Journal of Entomology and Zoology Studies

Available online at www.entomoljournal.com

E-ISSN: 2320-7078
P-ISSN: 2349-6800
www.entomoljournal.com
JEZS 2021; 9(3): 415-422

Received: 19-03-2021
Accepted: 21-04-2021

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Techniques to squid jigging in India: A review

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DOI: https://doi.org/10.22271/j.ento.2021.v9.i3f.8743

Abstract
The harvest technology of the high-valued squids has seen marked various developments, and Japanese fishermen are instrumental in the developing squid jigs and jigging technology. The technology spread from Japan to other parts of the world, including India, where it has been reported to be in operation since 1917 has been steady. The article discusses the various developments in squid jigging practices in India, and overview of technological aspects of the squid jigging.

Keywords: cephalopod, squid, jigger, jigging, LED lighting

Introduction
Squids are the significant contributors to the cephalopod fishery of export quality. The world production of squid was reported as 82% of the total cephalopod production, with a contribution of 2.98 million tonnes in the year 2010 [1]. In Indian waters, *Loligo duvauceli* (the Indian squid) is the dominant species that accounts for around 97% of the total annual squid production [2, 3]. Squids have been captured as a by-catch with trawl nets, boat seine, purse seine, traps, etc. Although these methods catch squid, squid jigging is the most appropriate commercial exploitation method [4]. Jigger is the specialized gear for resource-specific fishing of squid that has been developed in Japan. 'Jig' is a spindle-shaped structure with hooks fixed circularly with a lead weight at the end with or without a baitfish. In Squid Jigging, jigs act as lures that are intensely colored to attract squids. At present multiple mechanical jiggers are commercially used in Japan [5]. This method yields 90% of the total capture in the Japanese squid fishery [6]. This selective, reliable, effective method was slowly emerging into India. Now, the Indian waters engaged with squid jigging in small vessels and deep-sea vessels. Nowadays, we can get squid jigs all over the world through easily accessible online markets.

Historical development of squid jigging
In the early times, Japan was accomplished with simple pole and line jigs and hand-line jigs and pine-root torches for light attraction. During the year 1458, a prototype of modern squid jigging was invented especially for small-scale fishery of the Japanese flying squid (*Todarodes pacificus*) in Sado Island. It was a hand-operated squid jig with several hooks arranged in its axis and attached to a sinker [1]. In the modern squid jigging, fishing gear and methods are an improved version of the ancient squid jigging method, where the pine-root torches were subsequently replaced by kerosene, acetylene lamps and electric incandescent lamps [5]. Mostly mechanized boats (10-30t) using handline jigs and battery-powered lamps in the 1930s at inshore waters. After few decades, an improved method arrived that used serial jigs connected to lines, manually operated with drums and line reels. In the 1960s, the squid jigging method had developed from traditional to automated and with illuminated lights[7]. From the 1970s, ocean-going vessels (100-300t or up to 500t) started operating the complete automation of the entire fishing operation. This operation extended from the Japanese to Australia, New Zealand, West Africa, and the East coast of North America [5].

Squid jigging in the Indian context
From 1917, the squid jigging methods started in India, reported the primitive squid jigging by Hornel [8]. Different types of implementation and technological innovative ideas have a crucial role in the fisheries sector to achieve economic, social benefits and increasing the country's Gross Domestic Products (GDP). Usually, Fish Aggregating Device (FAD) used to promote

squid accumulation and their productivity in cephalopod fishery. Squid jigging vessels, in Indian waters, i.e. indigenous craft like 'vallam' with 4 to 5 persons and 'catamaran' assisted with 3 to 4 persons. In addition, plants like *Tephrosia purpurea* (Kozhiniji), *Prosopis spicifera* (Odai) have been used for FAD which has a capacity of up to 8 months and also with artificial jigs from local markets [9, 10]. The recent innovations in the squid jigging system include modifying the jigging gear and craft, automated machines, electronic finding equipment, low energy consuming lights (LED), low fuel consuming engines, and the selective practices of squid jigging. Surveillance with satellites is done to regularly monitor the fishing effort and ensure that the fishermen abide by fishing regulations in India [11]. There are three types of jigs that can be operated in India: (i) local jigs, (ii) jigs with LED lights, (iii) imported jigs [12]. Fishing by jigging is an essential method to exploit squids selectively and avoid overexploiting to conserve resources and energy. One of the rich regions for oceanic squid abundance was observed in the deep waters of the central Arabian Sea [12]. Those fast-growing, oceanic squids can be exploited by the deep-sea squid jigging vessels.

