable size, command low price or regulatory restrictions [18, 42]. Most commonly bycatch species unintentionally caught during fishing with light operations include marine mammals, turtles, birds and invertebrates. Some of them are retained while others are thrown back into the sea due to regulatory purpose. The survival rates for discarded by-catch as well as the impacts on marine ecosystem, are highly variable [12 reviewed in 2, 16, 26]. Bycatch leads to wasting of living resources, threatening of the population of endangered species, changes in trophic structure [3, 15, 34]. Because of persistent decline in the global fish landings and increased competition for depleted stocks, the socio-economic and ecological arguments to decrease bycatch have received much attentions from policy makers and general public [3].

After the 30 days Hauling experiment for the catching tendency of Bagan Rambo in Makassar Strait by [57], they reported that the catches could be grouped into 3; the Main Catch (which include the pelagic species, anchovy, squid, mackerel); the By-catch (*Caesio sp, Siganus sp, Caranx sp, Theropon sp, etc) and the Discard catch (Apogon sp, Priachantus sp, Anomalps sp, Amanses sp, Chanda sp, Chantigaster sp* ,etc.) with average of discard rate of 2.18% during 30 hauling. Some reasons for discard catch are; inedible, unmarketable and unfamiliar by the people. Comparison was made between the Main Catch and the Discard for each hauling during the experimental days as shown in Figure 14. Discard catch was very high in day 7 but tends to decrease as hauling day progresses. It was also found out that by-catch species predominantly vertebrates and invertebrates were to be discarded and were of higher quantities than the main catch. This leads to waste of resources, affects the population dynamics and results to economic loss.

The experimental fishing conducted by [58] in the coastal areas off Prachuab Kirikhan, Chumporn and Surat Thani provinces of Thailand between May 29th to June 26th, 1987 which aimed to analyse the catch of Indian squid, *Loligo duvauceli*, by light luring fishing in relation to the abundance of other species and the size structure of main by-catch species, Indian mackerel, *Rastrelliger kanagurta*. Sixty experimental light luring fishing were made using stick-held cast net (2.5cm mesh) with a mouth surrounding length 50m and thirty four incandescent bulbs (500W) including two red spot-lights on board the research vessel SPT-9 (14.8m, 74HP) from the Eastern Marine Fisheries Development Center, Rayong. Six bamboo poles (6m length) having bulbs were made to stand out from vessel. The result showed that the catches were made up of the high diversity of pelagic and demersal fish. Five species of Cephalopoda (51.31%), twelve commercially important fish groups (38.68 %), other twelve fish groups (5.19%), two crustaceans (0.28%) and unclassified fish and crustacean (4.54 %).

[61] reported that squid fisheries may experience significant interactions with marine mammals, sea-birds and sea turtles. Some species of marine mammals, e.g Sperm whales, prey on squids and therefore might approach jigging vessels. Jigs pulled through the water column in a faster rhythmic jerking movement might pose a greater danger of accidental hooking. [14] reported the results of monitoring interactions between marine mammals and the squid jigging fleet in the central Patagonian coast. Records of the interactions were made but not quantified but Southern Sea-lions and Commerson's dolphins were reported entangled with the lines of jigging machine, prey on squids and scatter the school. [1] cited by [25] argued that squid fishing have very low fish by-catch and was regarded to be highly selective fishing method in Maldvies coast. The most commonly caught by-catch by the High Sea, US squid jigging fleet are small number of blue sharks whose weight break the 30-60lb test-line.

Other impacts of light fishing include;

- Greenhouse gas emissions: The annual carbon-dioxide gas emission from 110,000 pressurized kerosene lanterns was estimated to be 85,000 Metric tons per year. This can contribute to global warming.
- Kerosene spillage
- Human Health

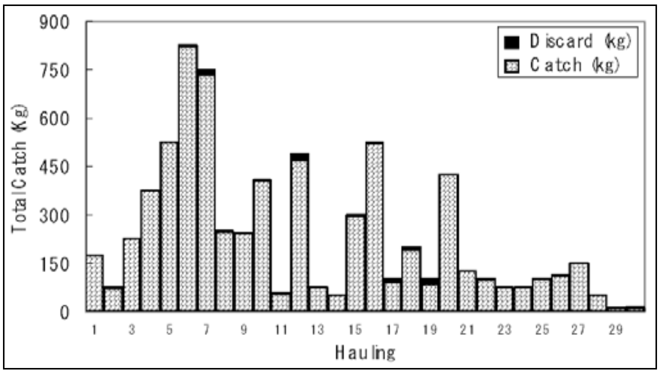

Fig. 14: Comparison of catch and discard each hauling of Bagan Rambo [57]

5.0 General Control Measures

During night fishing, there is evidence, as discussed earlier, that the use of small boats – skiffs using underwater lights to attract fish and the main vessel catching bait – can increase catch rates [49], as can employing above water lights in addition to the usual underwater ones [52, 23]. This statement was strongly supported by [5] that with continuous perfection and advancement in light and lighting technology, light fishing operation becomes one of the highly effective fishing methods. However, as noted above, there is evidence that using lights to aid in bait capture can substantially increase incidental capture of juveniles and by-catches, so caution and management actions are required. A combination of actions are therefore needed to rebuild the small pelagic stocks and for these actions to bring desired results of stock recovery and sustainable fisheries, all stakeholders, including the fishermen, fish processors, fish mongers and the government (co-management), must work together and follow the agreed rules with proper monitoring and surveillance.

