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CRUSTACEANA

INVESTIGATIONS ON UNEXPLORED BRACHYURANS (DECAPODA), *CHARYBDIS HOPLITES* (WOOD-MASON, 1877) AND *CHARYBDIS SMITHII* MACLEAY, 1838, FROM TRAWL DISCARDS OF THE SOUTHEAST ARABIAN SEA ECOSYSTEM

BY

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ABSTRACT

The effectiveness of GIS-based resource mapping to strengthen the database for Ecosystem-Based Fisheries Management (EBFM), was tested in an attempt at resolving the existing gap in the data on non-commercial resources. In this paper we describe the result of that try by giving an example of one of the most important influential species in the benthic ecosystem of the Southeast Arabian Sea (SEAS). An estimated 2803 t of *Charybdis hoplites*, a relatively little known species from the coast, are yearly caught and discarded by trawlers operating from the Mangalore fisheries harbour. A GIS-aided study on distribution and abundance estimated, that the average biomass of the species is 322.7 t, at any time in the area covered. This study brings out the fact that a number of non-commercial biota are serving as non-detectable factors in sustaining productivity. The identification of their role and the quantification of their biomass thus constitute important data for an effective implementation of EBFM.

Key words. — GIS, trophic importance, EBFM, trawling, crabs, biomass, Arabian Sea

RÉSUMÉ

L'efficacité du système d'information géographique (GIS) dans la cartographie des ressources afin de renforcer les données pour la gestion écosystémique des pêches (EBFM), a été testée pour essayer de résoudre la lacune existant dans les données sur les ressources non commerciales. Dans ce papier nous décrivons le résultat de cet essai en donnant en exemple l'une des espèces la plus influente sur l'écosystème benthique du sud ouest de la Mer d'Arabie (SEAS). Une estimation de 2803 t de *Charybdis hoplites*, une espèce relativement peu connue de la côte, ont été pêchées et débarquées annuellement par les chalutiers des pêcheries opérant à partir du partir du port de Mangalore. Une étude par GIS sur la distribution et l'abondance a estimé que la biomasse moyenne de cette espèce était de 322,7 t dans l'aire étudiée. Cette étude souligne le fait qu'un nombre de biota non commerciaux représentent des facteurs non détectables dans le maintien de la productivité.

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L'identification de leur rôle et la quantification de leur biomasse constituent donc des données importantes pour une mise en œuvre efficace de EBFM

Mots clés. — GIS, importance trophique, EBFM, chalutage, crabes, biomasse, Mer d'Arabie

INTRODUCTION

The area known as the Southeast Arabian Sea (SEAS) is considered one of the richest marine ecosystems along the Indian coast (Vivekanandan et al., 2002), and accordingly displays a scenario of a complex multi-species fishery that obviously encompasses multi-gear exploitation. Trawls have become the dominant contributor to the fishery in the last two decades, with an extension of regular fishing depth from 50 to 200 m, and an increase in fishing days from 3 to 13 days. Both the commercial trawl catch and the low-value catch have increased substantially, and 205 species or species-groups of fishes were identified from the trawling grounds off the southwestern coast of India (Dineshbabu et al., 2012). Ecosystem-Based Fisheries Management (EBFM), which is considered as a well-adopted methodology for the management of multispecies fishery in tropical waters (Vivekanandan et al., 2003) requires quantitative information on commercial and non-commercial fishes and other marine organisms. The biomass of groups at different trophic levels in the ecosystem provides an indication for the flow kinetics governing that system (Pauly et al., 2000), and the incorporation of information on spatial distribution and abundance of discards is suggested as a reliable option for effective trawl fisheries management (Walters et al., 2000).