Status of cephalopod fisheries in India

The exploitation of cephalopods was increased rapidly after the 1960s. The perennial increase in export of frozen squids and cuttlefishes is a trend from 1975 onwards [13]. Certain developing countries like India consider squid rank next to shrimp as the most crucial seafood for export. In the case of Indian frozen squid exports, which have increased to 21.53% INR value and 17.46% in US dollars, and unit value also increased to 32.95% in 2012 [14]. In the beginning, the commercial cephalopod production was 1,636 tonnes as by-catch in 1968 and was more than double in 1974 as there was a demand for the export of squids and cuttlefishes. A progressive rise in demand and export increased the production of cephalopods in India. For instance, cephalopod production was around 31,500 tonnes in 1985 has risen to 42,500 tonnes in 1986, while slight falls appeared in the production of cephalopods in 1987 and 1988. Then there was a recovery in further years. In 2020, cephalopod production was around 2.17 lakh tonnes, with squid, cuttlefish and octopus landings at 1.12 lakh tonnes, 0.92 lakh tonnes and 0.12 lakh tonnes respectively [15, 16].

Seasons for squid exploitation vary throughout India. From January to March and October to December is the most productive period of squid species along northeast and northwest coasts. In southern coasts, equal productivity was observed from July to September [3]. Teuthoidea (squids), Sepiida (cuttlefishes), Octopoda (octopus) are three cephalopod orders that have been exploited in India. The most dominant species are *Uroteuthis duvauceli* (*Loligo duvauceli*), *Sepioteuthis lessoniana*, *Symplectoteuthis oualaniensis*, *Sepia pharaonis*, *Sepia aculeata*, *Octopus membranaceus*, *Octopus lobensis* and *Amphioctopus neglectus* [3, 17–19]. The Indian cephalopod fishery is majorly contributed by Kerala, Tamil Nadu, Gujarat, Karnataka and Andhra Pradesh [16].

Various squid fishery in India

Apart from these modern squid jigging practices, many traditional ways are used for exploiting squids in India. Some traditional hand-jigging gears are used for squid fishery on the southern coast of India. The gear 'Vidukayiru' made for cuttlefish resembles 'Achil' hook line that is mainly used for sardine fishery, 'Nangoora choonda' for cuttlefish, 'Nangoora choonda' for squid, 'Disco nangoora choonda' for cuttlefish. Those hand-jigs have been operated from catamartan at Vizhinjam [5, 20, 21]. Prawn-shaped jigs with a double circle of hooks (Japanese-made hand-jigs) have been used in Palk Bay and the Gulf of Mannar of Tamil Nadu [22]. Squid jigging has been used by plank-built vessels at Palk Bay and locally made jigs have been used in Thoothukudi, Tamil Nadu [10]. Fish Aggregation Device (FAD) assisted squid jigging has reported in Karnataka [23]. 'Garkadi' is the local name for squid jig, usually carried out at night in Ratnagiri coast of Maharastra, with halogen lamps and motorized vessels [24, 25]. Squid jigging with FRB fishing boats and wooden jigs made by the fishermen are found in the Kombudurai region of Thoothukudi [26]. Other than these traditional hand-jigs, modern jigs are also being used by fishermen in India. Several other fishing methods were used for squid fisheries which are as follows:

a. Shore Seines such as 'Ola valai' in Palk Bay [27]; 'Sarini jal' in West Bengal; 'Pedda vala' and 'Alivi vala' in Andhra Pradesh; 'Kara valai' and 'Peria valai' in Tamil Nadu; 'Kara vala', 'Kara madi' and 'Kamba vala' in Kerala; 'Rampan' and 'Yendi' in Karnataka.
b. Boat seines such as 'Turi valai' in Tamil Nadu, 'Iraga vala' in Andhra Pradesh, and 'Thattu madi', 'Kolli vala' and 'Paithu vala' in Kerala.
c. Dol net, trawl, traps used in Maharashtra and Gujarat.
d. Harpooning or poisoning coral rock pools with the grated seed of '*Barringtonia*' in Malacca Bay, Car Nicobar.
e. Spearing with iron rods in Lakshadweep Islands [28, 29].