The specific instruments considered are discussed below;

5.1 Input and Output Controls

Input controls describe the capacity and efforts of the fishing fleets and seek to limit the total size and the fishing activity of the fleet which can eventually reduce fishing mortality on the entire species complexes i.e multi-species fisheries.

Catch controls in form of fishing limitations and quotas can help to directly and indirectly reduce fishing mortality on target species and protect the associated species (by-catch) as well [11]. Issuing of licenses to fishermen with canoe or vessel registration will ensure proper monitoring, control catch and effort and long term sustainability of fish stocks. Fishing ban is also another tool that ensures fish stock sustainability. Fishing with electric light was recently forbidden in Ghana [51].

5.2 Technical Measures
Size selectivity of target species is achieved through the adoption of mesh size restrictions which helps to avoid capturing of target species at their immature stage. This allows them to grow bigger and have the ability to spawn at least once before they are caught. Reduction of non-target species selectivity is effected using By-catch Reduction Devices such as Turtle Excluding Devices, sorting grids that allow unwanted by-catch to escape. Spatial and temporal control on fishing is achieved by restricting fishing activities to certain closed areas (establishment of Marine Protected Areas) and seasons of the year. These help to protect the spawning biomass which can replenish surrounding fished areas [11]. For instance, fishery closure was imposed in the Bay of Biscay (Figure 15) off the coasts of France and Spain and within few years later the fishery returned to a more healthy state.

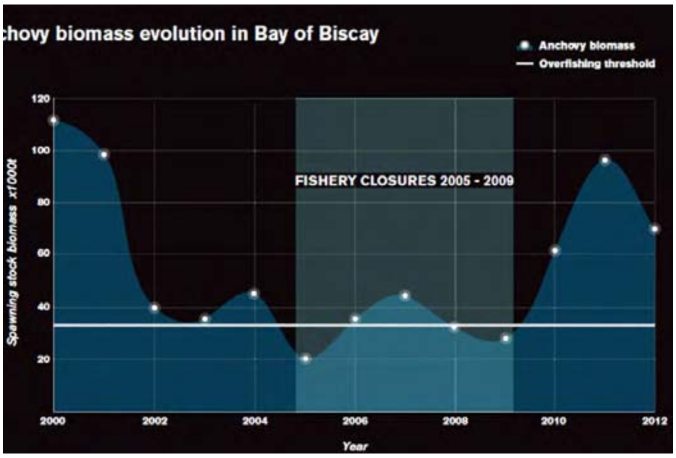

Fig 15: (Source credit: Oceana Magazine Fall 2012: "Anchovy's Return")

6. Conclusion and Recommendations
Light fishing at present acts as a good means and efficient way of obtaining adequate catches of bait-fish and cephalopods such as sardines, herring, anchovies, mackerel, squids, etc. Light fishing itself is not necessarily destructive but tends to eliminate traditional rest period of fish and pose more problems or have negative impacts on sustainable fisheries than expected coupled with and exacerbated by non-selective unregulated fishing gears used (purse-seine and lift-net).It is therefore important that fishing regulations (mesh-size, closed seasons, closed area, etc) should be in place, enforced and monitored which can serve as positive resource management measures. Furthermore, strict compliance with the light fishing ban is one way to reduce fishing effort, allow fish stock to increase and give rest period to grow and reproduce. Governments should also provide alternative sources of income for the fishermen. In addition, an environmental-friendly light fishing technology should be researched on and enforced in the near future [10] reported that it would be highly beneficial if the application of underwater illumination through the use of appropriate lamps (setting agreed maximum lighting output) coupled with selective fishing is adopted. This will conserve our marine environment by reducing the disturbance caused to all organisms involuntarily.

7.0 Acknowledgements
We would like to thank Dr Thava Palanisami of the University of Newcastle, New South Wales, Adelaide, Australia for his proof-reading, reviewing, criticisms, insights, inputs, corrections/adjustments and suggestions made for the successful write up of this paper. Special thanks to German Academic Exchange Service (DAAD) for their financial support.

8.0 Competing Interest
The authors declare that no competing interest exists.

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