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REVIEW

Environmental–Economical Aspects of *Protonibea diacanthus*: A Heavily Priced Marine Fish of India

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Abstract A comprehensive review of *Protonibea diacanthus* (PD) focused on India's coastal waters was conducted, with the aim to improve understanding of its spatio-temporal distribution and scope of aquaculture/mariculture. PD is one of the most commercially important fish due to its food value and medicinal properties of its body parts. As this fish is usually exported from India, occasional catch yielding in instantaneous higher income (reaching 3.45 crores INR for 20 tonnes catch per unit effort) has caused exhilaration in the regional fishing community. PD is caught occasionally during regular fishing operations in different parts of the Indian maritime states with a higher number of catch events along the west coast (maximum in Maharashtra) in comparison to the east coast (maximum in West Bengal). In context to fishing gears, PD is caught by the Indian fishermen using bottom trawls, handlines, and gillnets, and purse seines. The swim bladder of PD has a higher medicinal value, thereby the selling price of dried male air bladder has reached up to ~ 40,000 INR/kg. The literature review confirmed that inshore migration of PD is driven by the seasonal availability of food, and river influxinduced low saline conditions. Seasonally, the post-southwest monsoon has been observed as the productive season for PD fishery in India. Considering the rising demand in the international market, this study recommends initiation of aquaculture/mariculture of PD in India, which requires species-specific research, technology development towards captive breeding, seed production, larval rearing, feed management, relevant post-production industrial processing, and a proper marketing strategy.

Keywords Arabian Sea · Aquaculture · Bay of Bengal · Blackspotted croaker · Pharmaceutical Products

Significant statement: This article deals with a comprehensive review of one of the most heavily priced marine fish (*Protonibea diacanthus*) of India and has a broad interest. This review highlights the capture methods, including the fishinggear, different commercial use, potential capture locations, seasonality, and future research directives towardthe development and implementation of aquaculture/mariculture practices in India.

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Introduction

Protonibea diacanthus (commonly known as blackspotted croaker) is a demersal marine/brackish fish found in coastal and estuarine regions [1]. This is one of the commercially important fish in the world ocean and is acclaimed as the most expensive marine fish in the Indian waters [2, 3]. The body parts of *P. diacanthus* (hereafter PD) are utilized in the preparation of food, pharmaceutical, cosmetic, and packaging industries. Most significantly, PD body parts are used in pharmaceutical products to cure kidney stones and to make dissolvable stitches, which is why it is so pricey [4, 5]. PD is native to several Indo-Pacific countries viz. Australia, Bangladesh, China, Taiwan, India, Indonesia, Iran, Japan,

Malaysia, Myanmar, Oman, Papua New Guinea, Philippines, Sri Lanka, Thailand, Viet Nam, etc. [6, 7].

In the context of the Indian waters, PD is sporadically caught by fishermen during regular fishing operations in all maritime states (Fig. 1, Table 1). The capture of this species, which results in instantaneous high income for the fishermen, has been reported in several local news (print and electronic) media (Table 1). Some snapshots of PD catch in different parts of the Indian coast are presented in Fig. 2. PD is usually exported from India to other countries with the reported higher selling price of ~ 16, 000 INR per kg, which has caused exhilaration in the regional market and local fishermen community [8]. However, there is a paucity of scientific literature/business-reports on PD fishery in India. Although the PD fishery is not extensively documented in Indian waters, its high commercial significance, rising demand in the international market, enthusiasm among regional fishermen and fishing businesses necessitate an effort to comprehend its spatio-temporal occurrence and captive culture scope. Against this backdrop, the present study attempts to provide a scientific basis for the PD fishery in Indian waters.