Emerging of squid jigging

Globally, about 40% of the cephalopod catches are taken by squid Jigging and 25% by trawling [30]. The squid jigging method is very selective and brings larger squids when compared to aimed trawling for squids and other cephalopods [4]. Since the use of lining and jigging for fetching fresh catch, the value of the commodity is very high. Though the hand-jigging fishery was developed during the 1970s, the Indian cephalopod landings were made as by-catch by trawlers and shore-seiners until the late 1980s [10]. In 1981, experimental squid jigging operated from a Fishery Survey of India (FSI) vessel, but it did not give positive results due to lack of expertise [4]. Marine Products Export Development Authority (MPEDA) carried out experiments in 1985 at Cochin and Vizhinjam. They have done experiments with manual squid jigging and dip net by 13 m onboard vessel because these two methods are standard for pelagic squid fishery in Japan, and it yielded 102 squids per hour. It indicated the technical feasibility of operating those gears in the Indian coastal waters [2, 30]. At the end of the late 1980s, FSI revealed cephalopod ground potential along the Indian coast, where it introduced a vessel named Matsya Sugundhi and the automated squid jigging method for exploration of squid resources. The depth of operation of vessels ranges from 25 to 200 m for neritic squids, and 500 m for oceanic squids. The result was 96,213 kg of fish caught using 823 hauls. FSI also reported that an average catch along the southwest coast was 6 squids per hour by automated squid jigging, while in 1990, the average catch reported was 4 squids per hour by hand-jigging method along with the Gujarat coast [2, 3, 31]. Central Institute of Fisheries Nautical Engineering Training (CIFNET) experimented with the high-opening bottom trawl in harvesting the squids along with Gujarat and Tamil Nadu

coast (as a part of the Bay of Bengal program), and it resulted in a 24.1% contribution of cephalopod catches. Fishery Survey of India conducted another experiment on the depth-wise distribution of cephalopod with a bottom trawl, which showed the west coast was more productive than the east coast [2]. There are many surveys and experiments conducted in India i.e. Indo-Pacific region recorded by R, V, SHOYA MARU of Fishery Agency of Japan in the North Arabian Sea; Drift nets have caught oceanic squids by R, V, KALAVA off the southwest coast [28, 32]. Pelagic trawl at different stations with a depth of 1000 to 3100m by FARV, SAGAR SAMPADA off Gujarat and Maharashtra, Goa and Kerala in the Arabian Sea and off Andhra and Orissa coasts in the Bay of Bengal. Squids were observed to be attracted to squid jigging vessels due to the phototaxis [29, 33, 34]. An exploratory survey conducted by CMFRI from 2008 to 2011 with a converted squid jigger MV Titanic and FSI vessel MV Varshini in the Central Arabian Seas, established the abundance of Purple back squid (*Sthenoteuthis oualaniensis*) in EEZ of India [19]. These government institutes have initiated the conversion of trawlers to squid jigger from Mangaluru. Further, this operation created commercial light fishing ventures and small-scale jigging with lights[25]. The light-assisted fishing leads to conflict between traditional fishers and purse seiners of Karnataka and Goa in 2018. The Government of India specifically banned pair trawling and prohibited using lights for fishing. However, in Kerala, the Kerala Fishing Boat Operators Association has approached to High Court for light assisted squid jigging in the Indian waters [35, 36].

Squid jigging technology

Technological aspects of squid jigging comprise structure and parts of squid jig, typical methods of squid jigging, and their principle behind the operation.

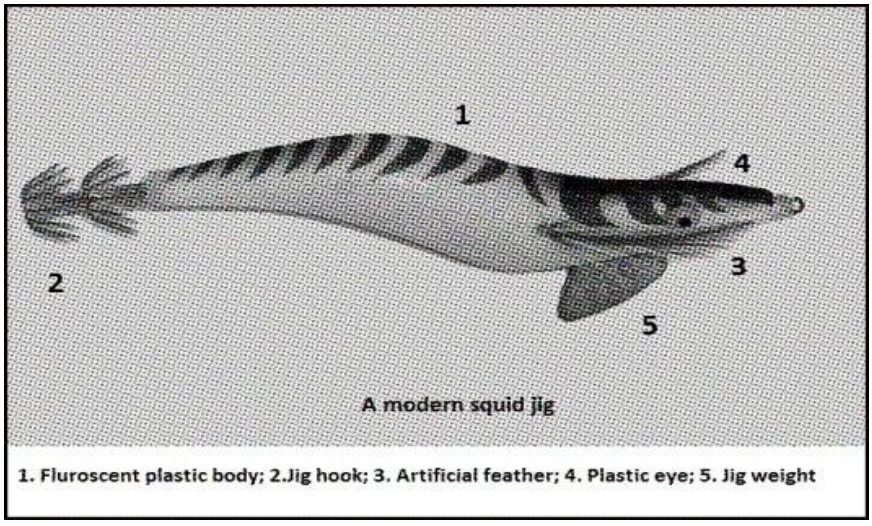

Fig 1: A modern squid jig's parts

Typical parts of a modern squid jig

Among different types of local and imported jig (Fig. 1), a typical jig consists of shrimp or stalk-like body made up of flexible plastic with one to three hooks or more sharp barbless steel hooks at end of the handline. It has rings at both ends (hook and stalk) are joining by steel wire through which a jig is attached to the line. It is operated by jerking or moving up and down, which is otherwise called 'Jigging'. Jigger may change in color (Fig. 2), shape & size (Fig. 3). The Jigging line is made by monofilament of polyamide (Nylon) because of their better transparency, efficiency, low visibility underwater, and a thinner line. Based on the operation and fishermen's experience, it may be changed [37, 38].

