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# THE EFFECTS OF DIFFERENT ARTIFICIAL LIGHT WAVELENGTHS ON SOME BEHAVIOURAL FEATURES OF JUVENILE PELAGIC ATLANTIC HORSE MACKEREL, *TRACHURUS TRACHURUS* (ACTINOPTERYGII: PERCIFORMES: CARANGIDAE)

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**Background.** Atlantic horse mackerel, *Trachurus trachurus* (Linnaeus, 1758), is among bento-pelagic species subject to discard within deep-water rose shrimp fisheries, and how such species would react to light wavelength is therefore important, to be consistent with the Common Fishery Policy (CFP). Despite the existing literature currently available, there is still paucity of relevant information about how artificial light wavelengths affects the behaviour of *T. trachurus* juveniles. In this context, the effects of different artificial light wavelengths on some behavioural features of juvenile *T. trachurus* were investigated**.**

**Materials and methods.** Maintained in a fish tank, the juveniles of Atlantic horse mackerel, after acclimatization, were subject to six different light wavelengths, representing the following colours: white, violet, blue, green, yellow, and red. Subsequently, behavioural features, specifically phototaxis (degree of attraction or repulsion toward the light source) were tested.

**Results.** By phototaxis per light wavelength, the studied juvenile individuals produced statistical differences in the presence frequency ($P < 0.05$) revealed by blue that noticeably attracted some, relative to the white light that repulsed others. Yet, violet and red lights produced much less but no significant attraction of these juveniles ($P > 0.05$).

**Conclusion.** The presently reported study has provided additional information about ecological knowledge and understanding specific to juvenile *T. trachurus* individuals, which can further the development of (selective) light fishing techniques, aimed at reducing unwanted catches of commercial pelagic fisheries.

**Keywords:** trawl fishery, horse mackerel, artificial light, attraction, repulsion

## INTRODUCTION

In general, fish depend on vision as a source of sensory information for living processes (Guthrie 1986). Further, light is one of the ecological factors that affect organisms at sea (McFarland 1986). Such factors as day, sea depths, time, and weather conditions can influence the changes in lighting conditions within the marine environment (Forsgren et al. 2013). Fundamentally, such fish activities as aggregating, breeding, feeding, moving, and resting can be influenced by either light during the diel cycle (Helfman 1986) and/or factors like ambient light, orientation, and visual capacity (Olla and Davies 1990). In addition, reaction(s) emerging from both fish behaviour and rhythm can be influenced by differences in stimuli from natural and artificial lights (Matsumoto et al. 2010, Queirolo et al. 2012, Bryhn et al. 2014). Notably, the capability of light to attract some fish during the night has been well reported (Glass and Wardle 1989, Liao et al. 2007). It is such (above mentioned) knowledge underscoring fish behaviour that fishers have incorporated for centuries, with the primary

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purpose of increasing their catch (Arimoto et al. 2010). To further delineate how light-fish responds at different wavelengths should be considered very essential, and such (emergent) knowledge would add to existent information about behavioural aspects of commercially pelagic fish species—an example being horse mackerel (Ryer and Olla 2000, Marchesan et al. 2005, Hannah et al. 2015).

Among gregarious bentho-pelagic species, Atlantic horse mackerel, *Trachurus trachurus* (Linnaeus, 1758), abundant within the Mediterranean Sea and representing the third taxon ranking by mean catch per year has accounted for about 75 000 t within the period 2000–2013 (Anonymous 2016, Giordano et al. 2017). Indeed, juveniles of this particular fish species are understood to represent most (above 40%) of discards within deep-water rose shrimp fisheries (Atar and Malal 2010, Milisenda et al. 2017). Owed to unselective fishing techniques as well as excessive fishing efforts, bottom trawling continues to bring about increases in discard levels within the Mediterranean Sea (Veiga et al. 2016). In this context, discard would depict a waste of natural resources that impacts negatively the marine ecosystem, which provokes changes in the overall structure of trophic webs—a risk to the current fishery sustainability (Bellido et al. 2011, Veiga et al. 2016). Besides, the European Commission has introduced the obligation to land all catches for species with minimum landing size (CFP–EU regulation 1380/2013) (Anonymous 2013), otherwise named “Landing Obligation” in the view to tackle fishery discard challenges/issues (Damalas and Vassilopoulou 2013, de Vos et al. 2016). It is well known that through reforms of the Common Fisheries Policy (CFP) (Anonymous 2019), there is action of gradual elimination of wasteful practice of discarding through this “Landing Obligation” via European Union (EU) discarding and landing obligation framework, which has currently been operating in phases across fisheries and species with several discard plans. Further, other workers have understood that despite the governance approach in reducing both bycatches and discards—thanks to the selectivity of fishing gears, to identify with solutions (to this challenge/problem) still remain complex given the multispecies demersal fisheries present in the Mediterranean Sea (Bellido et al. 2011, Damalas and Vassilopoulou 2013). However, researchers will not stop to seek pathways to reduce the unwanted catches, essentially for the fish juveniles (Milisenda et al. 2018).