Taxonomic Position of *P. diacanthus* and Regional (in India) Nomenclature

PD is commonly known as "Blackspotted Croaker". The taxonomic nomenclature history of PD reveals several synonyms. A detailed account of PD taxonomy is given in Table 2 highlighting the presently accepted name as *P. diacanthus* [9]. In the Indian context, PD is differentially known with a multitude of common names with respect to regions (i.e. maritime states). In Gujarat, Maharashtra, and West Bengal, PD is commonly known as Ghol; in Kerala as Cherukora, Kora, and Pallikora; in Tamil Nadu as Kathalai, Kooral, Panna, Vanakathalai, and Vellaikathalai; in Andhra Pradesh as Gorasa, Nella-katchelee, and Pullipanna; and in Odisha as Telia. Over the years, several scientific literatures on PD have used different taxonomic nomenclature and regional media reports used different local names of PD. Therefore, it is very important to consider all the nomenclature and regional names while mining data for PD and literature surveys to study its physiology and ecology.

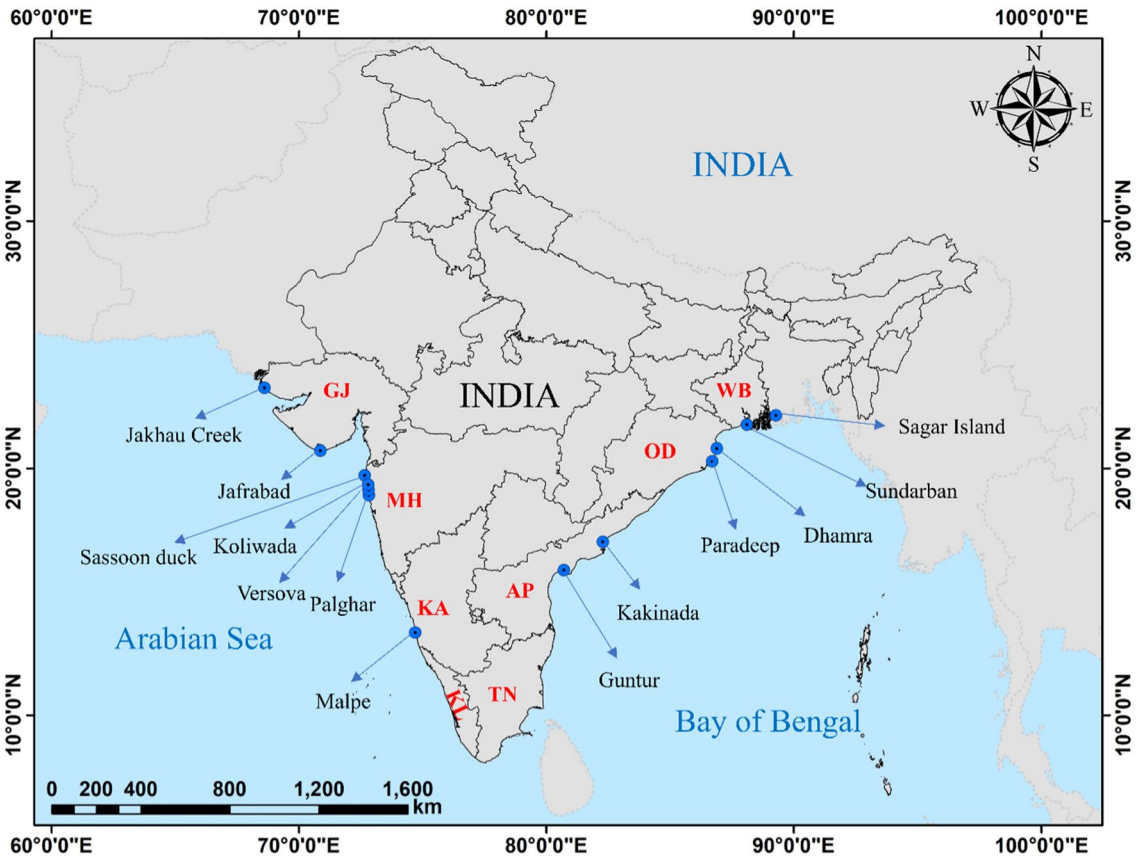

Fig. 1 Map showing *Protonibea diacanthus* capture locations in the coastal waters of India. GJ: Gujarat, MH: Maharashtra, KA: Karnataka, KL: Kerala, TN: Tamil Nadu, AP: Andhra Pradesh, OD: Odisha, WB: West Bengal

Table 1 Capture-commercial fishery fact sheet of *Protonibea diacanthus* in India. The Indian maritime state to which the landing location belongs is given in the parentheses. (Source of information: supplementary material)