The handline jigging unit (Vertical line) has 15 to 20 jigs at regular intervals on the mainline of 20 to 30 m in length and weight at the end of the handline [5]. However, one squid jigging line may consist of 30 jigs [39, 40].

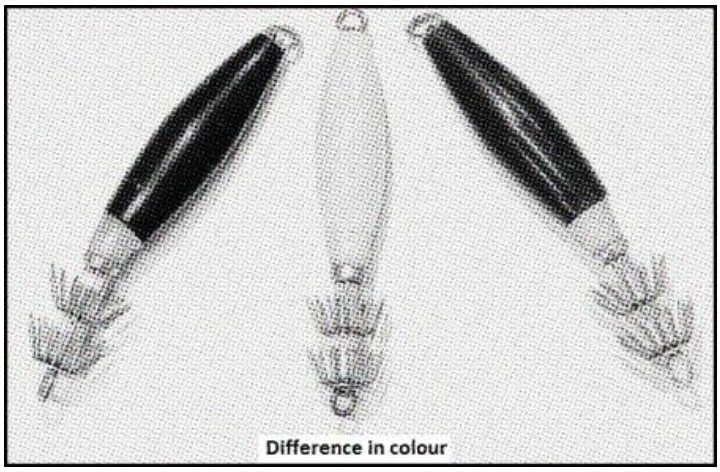

Fig 2: Squid jigs in different colors.

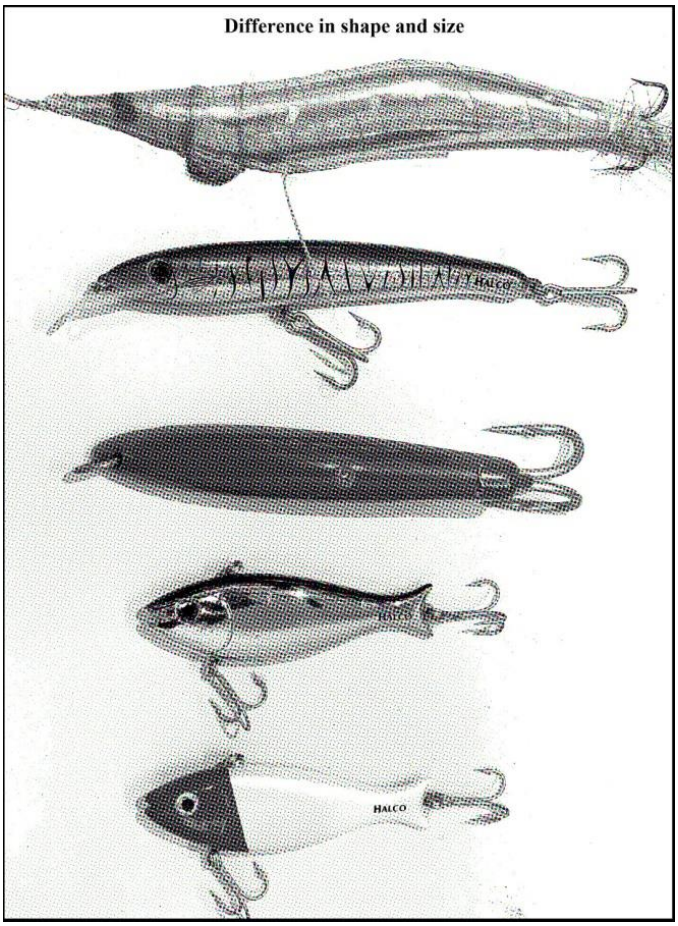

Fig 3: Differently shaped and sized squid jigs (with triple hooks).

Squid jigging machine

Squid jigging machine operated with squid jiggers either electrically or hydraulically. It consists of a guide roller, wire mesh frame, and bulwark to guiding the squids from hauled jig's hooks. Bjarnason & Carlesi stated that one squid jigging line consists of 8 to 12 jigs used on automated squid jigging machines[38]. But now, a mechanically powered jigging machine can be used with 15 to 30 jigs at each line [6].