Amidst the ample literature available about Atlantic horse mackerel, there is still a paucity of relevant information about how artificial light wavelengths affect the behaviour of juveniles of this fish species. Indeed, further research into how specific light wavelengths would either attract or repel juveniles of Atlantic horse mackerel would be worthwhile. Understanding the behavioural response of such juveniles would help update the ecological knowledge about such bento-pelagic fish species. Based on the aforementioned, the specific objective of the presently reported study was to determine the effects of different artificial light wavelengths on some behavioural features of juvenile pelagic Atlantic horse mackerel.

## MATERIALS AND METHODS

**Study overview.** The schematic outlay of step-by-step methodology applied in the presently reported study, from collection of samples to behaviour analysis, is shown in Fig. 1. Prior to carrying out the study, ethical approval was obtained consistent with the procedures specified by the Risorse Biologiche e le Biotecnologie Marine – Consiglio Nazionale delle Ricerche (IRBIM–CNR). All the methodology applied herein was guided by standards of previously published references (Marchesan et al. 2005, Liao et al. 2007, Meager et al. 2010, Okpala et al. 2017).

**Collection of juvenile fish individuals.** Juveniles of *Trachurus trachurus* were collected during one experimental haul of International Bottom Trawl Survey in the Mediterranean (MEDITS) (Bertrand et al. 2002) performed at 47 m depth, at the end of July 2016 within the Sicilian Channel (approximate coordinates 37°34.0′N, 012°34.5′E). A total of 13 individuals of *T. trachurus* were sampled, ranging from 11 to 15 cm in total length (TL). After catch and using an aerated container, juvenile fish individuals were immediately transferred to the laboratory of the IRBIM—CNR the same day of the catch.

**Experimental tank.** A diagrammatic representation of the experimental tank showing the various key parts, from the light projector to seawater, is shown in Fig. 2. The Atlantic horse mackerel juvenile individuals were kept in a rectangular fiberglass aquarium tank (Juwel Aquarium GmbH, Rotenburg, Deutschland) of 400 L (length × width × height: 1.51 × 0.51 × 0.66 m) filled with seawater, replaced weekly with approximately 20% of its volume. Water quality was maintained using a submersible Bioflow Filter (Juwel Aquarium GmbH, Rotenburg, Deutschland) and an internal Blueskimmer 550 (Ferplast Spa, Castelgomberto, Italy). An inbuilt supercharger was used to oxygenate the aquarium water. Temperatures of laboratory (~18°C) and water (~20°C) sufficiently maintained via air conditioning

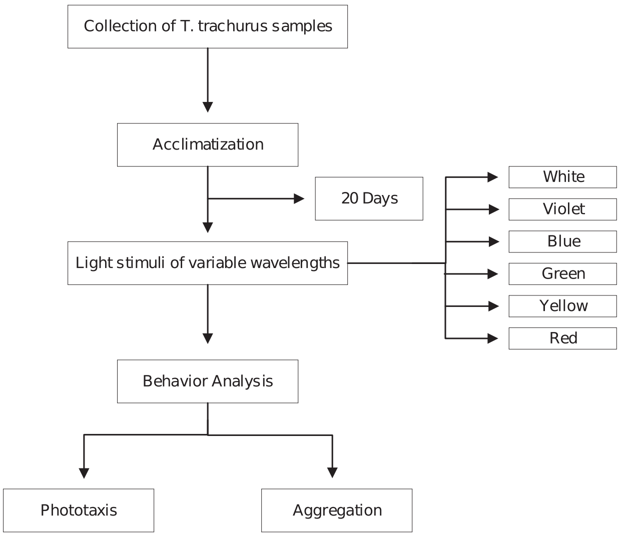

**Fig. 1.** Schematic outlay of the methodological approach applied in the presently reported study, from collection of samples up to the test of behavioural responses