Demersal crabs have been identified as one of the major food items for demersal fishes along the Southeastern Arabian Sea (Abdurahiman et al., 2010) and in this context, an attempt was made to study the distribution and quantification of some of the less well-known brachyuran crabs. Earlier studies on bycatch and discards from the trawlers in these fishing grounds showed, that huge quantities of non-edible crabs belonging to the genus *Charybdis* are regularly discarded (Dineshbabu et al., 2012). Thus, GIS-based resource mapping was performed in an attempt to illustrate the distribution of these brachyuran crabs in the trawling grounds. So, the present study is intended to contribute to an understanding of the importance of non-commercial brachyuran species in the trawl fishing grounds of the SEAS area in terms of distribution and abundance. As a consequence, these data can serve to emphasize the need for conservation of those non-commercial species through trawl discard management, specifically intended for sustaining commercial marine fisheries. The methodology described in this study can be applied to more than 200 species (or species-groups) identified from the trawl catch/bycatch off the coast, and, thus, for strengthening the Ecosystem-Based Fisheries Management purported to guarantee sustainable fisheries activities in the region.

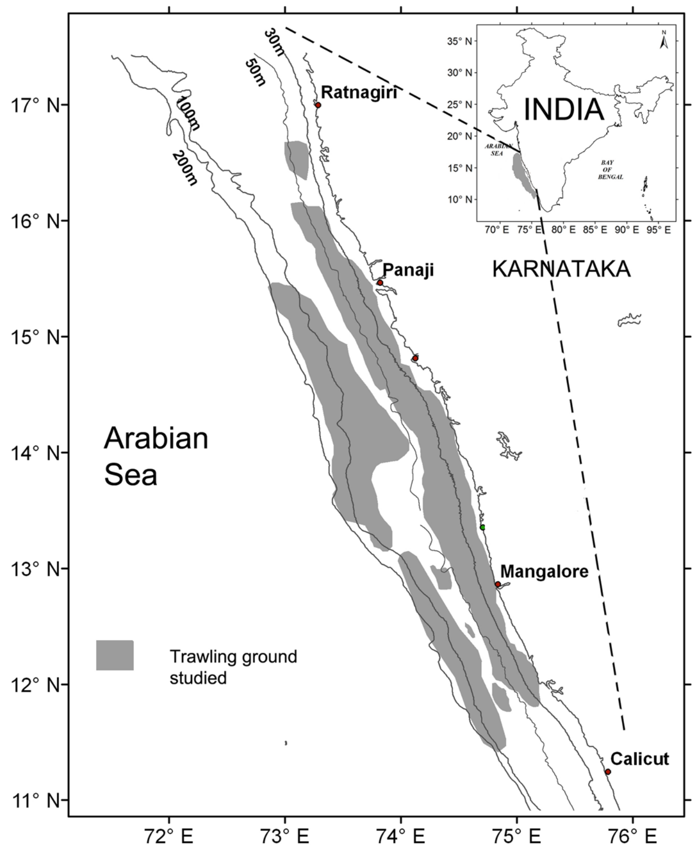

Fig. 1. Map of the southwestern part of the coastline of India, showing the area in the Southeastern Arabian Sea (SEAS) that encompasses the fishing grounds and that was selected for this study.

MATERIAL AND METHODS

Area of study

The commercial trawlers from Mangalore fisheries harbour operate between Malabar (north off Calicut, 11°N 75°E,) and Konkan (north off Panaji, 17°N 73.5°E) along the southwestern Indian coast, i.e., in the Southeastern Arabian Sea (fig. 1), and these fishing grounds were selected for the study. GIS mapping of the trawling ground showed that there are well-defined areas, some suited for trawling and others unsuitable for trawling, depending on the bottom characteristics. The study here reported was done for a period of four years (2009-2012).

Data collection and analysis

Data on brachyuran crabs were collected using a commercial trawler operating along the coast. The LOA (overall length) of the trawler was 15.85 m, it was equipped with a 350 hp engine, and the vessel was engaged in trawling for 8 to 13 days on each trip. Specially designed logbooks were prepared, and the crew members of the sampling boats were trained in data collection. Onboard information collected and recorded were the date of operation, depth of shooting, time of the shooting, shooting longitude, shooting latitude, hauling depth, hauling time, latitude and longitude; also the total catch (kg), total discard (kg) and the number of hauls/day were carefully registered (Dineshbabu et al., 2016).