Considerations on the selection of materials

Though the factory-made squid jigs are available in markets, the design of hand-made jigs changes based on the practical fishing experience of the fishermen, which in turn depends on the behavior of target species.

Twine

The squid type, size, and power of the vessel should be considered in selecting handlines of squid jigs. The feel or sensitivity of the line plays a key role in the success of the catch. Mostly monofilament nylon of thickness 0.80 mm, and breaking strength up to 15 kg are used [38, 39].

Hooks

Shape, size, number of hooks, materials and fish size & power are several factors that have to be kept in mind during the selection of hooks. For squid jigging, barbless hooks are more suitable. Modern technology has a jig with multi-prong hooks with two steps of barbless hooks in a circular axis [38] (Fig. 4).

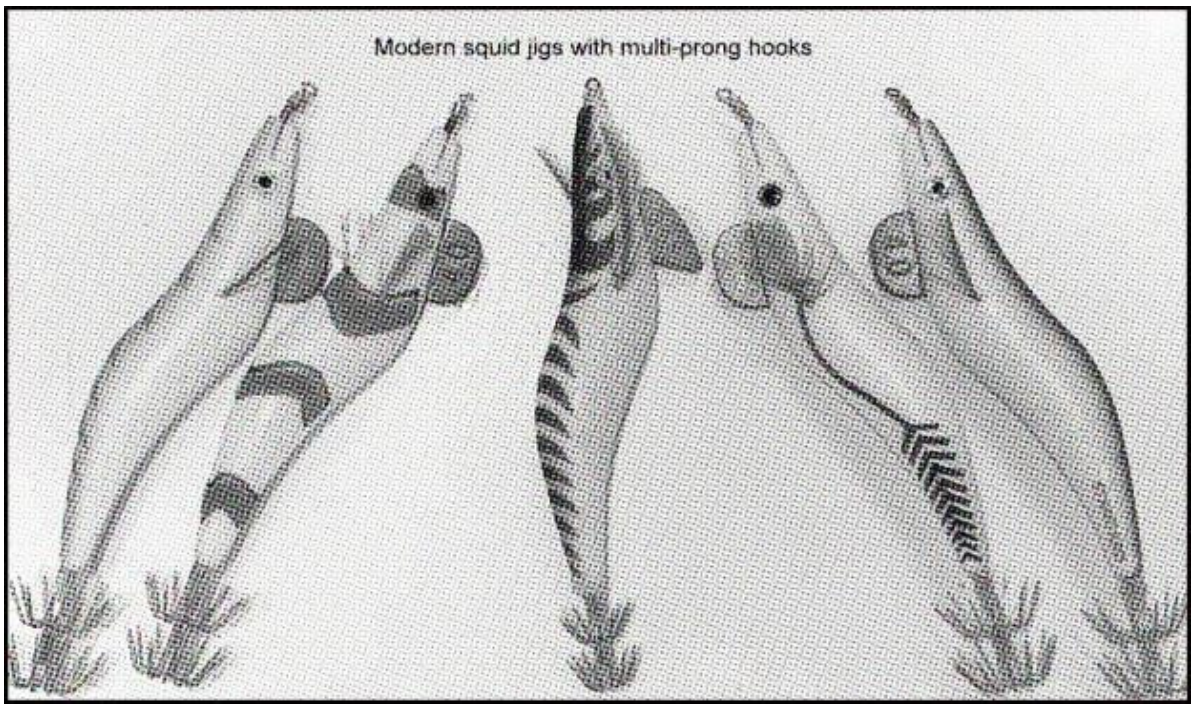

Fig 4: Modern squid jigs with multi-prong hooks.

Sinker

Lead, stone, clay, steel, etc can be used as sinkers, and 1.5 kg is optimal for a squid line [37, 38]. For squid jigging, most fishermen prefer to use lead as a sinker.

Swivel

Various types are available; it connects the snood to the mainline and mainline to the sinker. It is used to make strength, prevent twisting, for easy swiveling. It is mainly made up of brass or copper and steel).

Knots

Different types of knots are used to tie the lines, i.e. Japanese fisherman's knot for monofilament [37].

Lure
Wool, cotton, rope fiber, strips of cloths or plastics, feathers, thin twine, rubber are materials that can act as a lure. Artificial lures have different colors such opaque white, green, red, blue, purple ,and their fluorescent colors [37]. With or without bait, we can catch squids by jigging is possible.