(2.6 kW · 9000 BTU$^{-1}$ Split unit Ariagel, Monclick S.r.L., Monza e Brianza, Italy) were regularly assayed using electronic thermometer (Diligence EV N2014, Comark Instruments, Norwich, United Kingdom). Basic water parameters of salinity and oxygen concentration (salinity = 37‰[*], oxygen concentration = 8.19 ppm) were determined using a multiparameter probe (Hydrolab HL4, Corr-Tek Idrometria S.r.L., Verona, Italy).

**Acclimatisation process.** Acclimatization period has always been deemed very useful particularly when fish are brought into a new closed environment (Marchesan et al. 2005, Okpala et al. 2017). Introducing the acclimatisation period appears routinely observed in other fish-related studies (Marchesan et al. 2005). Before the start of the experiment, the fish juvenile individuals were acclimatized (Okpala et al. 2017) for 20 days. Specifically, this acclimatization process involved the use of an isolated chamber with a photoperiod of both twelve hours of light (from 0800 to 2000 h) and dark (from 2000 to 0800 h). Given that high feeding intensity of Atlantic horse mackerel especially during early mornings and night has been reported (Jardas et al. 2004), the fish juvenile individuals were fed *ad libitum* twice per day (at scheduled times) with crushed frozen shrimps (Okpala et al. 2017). Importantly, no juvenile individuals died during the entire acclimatization process.

**Experimental procedure.** At the end of acclimatization process, six different light wavelength treatments were applied to the fish juvenile individuals contained within the experimental tank, namely: white (visible spectrum of light given by the sum of all wavelengths), violet (peak at approx. 410 nm), blue (peak at approx. 460 nm), green (peak at approx. 525 nm), yellow (peak at approx. 580 nm), and red (peak at approx. 650 nm). Five replicates, lasting three hours each, were carried out independently per light wavelength. Therefore, the total amounted to 30 replicates within the 30-day period, which involved both evening and night(s) hours (between 2000 and 2400 h). Specifically, the experiment was conducted at evening and night hours so as to reduce the luminous interference of background light levels outside the tank, as well as to isolate the light source.

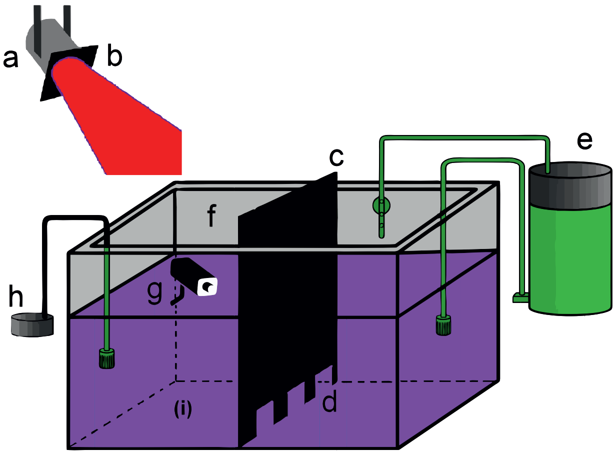

**Fig. 2.** Representation of the experimental tank. (a) light projector; (b) light filters; (c) barrier of Plexiglas; (d) basal square-like openings; (e) water filters; (f) aquarium tank; (g) video camera; (h) supercharger; and (i) seawater (blue shade)

The emission of light beam provided by SEF Slim illuminator (Beghelli S.p.A, Monteveglio-Bologna, Italy) equipped with a 30 W LED lamp was located above the left half side of the tank (length × width = 0.75 × 0.51 cm). There were LEE filters (Rossini Musica e Luci S.r.L., Cagliari, Italy) and monochrome gelatine sheets in front of LED lamp, respectively. To design two different (light and dark) illumination zones, a black plexiglass barrier has been provided. In addition, to ensure passage for the fish juvenile individuals (between the two different illumination zones), three basal square-like openings were created at the lower part of the black plexiglass barrier (Fig. 2).