Region (State)	Period	Nos/weight / counts	Length (mm)	Cost (INR)
East Coast of India				
Sundarban (West Bengal)	October 2021	75 kg	2134	36.53 lakhs
West Bengal	September 2020	52 kg	–	3 lakhs
Digha (West Bengal)	October 2021	33 nos	–	1 crore
Digha (West Bengal)	November 2021	27 kg	–	4 lakhs
Bhadrak (Odisha)	October 2020	22 kg	–	1.56 lakhs
Bhadrak (Odisha)	June 2019	30 kg	–	1.8 lakhs
Paradeep (Odisha)	June 2021	28 kg	–	5.80 lakhs
Paradeep (Odisha)	March 2019	28 kg	–	1.1 lakhs
Palghar (Maharashtra)	August 2021	157 nos	–	1.33 crores
Kakinada (Andhra Pradesh)	June 2021	–	–	5 lakhs
Kakinada (Andhra Pradesh)	November 2021	21 kg		2.6 lakhs
Guntur (Andhra Pradesh)	September 2020	24.8 kg	–	1.4 lakhs
West Coast of India				
Malpe (Karnataka)	November 2021	20 kg	–	1.90 lakh
Palghar (Maharashtra)	August 2018	30 kg	–	5.5 lakhs
Pachubunder jetty (Maharashtra)	July 2021	30 kg	–	5 lakhs
Raigad (Maharasthra)	January 2013	20 tonnes	–	3.45 crore
Maharashtra	October 2006	8.82 tonnes	–	–
Versova (Maharashtra)	November 1984	5.50 tonnes	700–900	–
Satpati (Maharashtra)	November 1986	39.52 tonnes	85–120	–
Bassein Koliwada (Maharashtra)	October 1992	3.48 tonnes	810–1560	–
	October 2002	5.26 tonnes	690–1210	–
	October 2006	8.82 tonnes	800–1100	–
	October 2007	20.05 tonnes	660–1179	–
Bedi Port, Jamnagar (Gujarat)	1957	7.96 tonnes	–	–
	1958	7.76 tonnes	–	–
	1959	7.13 tonnes	–	–
	1960	7.04 tonnes	–	–
	1961	15.03 tonnes	–	–
Vanakbara (Gujarat)	October 2021	1500 nos	–	2 crores
Jakhau (Gujarat)	July 2021	380 nos	–	80 lakhs
Jafrabad (Gujarat)	December 2018	10.7 tonnes	679–1298	1.10 lakhs
Jakhau (Gujarat)	April 2012	350 nos	–	70 lakhs

P. diacanthus: Commercial Perspective with a Focus on India

India is the second-largest fish producing and second-largest aquaculture nation in the world after China [10]. The marine fishery potential of India is ~ 4.41 million tonnes [11]. India exports several marine fishes (raw and processed) for a multitude of end-use. However, there is no particular information available for PD, which is attributed to non-periodic catch, no proper reporting, and the existence of intermediary between fishermen and export agencies. In India, PD has emerged as the most expensive fish due to its record-breaking price at fish auctions [3, 12]. Based on the available information in literature and media reports, a brief account of the commercial perspective of PD is discussed below.

The body parts of PD are utilized in the preparation of specific food supplements, pharmaceutical products, photographic products, cosmetic products, and specific materials used in packaging industries. In the food industry, possibly PD gelatin is used as a food additive that improves the elasticity, consistency, and stability of foods. It is also used in some medical and biotechnological applications [13]. The bladder of PD is reported to cure kidney stones, and its heart is believed to boost sex power and immunity. PD fins are also known to have therapeutic properties. PD also contains a variety of vitamins, minerals, and proteins that aid in eye health [5]. PD skin has been reported as a greater source of high-quality collagen, which is used in the manufacturing of functional food and many cosmetic

Fig. 2 Electronic media images showing *Protonibea diacanthus* capture in the Indian coastal waters. **a** Jafrabad (Gujarat), **b** Paradeep (Odisha), **c** Kakinada (Andhra Pradesh), **d** Gujarat, **e** Guntur (Andhra Pradesh), **f** West Bengal, **g** Palghar (Maharashtra), **h** Gujarat, and i) Paradeep (Odisha)