Squid reel
The difference between a normal reel and the squid reel (Fig. 5) is elliptical or oval-shaped for creating up and down movement (jerking) of the reel during hauling and the hub of the reel should be thicker than a normal reel. The reel shaft and handle shaft should be a little wider than a normal reel [38].

Guide roller and wire mesh frame
Guide roller and wire mesh frame make the jigging more effective. Bulwark with steel frame (Fig. 5) is base for fixing the guide roller through which receives the fall off squid from barbless hooks and passing them into the vessel. Tangling and collapsing of the jigs with wire mesh netting are prevented by increasing the roller's height based on the operation (automatic or manual).

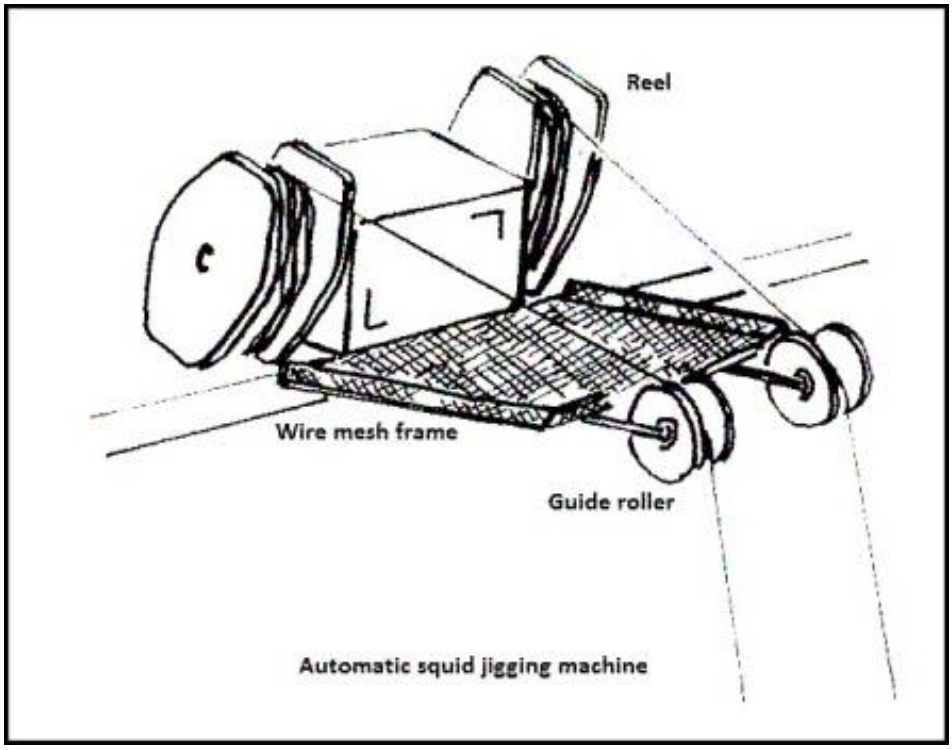

Fig 5: Automatic squid jigging machine [38].

Sea anchor
Strong weather, heavy rolling, and fast drifting of the boat will affect the efficiency of squid jigging. Rigging and the use of sea anchors, especially parachute anchors can minimize this problem [38].

Lights
At night more often fishermen catch squid by using light that illuminates in water as well as jigs to attract the squids to aggregate and bite the jigs. There are three points to be considered for determining the appropriate power of fishing lights for small-scale squid jigging fishery such as underwater irradiance distribution by the lights, the relationship of optical water to underwater irradiance and the behavior of squid towards the light intensity [38, 41]. Nowadays, Light-emitting diodes (LED) are available in markets, but studies are still emerging globally for squid fishing methods. A few years ago, Ulas & Aydin researched the effect of jigs color and lunar brightness based on statistical methods[42]. Red color jigs were found to be the most efficient and lunar brightness of the full moon phase showed a positive effect for catching the squids [42].

Typical methods of squid jigging
Among the different methods of squid jigging, based on local fishing conditions, materials or device assisting squid jigging, the four basic methods are as follows:

Pole and line or handline jigging
One rod for each line is operated in a suitable fishing ground. The gear consists of one line with a maximum of two branch lines. The stalk or stem of the jig is made up of wood, steel, plastic or bamboo with a sinker [40].

Serial jigging
Serial jigging with a pole differs from a line or handline jig, which has several jigs in a single jigging line. Immediately the line is hauled when squid gets entangled with jigs. Each line has 20 to 30 jigs arranged in an adequate interval and the end is tied with a sinker. Catch efficiency is affected by wear and tear of the jig, abrasion of monofilament on the guide roller, and on the line drum [40].