The geocoded subsample from the catch (i.e., a sample with GPS information on the area of capture) was collected from the operating trawlers and brought to the laboratory for further analysis. Hauls from 915 fishing days of regular fishing operations were analysed for the study. The species composition of the catch, including discards-at-sea, in each haul, were recorded. For the mapping of the spatiotemporal distribution and for a smooth handling of the data, two software programs, "ArcGIS" and 'Visual Basic 6" were used. The analysis of GIS maps to derive information on fishing and species distribution was carried out following the methodologies described by Baird et al. (2015). For the average biomass estimation, the "swept" area methods suggested by Sparre & Venema (1998) and Klima (1976) were used. The use of GIS coordinates of the fishing operation for the area calculation was employed as per the methodology described by Wood & Baird (2010). For an estimation of the landing of commercial crabs and also to understand the hours of operation of trawlers on the fishing grounds, catch-and-effort data collected from Mangalore fisheries harbour (Srinath et al., 2005) during 2009-2012 were also analysed. For testing the seasonality of the species, a "One way analysis of variance" (ANOVA) was done with SPSS (ver. 16) software, and analyses for graphical representation were performed in RStudio (Version 1.0.136) using the inbuilt package "gg plot" (version 2.2.1) (RStudio Team, 2015).

RESULTS

Distribution and abundance of brachyuran crabs

About 20 species of brachyuran crabs were found to have a wider distribution in the depth range of 10-200 m during the period 2009-2012. Brachyuran crabs occurred in 66% of the total of 915 fishing days analysed for the study. The species with maximum occurrence was of *Charybdis* (*Goniohellenus*) *hoplites* (Wood-Mason, 1877) (256 days), followed by *Charybdis* (*Charybdis*) *feriata* (Linnaeus, 1758) (132 days), *Portunus sanguinolentus* (Herbst, 1783) (110 days) and *Charybdis* (*Goniohellenus*) *smithii* MacLeay, 1838 (96 days) (fig. 2).