Each light treatment lasted for thirty minutes, measured using a stop timer. This time period was also set to allow for the habituation of the juvenile Atlantic horse mackerel individuals, resembling that reported by Marchesan et al. (2005). The recordings of treatments were performed during the first 20 min of exposure to each wavelength level using a GoPro Hero4 Black video camera (GoPro GmbH, München, Deutschland). The total recordings of entire wavelength treatments summed up to 600 minutes. To quantify the observed data, all images/videos were analysed with the help of Image J software (version 1.50i, Wayne Rasband, National Institutes of Health, USA).

**Behavioural data collection.** The behavioural response in terms of positive (attraction) and negative (repulsion) phototaxis of juvenile Atlantic horse mackerel individuals was measured by the frequency of presence recorded in percentage (%), resembling the method reported by Hunter (1966). The observation period has been divided into three main phases: 'Early' (1–5 min), 'Middle' (6–15 min), 'Late' (16–20 min), consistent with that reported in Okpala et al. (2017). Recordings were observed at 2× speed with a temporal sequence of 30 frames, randomly chosen within 1 min intervals throughout the session. The fish were counted when observed within the light zone during the temporal sequence chosen for the analysis. To differentiate between 'attraction' and 'repulsion,' the juvenile individuals found within the light zone were considered as 'attracted,' whereas those that would pass through the three basal square-like openings in order to seek shelter within the dark zone were considered as 'repulsed.'

**Statistical analysis.** The emergent data were subject to Shapiro–Wilk normality as well as Bartlett variance tests, which resulted in a non-parametric ($P < 0.05$) outcome. Thus, all emergent data were processed using non-parametric statistics. Specifically, Friedman post-hoc test (Zimmerman and Zumbo 1993) was performed to determine the overall differences in presence of juvenile individuals across light wavelength treatments. In addition, the Conover test

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[*] In the wake of the growing criticism of the Practical Salinity Scale concept (and especially "PSU" as a "unit"), Acta Ichthyologica et Piscatoria is in favour of expressing salinity in parts per thousand (‰), regardless if a direct or indirect method was employed to determine the water salinity.

(Babulak et al. 1986) was performed to establish differences in presence of juvenile individuals between light wavelength treatments. Probability level $P < 0.05$ was considered as statistically significant. The analysis was conducted in the R Statistical Environment (RStudio software, version 0.99.903 for Windows, Boston, MA, USA).

## RESULTS

Mean number (rounded to the nearest integer) recorded of juvenile Atlantic horse mackerel, *Trachurus trachurus*, individuals per replicate of different light treatments within the light zone, is shown in Table 1. Only about 4/5 individuals appeared present during the white treatments whereas others can be considered to seek shelter in the dark zone. At the 2nd and 5th replicates however, the blue spectrum appeared to concentrate more fish within the light zone depicted by 9 and 8 juvenile individuals, respectively. Fluctuating trends of repulsion seemed apparent at the green and yellow lights, but less marked than the white spectrum. On the other hand, the juvenile individuals seem neither attracted nor repulsed to both red and violet spectra, respectively. Further quantification of these (current) data has helped to identify with the frequency of presence of juvenile individuals recorded in percentage (%) trending within the light zone (Fig. 3, 4A and 4B).

**Table 1**

Mean number (rounded to the nearest integer) recorded of juvenile Atlantic horse mackerel, *Trachurus trachurus*, individuals per replicate of different light treatments within the light zone

| Wavelength [nm] | Colour | Rep. 1 | Rep. 2 | Rep. 3 | Rep. 4 | Rep. 5 |
|---|---|---|---|---|---|---|
| 400–700 | White | 5 | 5 | 4 | 4 | 5 |
| 400–450 | Violet | 4 | 6 | 5 | 9 | 6 |
| 450–490 | Blue | 6 | 9 | 7 | 6 | 8 |
| 520–560 | Green | 7 | 6 | 6 | 3 | 5 |
| 560–590 | Yellow | 4 | 5 | 6 | 6 | 4 |
| 635–700 | Red | 4 | 7 | 7 | 5 | 5 |