Hand-operated reel jigging
This type of squid jigging is mainly practiced in small vessels and multi-purpose vessels. A multipurpose vessel uses a handle on the drum to haul back the jigging lines. A wire mesh frame, outboard roller, bulwark are the parts of the hand-operated jigging machine. It guides the dropped-out squids into a box on the vessel's deck or to a conveyor system

that takes the squid to hold for freezing or icing. These fishing practices enhance the catching efficiency, smooth jigging and reduction of labor [38, 40].

Automated jigging machine

The machine operates two elliptical-shaped drums on one shaft and each central power steering unit. The machine operated by either an electrical drive (220 volt) or hydraulic drive, and about ½ hp (0.4kW) power required for one jigging machine. Usually, an automated jigging machine has a 0.75-1 mm diameter jigging line equipped with 30 modern squid jiggers [6, 40]. The light-assisted squid jigging vessels with automated machines to operate overnight in continental-self waters between the depths of 60 to 120 meter[38]. However, the speed of the fishing vessel determines the depth of operation [40].

Squid jigging operation

Squid jigging can be used in specialized vessels but may also be used for fishing from other types of fishing vessels[43]. Ancient fishing practices were based on celestial object, observing birds, mammals like dolphins, porpoises or single whale and floating objects, ripples or color changes on the surface, checking bottom using sinkers, etc. Advanced fish detecting devices such as echo sounder, sonar are being used in modern fishing practices. These help to adjust operational depth according to the concentration depth of squids. Due to the behavior of squids, they are being attracted by artificial lights and fast-moving bait or any bait-like object [44]. Squids are easily attracted to incandescent metal halide lamps. A single lamp is enough for a small fishing vessel. But, in the case of a large industrial vessel, there must be 150 or more lamps with 2 kW per lamp. Globally, around 95% of squid capture uses artificial lights as a primary component for harvesting with lure [45, 46]. During the early stages, burning a large fire on the beach was a regular practice; low-powered LED light installations are more efficient, increase catch rate, reduce by-catch, and energy efficient [46]. Essential accessories in a modern squid jigging vessel are divided into three: (i) jigging machine, (ii) sea anchor and (iii) array of lights [36]. The position of lights is also important, which influences the fishing efficiency at the time of operation. The shadow zone beneath the vessel's hull is crucial to maintain for effective fishing (Fig. 6). Squid avoid bright illumination around a jigger and accumulate in the shadow region under the vessel's hull [47]. Hence, in the middle of the vessel between the mizzen mast and foremast, lamps can be fixed horizontally. The attraction of the squid from deep seawater to the light or shade from above the deck light will occur when deep seawater squid jigging. The main aim of the fishing method is to place the jigs into the shadow boundary at the desired depth beneath the vessel. When the jigging lines are to be hauling vertically, congregated squids get entangled and then fall on the deck because inverting the barbless hooks will be released the squids [48]. During hauling, adequate hauling speed must be given; otherwise, squid may free from entangling [40]. Due to centrifugal force, falling off squids from the roller guide increased while rotating the drum with a faster angle velocity. Squid's falling off and jigging effects determined the hook opens. If the hook's angle is too small, the catch efficiency is raised and squid dropping out from the hook is reduced [47].

A special anchor (parachute anchor) is used for stabilizing the fishing vessel to improve the operational efficiency of the fishing method [49]. However, this method is effective due to enlarging the jig, widening the hooks and multi-step hooks.