Table 2 Different taxonomic nomenclature of *Protonibea diacanthus*

Synonymised names	Classification	
Lutjanus diacanthus,	Present accepted name: *Protonibea diacanthus*	
Johnius diacanthus,	Kingdom	Animalia
Nibea diacanthus,	Phylum	Chordata
Pseudosciaena diacanthus,	Subphylum	Vertebrata
Protonibea diacanthus,	Infraphylum	Gnathostomata
Sciaena diacanthus,		
Protonibea diacanthus,	Gigaclass	Actinopterygii
Corvina catalea,	Class	Actinopteri
Corvina platycephala,	Subclass	Teleostei
Johnius valenciennii,	Order	Eupercaria
Sciaena goma,	Family	Sciaenidae
Corvina nigromaculata,	Genus	*Protonibea*
Sciaena antarctica	Species	*Protonibea diacanthus*

(Source: https://www.marinespecies.org/)

products [13]. PD derivatives are also considered a great substitute for porcine and bovine gelatin [3].

It is important to mention here that among several body parts, the swim bladder of PD is highly valued due to its medicinal properties [14]. The swim bladder of PD is used as a traditional functional food because of its high collagen content, which is thought to promote brain function, keep endocrine balance, and regulate immune function [15, 16]. PD weighing in the range of 10–15 kg and 15–25 kg yield 350–450 g and 500–700 g wet weight of bladder, respectively. Dried air bladders of males range in length, breadth, and weight from 132 to 180 mm, 120 to 170 mm, and 100 to 290 g, respectively. The length, breadth, and weight of a female PD's dried air bladder vary from 155 to 190 mm, 145 to 190 mm, and 180 to 400 g, respectively [17]. A comparative account of the commercial value of the PD air bladder is given in Fig. 3. The cost of a dried air bladder for both males and females is much higher than the fresh air bladder. The commercial price of a male PD air bladder is more than that of a female PD air bladder.

Capture Fishery Events of *P. diacanthus* in Indian Waters

PD is occasionally caught by fishermen of all Indian maritime states (West Bengal, Odisha, Andhra Pradesh, Tamil Nadu, Kerala, Karnataka, Goa, Maharashtra, Gujarat) (Table 1). There is neither any specific fishing method for PD nor is this a target capture fish in India. Indian fishermen catch PD sporadically during routine fishing activities. A detailed list of PD catch events in different parts of the Indian coast is given in Table 1. A higher number of PD catches were observed on the west coast in comparison to the east coast of India. Among the Indian maritime states, maximum numbers of PD catches are noticed in Maharashtra followed by Gujarat whereas the lesser number of instances are from Karnataka. Along the east coast, a higher number of PD catch instances were observed from the coastal stretch of Digha (West Bengal). On the west coast, a higher number of PD in terms of weight (about 40 tonnes) were caught from Satpati (Maharashtra). The highest selling price (3.45 crores INR) of PD has been reported from the Raigad (Maharashtra) region for a catch of 20 tonnes (Table 1). In the northernmost coastal state of India (i.e., West Bengal), PD landings have been reported at the fishing harbours at Frasergunj, Kakdwip, Sundarban, and Digha [14]. In coastal Odisha, a couple of PD landing events have been observed in the Paradeep region. A recent report from this region says fishermen who captured PD (~33 numbers) have been moved to Digha for selling it at a relatively higher price. This suggests that there is no adequate framework in place in India for the export of PD (Table 1). There are several reports on instantaneous high income for the fishermen for selling PD; however, no particular information is available on its marketing strategy and end-users. As per the information compiled in Table-1, PD caught in India is mostly exported to Hong Kong [18]. Due to the higher commercial yield, there is an increasing interest among the local fishing communities and fishery industries regarding its seasonal availability pattern, the potential location of aggregation, knowledge on PD body parts for commercial use, and scope of aquaculture/mariculture. The following sections discuss the aforementioned facts based on available literature and reports.