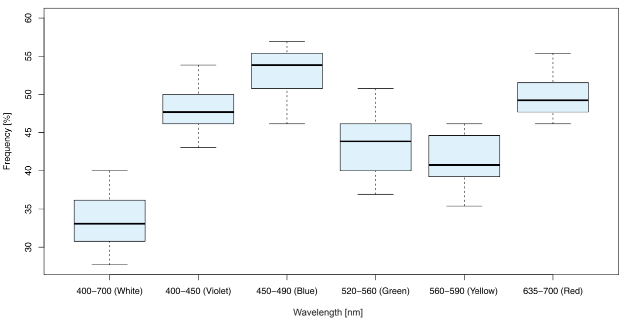

**Fig. 3.** Presence frequency of Atlantic horse mackerel, *Trachurus trachurus*, at different light wavelengths; 400–700 nm (white), 400–450 nm (violet), 450–490 nm (blue), 520–560 (green), 560–590 nm (yellow) and 635–700 nm (red)

Overall, the number of individuals appeared statistically different according to the various wavelengths applied (Friedman test: $P < 0.05$) (Fig. 3). In particular, white and blue spectra were statistically different (Conover test: $P < 0.05$) compared with other light treatments (Figs. 4A, 4B). Further, repulsion of individuals seemed particularly apparent with the white wavelength treatment (Conover test: $P < 0.05$), characterized by decreasing presence at both early and late observation phases (Figs. 3, 4A). Moreover, the yellow and green wavelengths exhibited rather a similar repulsion effect between them (Conover test: $P > 0.05$) but their effect looks weaker compared to the white wavelengths especially in the early, mid and late observation phases, respectively. Specifically, the attraction of Atlantic horse mackerel individuals seemed greater at the blue wavelength (Figs. 3, 4A) (Conover test: $P < 0.05$). Nonetheless, blue wavelength would produce rather stable attraction of these juvenile individuals especially at early and middle observation phases (Fig. 4A). This would be followed by an apparent decrease in presence at the late observation phase and subsequently, a sudden increase within the remaining minutes of observation (Fig. 4A). In addition, the red and violet wavelengths (Figs. 3, 4B) would produce less, but not statistically significant attraction (Conover test: $P > 0.05$).

## DISCUSSION

The Mediterranean Sea has been among the clearest marine bodies of water with light spectrum tending towards either blue or green (Dartnall 1975, Jerlov 1976) having between photopic and scotopic vision thresholds emerging from depths of 150 m (Clarke and Denton 1962). Besides, Atlantic horse mackerel is among the typical fish species affected by light/vision spectrum (Ben-Yami 1976, Pavlov and Kasumyan 2000, Abaunza et al. 2003) that would form large shoals near sea bottoms during the day and disperse at night (Barange et al. 2005, Vaz Velho et al. 2010). Mostly, such large shoals can occur on muddy bottoms at depths between 100 and 500 m, especially the juveniles that largely concentrate at such bottom depths (Smith-Vaniz et al. 2015).

Positive phototaxis toward blue wavelength observed in the presently reported study would suggest a possible adaptation of visual pigments to a scotopic vision (dim light condition). Visual sensitivity would depend on rod photoreceptors (rhodopsin) that capture photons within the blue spectrum (470–490 nm) (Bowmaker 1990, Fernald 1990). In addition, the sensitivity of fish toward the blue spectrum can corroborate with lights of marine plankton emitting bioluminescence, the latter depicting a response to the movement (Hobson et al. 1981). And putting this bioluminescence sensitivity in context of this current study, such positive phototaxis of juvenile Atlantic horse mackerel individuals would associate with its feed requirements, understanding that its diet is governed by planktonic organisms like euphausiids, pelagic copepods, and fish populations (especially those of very premature age) (Herrmann and Enders 2000, Jardas et al. 2004). Negative phototaxis observed in this current study, largely demonstrated by juvenile Atlantic horse mackerel individuals hiding from the white light but slightly from the green. Moreover, protective measures explained by the impact of yellow light spectrum