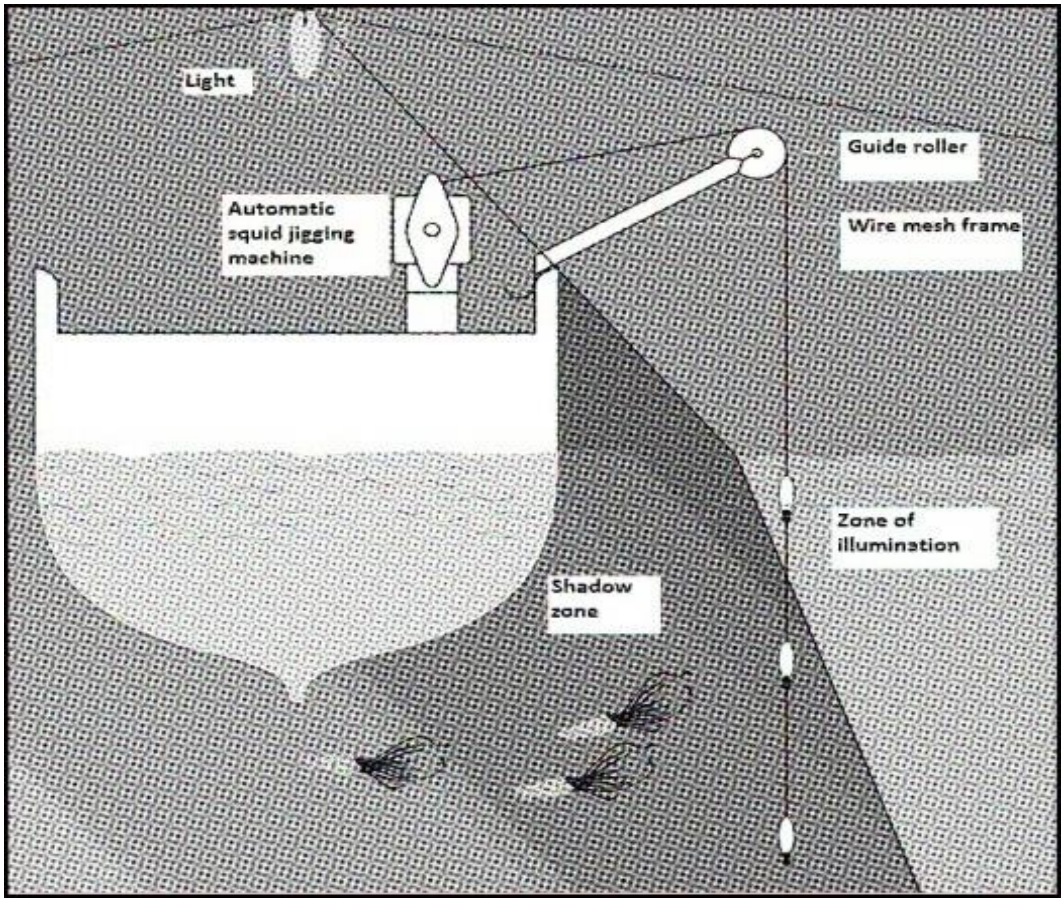

Fig 6: Zone of shadow (http://fish.gov.au/fishing-methods/hook-and-line).

Squid jigging vessel

Squid jigging is a versatile technology that can be adopted by near-shore, offshore and deep-sea fishing vessels. Primarily, squid jigging was a near-shore fishery by small-scale fishing vessels, but fishing vessels were enlarged and fishing ground extended due to the introduction of automation of jigging and increase in the value of squid [50]. Deep-sea vessel for squid jigging has almost 50 jigging machines, an engine with 1800 BHP (Break Horse Power), 150 bulbs (2 kW/bulb), in addition, three underwater lights (5 - 10 kW/light). Japanese has been developed an advanced bridge control of the jigging machines, which were operated in deep-sea squid jigging vessel [37, 51]. More vessels in Japan, followed by Korea and Taiwan, have been used bridge controls fitted with monitor and eco-sounder, which manage all jigging machine based on the depth of fishing [37]. Researches related to the advancement of squid jigging technology are still growing.

Considering factors to the efficiency of squid jigging

Many factors affecting the efficiency of squid jigging are jig structure, jigging motion, light intensity, sea state, sea temperature and lunar phase etc. During squid jigging with lights, some factors affect squid attraction, such as the quality of light (e.g. wavelength), the quantity of light (e.g. power), and the arrangement of fishing lights. These factors create underwater irradiance level and distribution influenced by the optical characteristics of seawater, and it influences squid behavior during fishing [41, 51]. However, the most considerable major factors are divided into three: (i) Lunar phase and light intensity, (ii) Wind direction and tide, (iii) Squid abundance [36].

Conclusion

Squid jigging is the best fishing method for selectively harvest a higher quantity of Oceanic squids in the Indian deep seawaters. So, encouraging deep-sea fishing can be lead to more squid jigging methods in India. On the other hand, most of the Indian squid fishery is occupied by small-scale fishing system where the boats of 20 m size are optimal for squid jigging. Traditional fishing vessels like 'vallam' and other fishing vessels can be modified and best applied for squid jigging. There are different type of squid jigs which differ in the machine used, parts and method. The cost of jigs needs to be improved, and technologies feasible for all levels of the fishing community in India and indigenous squid jigs can best achieve it. Cheap and low-cost technology in the field would improve the efficiency of squid jigging and can be enhanced squid jigging methods in India.

Declaration of competing interest

The authors declare that there is no conflicts of interest.

Acknowledgement

The authors are grateful to T. Ravikumar and S. Aanand (Tamil Nadu Dr. J. Jayalalithaa Fisheries University, Nagapattinam, Tamil Nadu, India) for their support and encouragement during preparation of the figures and the manuscript.

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