Environmental Condition Preference of *P. diacanthus*

PD is demersal marine-brackish fish and is generally found in coastal waters over muddy bottoms [1, 6]. This species

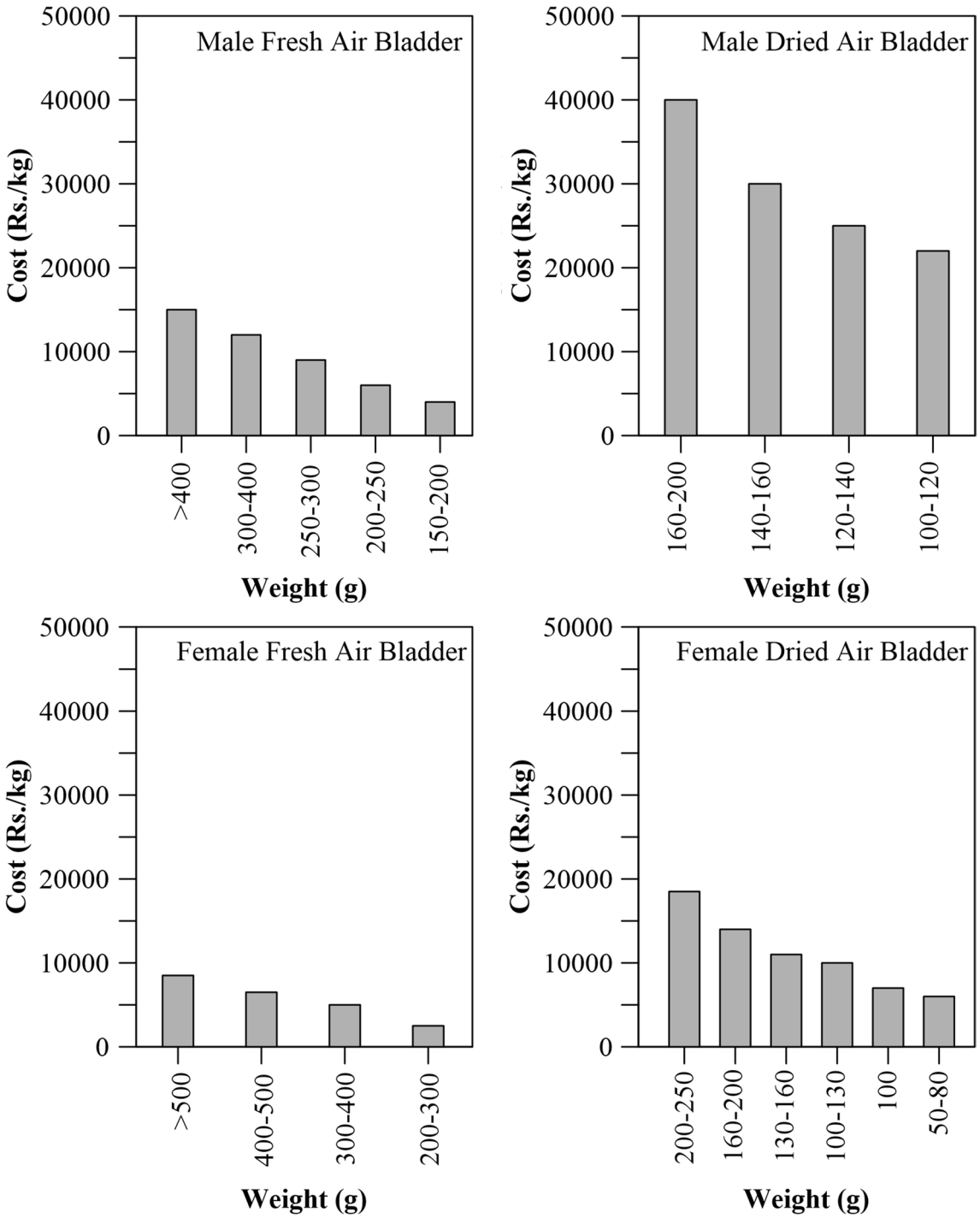

Fig. 3 Commercial value (in INR) of *Protonibea diacanthus* air bladder in Indian market. (Source: 17)