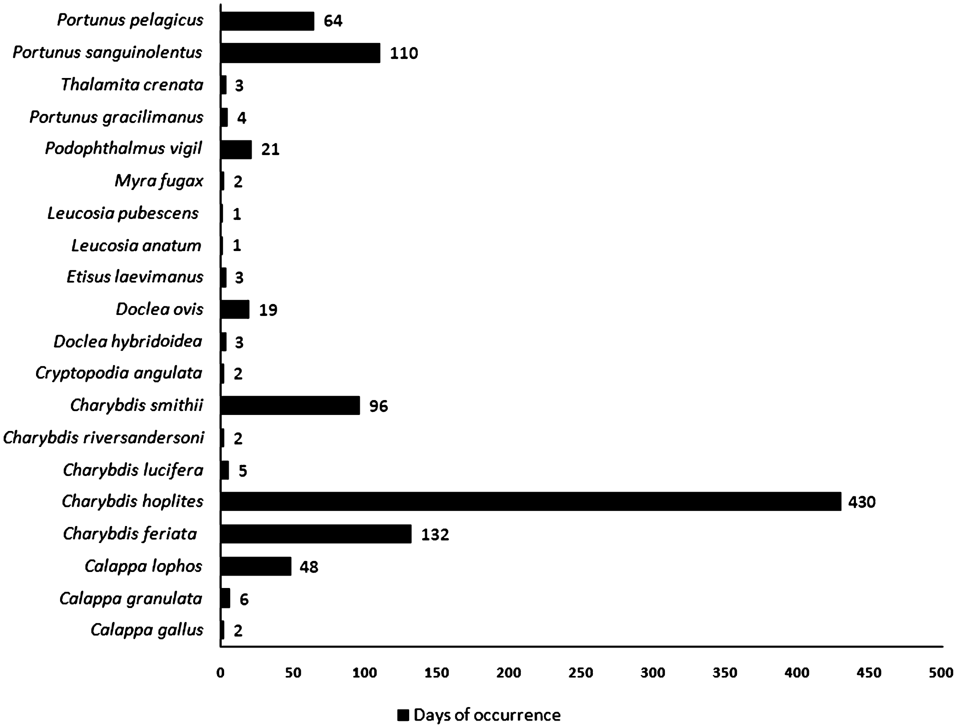

Fig. 2. Frequency of days of occurrence of the various crab species in the trawl catch during 2009-2012. The species found were: *Portunus pelagicus* (Linnaeus, 1758), *P. sanguinolentus* (Herbst, 1783), *Thalamita crenata* Rüppell, 1830, *Portunus gracilimanus* (Stimpson, 1858), *Podophthalmus vigil* (Fabricius, 1798), *Myra fugax* (Fabricius, 1798), *Leucosia pubescens* Miers, 1877 [currently also known as *Seulocia pubescens* (Miers, 1877)], *L. anatum* (Herbst, 1783), *Etisus laevimanus* Randall, 1840, *Doclea ovis* (Fabricius, 1787), *D. hybridoidea* Bleeker, 1856 [currently also known as *Doclea muricata* (Herbst, 1788)], *Cryptopodia angulata* H. Milne Edwards & Lucas, 1841, *Charybdis smithii* MacLeay, 1838, *C. riversandersoni* Alcock, 1899, *C. lucifera* (Fabricius, 1798), *C. hoplites* (Wood-Mason, 1877), *C. feriata* (Linnaeus, 1758), *Calappa lophos* (Herbst, 1782), *C. granulata* (Linnaeus, 1758), and *C. gallus* (Herbst, 1803).

Seasonal distribution and abundance of commercial crabs in the fishery

Major contributors to the crab fishery along the SEAS coast were *Charybdis feriata*, *Portunus sanguinolentus* and *P. pelagicus* (Linnaeus, 1758). Specimens of *C. feriata* were observed throughout the study period, whereas *P. pelagicus* and *P. sanguinolentus* formed a regular fishery from December onwards until the end of the fishing season (June). The average annual landing of commercial crabs at the Mangalore fisheries harbour was 127 t, of which *C. feriata*, *P. sanguinolentus* and *P. pelagicus* contributed 43, 43 and 41 t, respectively (fig. 3) with a catch rate (CPH) of 0.029, 0.029 and 0.027 kg/hour, respectively. The ANOVA test showed that the catch of these species varied significantly over the fishing season.

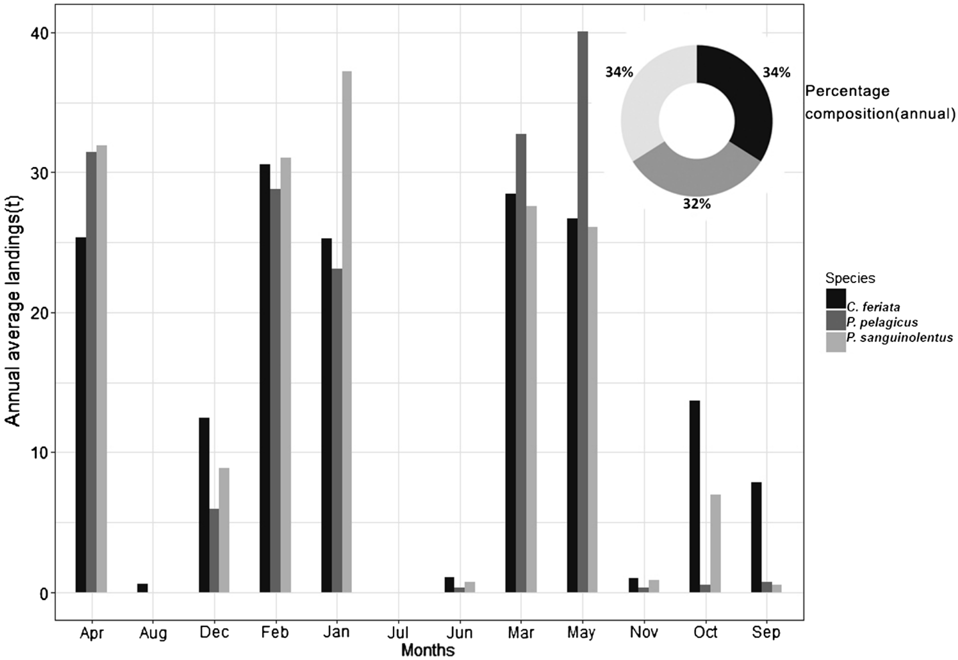

Fig. 3. Commercial crab landings at Mangalore fisheries harbour in 2009-2012: *Charybdis feriata* (Linnaeus, 1758), *Portunus pelagicus* (Linnaeus, 1758) and *P. sanguinolentus* (Herbst, 1783).