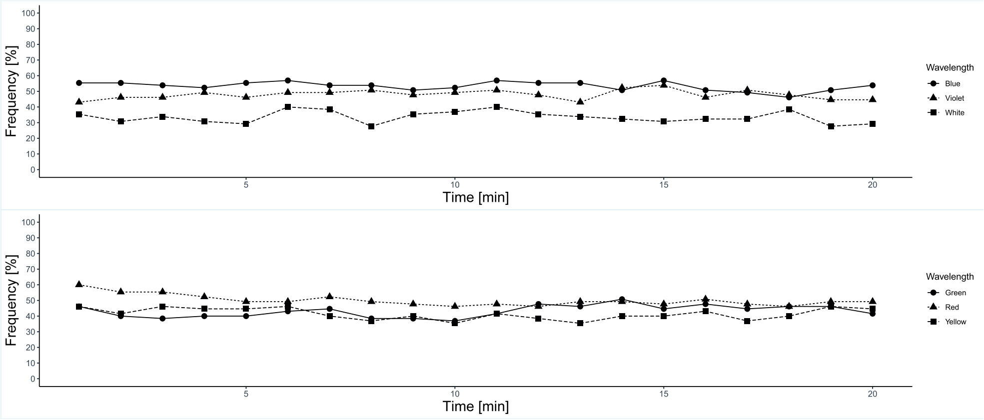

**Fig. 4.** Presence frequency of Atlantic horse mackerel, *Trachurus trachurus*, trending with respect to blue, white, and violet (**A**) as well as green, yellow, and red (**B**) wavelengths

may well suggest this juvenile *T. trachurus* to possess some repulsive behaviour, potentially associated with photosensitivity, additionally suggesting a strong adaptation in terms of a specific habit. Besides, Atlantic horse mackerel is believed to be a crepuscular predator during both dawn and sunset (Helfman 1986). Potentially, this may well occur with high feeding activity when dispersed in the water column. Moreover, such feeding activity would occur minimally during the day as fish aggregate in large shoals close to the (sea) bottom (Pavlov and Kasumyan 2000, Jardas et al. 2004, Okpala et al. 2017b).

Besides, positive phototaxis of juvenile of Atlantic horse mackerel depicted by (some) emergent differences in visual sensitivity and given by response of visual pigments to light may well become apparent with differences in environments, species as well as life stages (Olla et al. 1997, Bayarri et al. 2002). As the certain light wavelengths generally contribute to fish orientation during diurnal activities, any emergent variations in this context would likely influence both fish behaviour and rhythm (Olla and Davies 1990). Thus, artificial illumination in sea remains viable in facilitating the avoidance of juvenile fish onto components of trawl whilst providing it some additional time to effectively react when approaching the net (Fréon et al. 1993). On the other hand, negative phototaxis of juvenile of Atlantic horse mackerel toward white light and slightly so for both green and yellow light wavelengths may well look like the impact made when the headrope of trawl net forms a light barrier, which could eventually deter (any) fish to approach the net (Hannah et al. 2015). In this context, artificial illumination could serve as a promising candidate to increase the light contrast between the trawl components (Kim and Wardle 1998, Hannah et al. 2015). Amidst these (above mentioned) considerations, the Atlantic horse mackerel still represents a large part of discard especially for the deep-water rose shrimp (*Parapenaeus longirostris*) fisheries (Atar and Malal 2010, Milisenda et al. 2017) subject to the so-called "Landing Obligation" by the EU reg. 1380/2013 (Anonymous 2013) with the specimens lower than the Minimum Conservation Reference Size (e.g., 15 cm of total length for *Trachurus* spp.).

Overall, the results of the presently reported study have revealed blue and white light spectra as very promising in influencing the presence of juvenile Atlantic horse mackerel individuals particularly within the light zone. Consequently, the use of artificial light device with such specific wavelength(s) could play key role essentially to mitigate the catch of such fish juveniles. Recent workers (Hannah et al. 2015, Larsen et al. 2017, Melli et al. 2018) have shown artificial lights as very capable of reducing bycatch during commercial fisheries activities. In this context, it is very pertinent that workers in this specialist endeavour continue to improve their knowledge about behavioural responses of fish species toward artificial light wavelengths. Such improved knowledge can serve as an important step in promoting a build-up of an effective, efficient and sustainable fishing technology (Arimoto 2015). To supplement existing information, future light application studies of fishery activity should be directed to investigate the effects of different light wavelengths on other economically important fishery species, for example, either the deepwater rose shrimp (*Parapenaeus longirostris*) and or other bycatch species.

## COMPETING INTERESTS

Authors hereby declare that there are no competing interests (neither financial nor non-financial) associated with this current study.

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