can reach a maximum length of 150 cm standard length. PD can live up to 15 years and matures at the age of 3–4 years [6]. The body length of males is about 30–102.5 cm, females 28.5–108.0 cm, and juveniles 5.0–29.5 cm [14]. In general, PD is found in tropical regions of the Indo-West Pacific Ocean [19]. PD has been seen as ascending tidal rivers and estuaries, preferring muddy substrates [6]. PD moves in the water column up to 5 to 100 m [1]. PD occasionally arrives near the coast and in creeks to feed or breed [20]. A previous report has suggested that the annual inshore migration of PD is driven by the seasonal availability of food in inshore waters [21, 22]. A thorough perusal of the available literature revealed no particular scientific studies in the Indian waters highlighting environmental condition preference of

PD either in a natural environment or in captivity. However, a study carried out in coastal waters of the Thursday Island (Australia) has reported a water temperature range of ~ 24–28 °C during peak catch of PD [22]. Low salinity levels have been reported to attract PD schools. For instance, PD aggregation has been observed after an event of the peak of riverine water discharge to sea in coastal waters of the Muttee Head (Australia) [22]. PD aggregation has also a relation with tides and higher catches have been reported during the spring tide periods [22]. Regarding the distribution of PD in relation to lunar cycle, an event in the coastal waters of the Muttee Head (Australia) reported a higher catch 3 days before the full moon, which remained higher for the next 6 to 7 days [22].

Food and Feeding of *P. diacanthus*

PD is an active carnivorous feeder, prawns and small fishes forming the major food item. Except for prawns and fishes, they feed on other crustaceans like crabs, shrimp, barnacles, etc. [20]. The post-larvae and juveniles are reported to enter the inshore waters in June–July and remain there till January–February during which time they actively feed mostly on prawns. The juveniles move to the deeper waters when the availability of prawns becomes scarce [20]. For an instance, the food availability in the coastal waters of Goa (west coast of India) has been suggested as an important factor for shoreward migration of PD during the monsoon season [21]. However, there is a knowledge gap on the diet preference and nutritional requirement of PD. In captivity, PD has been reported to be fed with traditional feeds (usually given to other marine fishes) [23].

P. diacanthus Fishing Gears

In general, PD is captured occasionally and is not uniformly caught by the Indian fishermen at a time [14]. A thorough perusal of the available literature has revealed no specific fishing method for PD in India. In general, fishermen catch PD using bottom trawls, handlines, dol net, and gillnets, and purse seines [14, 20, 24]. It is important to mention here that PD has been categorized as "Near Threatened" by the International Union for Conservation of Nature (IUCN). However, due to overexploitation, PD is at the risk of being categorized as a "Threatened" species [25]. In this regard, PD fishing during its spawning aggregation and younger stages are the major threats affecting their natural distribution. Recently, PD has been protected by law in Australia [25]. In India, PD is unknowingly protected due to a fishing ban using all type of fishing vessels in the Indian Exclusive Economic Zone (EEZ) beyond territorial waters during the summer monsoon period for 61 days i.e., from 15th April to 14th June on the east coast and from 1st June to 31st July on west coast [26].

Seasonality in *P. diacanthus* Fishery

The seasonal changes in the gonad:body weight of PD indicate that the breeding season of PD lasts from April to August [20]. However, the reproductive season varies by climate and so differs in different regions. It exhibits migratory behaviour for spawning and in search of food [25]. PD has an affinity for aggregation sites. The presence of PD has been observed in the aggregation sites up to 18 months later. Some fish looked to be permanent aggregation site residents, whereas others left and returned up to 9 months later [27]. In Australia, PD abundance decreases during cooler months and increases during the warmer month when peak spawning occurs. The peak period for PD catch occurs during the time of their feeding period [28].

As per the available reports, the highest landing of PD has been observed during post-monsoon in the Indian waters as an aftermath result of the fishing ban during monsoon [24]. The highest landing of PD has been observed during January–February in West Bengal [14]. On the west coast of India, the PD fishery starts from October reaching a peak by January–February and lasts until about the beginning of June [29]. In some regions, there are reports of PD catch during the monsoon months. In a particular case study off Vanakbara (Gujarat), the highest PD fishery in terms of both catch and catch rate was observed during September to December with the highest (~ 166 tonnes) monthly average catch during November and the lowest (~ 19 tonnes) during May [24]. In general, the overall PD catch is relatively higher in Indian waters during September–November. Subsequently, the catch declines due to decrease in water temperature, which again attain peak during January–February with gradual increase in water temperature. Therefore, in terms of seasons classified based on monsoon, it can be noted here that the post-monsoon season remains productive for PD fishery in India. PD was observed to be distributed both in shallower and deeper waters. Previous reports reveal a higher catch of PD at a water column depth of 11 to 40 m in between 15 and 17°N [29]. Similar high concentrations of PD were also observed in 18°N to 22°N latitude zones between depths from 21 to 60 m [29]. In the Indian waters, the spawning period of PD occurs from June to August, the resting period occurs during October to March and the maturation period is during April-June [20]. In similar to this pattern, PD spawning has also been reported from Australia, during the summer monsoon period [27, 28].

Aquaculture/Mariculture of *P. diacanthus*

In India, there is no evidence of PD aquaculture/mariculture practice. In addition, a thorough perusal of available literature also confirms the availability of no basic information on PD eggs, larvae, and juveniles. The lack of information and research on captive breeding, seed production, larval rearing, feed management, and farming systems is a major knowledge as well as technology gaps towards non-initiation of PD aquaculture/mariculture in India. As there is an increasing demand for PD export from India, it is high time to carry out specific research on the above aspects including identifications of PD-specific habitats. In addition, it is very essential to develop their breeding and seed production technology to support their culture practices. The major constraint in the collection of live fishes for broodstock development in a confined environment is difficult when compared to other fishes because of its habitat and gear (Trawler and bottom set gill net) in which PD is captured. It lives in a large group and the fishery is highly specific to certain habitats. A system of trapping and transferring live fish to sea cages needs to be developed. Technology for captive rearing, maturation, and spawning also needs to be evolved. This requires a better understanding of the breeding and feeding behaviour and the location of the aggregation site. The above can be accomplished by establishing an end-to-end synergy between various responsible government-private entities towards species-specific research, technology development, relevant post-production industrial processing, and a proper marketing strategy.

In this regard, it is interesting to note that China and Taiwan have successfully cultured PD [19]. China has developed techniques for mass larval production of PD and started the culture of PD as an alternative to large-scale fishing [23]. Hence, technology transfer and symbiotic research are also options, which can be chalked out for early adoption of aquaculture/mariculture of PD in the Indian waters.

Conclusion

India has a long coastline, and a large number of ecologically as well as economically important fishes are harboured from the Indian exclusive economic zone. PD is one of the most expensive marine fish of India which has gained attention due to its high commercial significance based on rising demand in the international market. Most importantly, the body parts of PD are utilized in the preparation of functional food and pharmaceutical products. In the recent decade, media reports of PD catch yielding instantaneous high income for the fishermen has caused exhilaration in the regional market, local fishermen, and the general public. On the backdrop of the non-availability

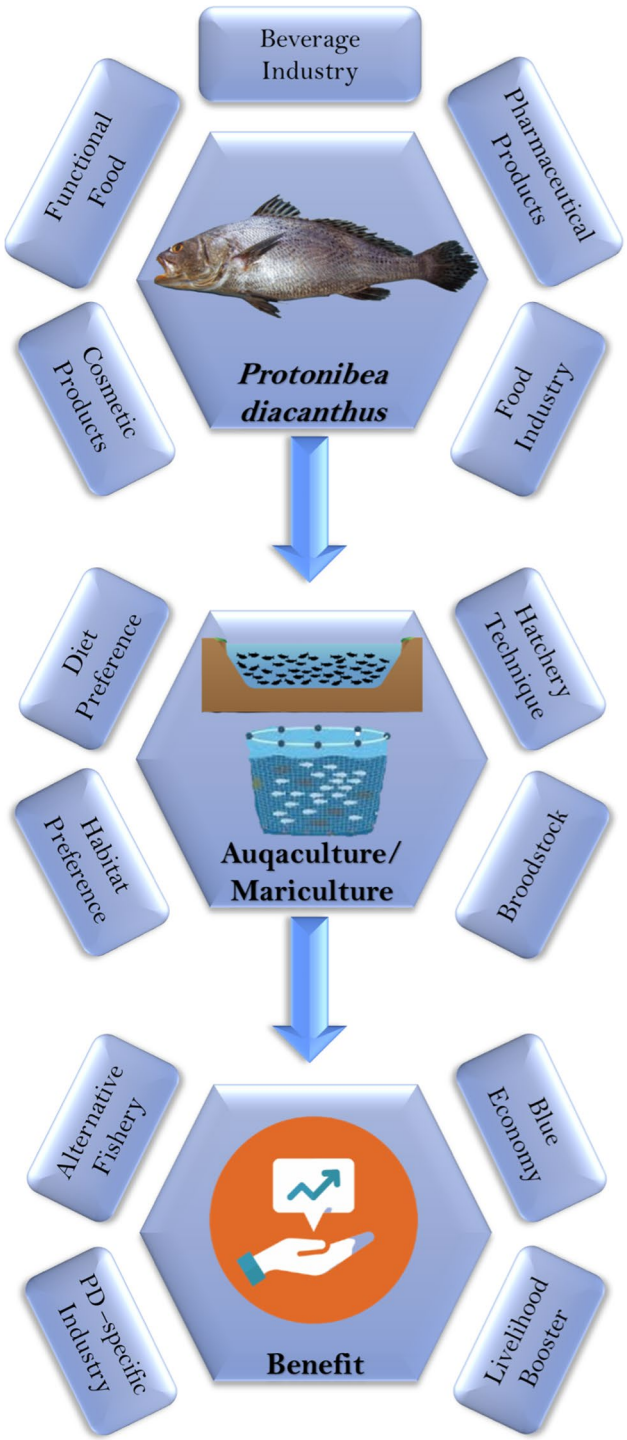

Fig. 4 Flowchart (on the Indian context) showing the economic significance of *Protonibea diacanthus*, the research/technology gaps that need to be addressed /developed, and its possible future benefits

of a comprehensive report on the environmental–economical aspects of PD, the salient outcomes of the present study are (1) reiteration of PD as one of the expensive marine fish in the Indian waters, (2) sequential updations in the scientific taxonomic nomenclature, (3) existence of

a multitude of regional names in India, which requires to be considered for PD-related data mining and scientific studies, (4) non-availability of particular information on PD due to its aperiodic catch, and no proper reporting, (5) although occasionally, PD catch by fishermen of all the Indian maritime states using bottom trawls, handlines, dol net, and gillnets, and purse seines, (6) higher number of PD catch events along the west coast of India (maximum in Maharashtra) in comparison to the east coast (maximum in West Bengal), (7) no particular available information on PD marketing strategy and end-users, (8) direct export of dried swim bladder of PD attributed to its high medicinal value, (9) higher commercial value of dried swim bladder of PD compared to a fresh one, (10) inshore migration of PD driven by the seasonal availability of food, peak of river discharge, as revealed from literature, (11) no-availability of scientific literature describing environment/diet preference/nutritional requirement of PD either in a natural environment or in captivity in the Indian waters, (12) post-southwest monsoon as the productive season for PD fishery in India, and (13) no evidence of PD aquaculture/mariculture practice in India.

As there is an increasing demand for PD export from India, it is high time to carry out specific research towards aquaculture/mariculture of PD in India. A flowchart (in the Indian context) showing the economic significance of PD, the research/technology gaps that need to be addressed /developed, and its possible future benefits are illustrated as Fig. 4. The Indian PD fishery can be developed by establishing an end-to-end synergy between various responsible government-private entities towards species-specific research, technology development towards captive breeding, seed production, larval rearing, feed management, relevant post-production industrial processing, a proper marketing strategy, and chalking out possibilities of aquaculture/mariculture technology transfer from other countries.

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Declarations

Conflict of interest On behalf of all authors, the corresponding author states that there are no conflict of interest.

Ethics approval and consent to participate No ethics approval or consent was required.

Consent for publication Not applicable.

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