Non-commercial crabs from discarded bycatch

Major contributors to the non-commercial crab catch were *C. hoplites* and *C. smithii*, in which *C. hoplites* had the wider spatial distribution, followed by *C. smithii*. The temporal distribution analyses showed that *C. smithii* occurred only during August, December and May, whereas *C. hoplites* was observed throughout all months. Also, the Analysis of Variance showed no significant difference in the availability of *C. hoplites* between months.

The analysis of the mapping of distribution and abundance of non-conventional crabs (i.e., crabs that are not caught and landed in the regular fishery), revealed that *C. smithii* was found in good quantities as pelagic or semi-pelagic aggregations in the depth range in excess of 100 m (fig. 4), whereas *C. hoplites*, which showed a more benthic affinity and a definite annual pattern of distribution (fig. 4) was caught in hauls taken from the bottom or near the bottom in zones of 10 to 150 m depth, showing the probability of having a high trophic significance in the benthic ecosystem.

Area swept by sampling trawler

The average “swept area” of the sampling trawler, with an average speed of 3.8 nautical miles/h (6.84 km/h) and with a breadth of the head rope opening of 20 m,

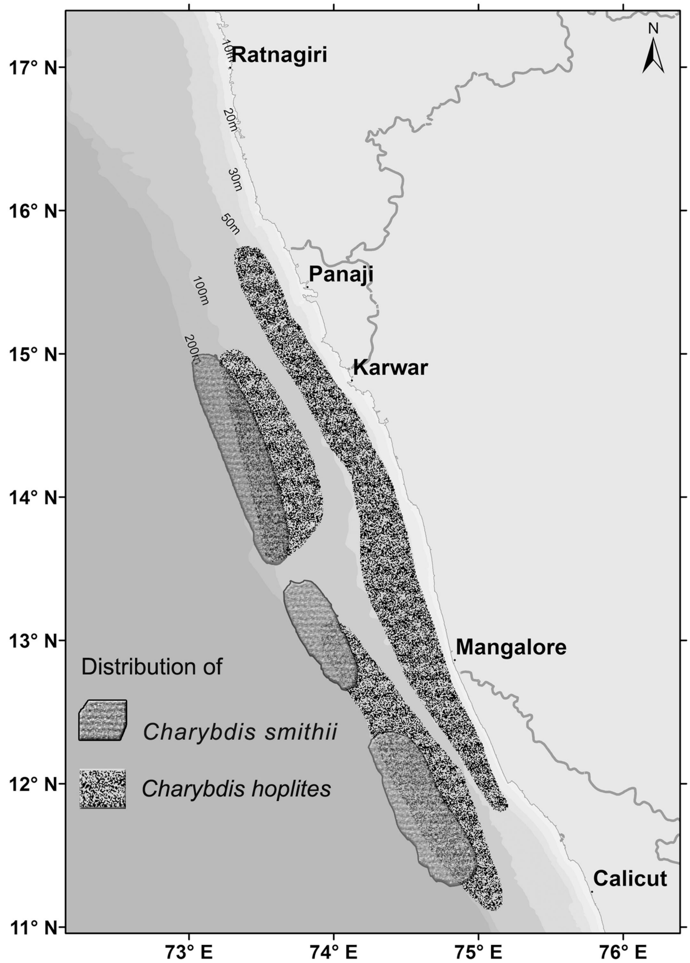

Fig. 4. Spatial distribution of *Charybdis hoplites* (Wood-Mason, 1877) and *Charybdis smithii* MacLeay, 1838 in the prospected area along the southwestern coast of India.

was calculated as 0.131 km^2 per hour. The area of the fishing ground was mapped and calculated with the help of GIS software. The area of the fishing polygon covered by trawlers was estimated at 40 666 km^2, but out of this total only 75% (30 221 sq.km) was found to be suitable for trawling. Unfavourable features of the sea bottom dominated by reef and rock restricted trawling in an area of around 10 455 km^2.

Average biomass and catch estimation

The catch per hour (CPH/catch rate) of *C. hoplites* ranged from 0.007 to 54 kg with an average of 1.40 kg CPH for the period of study. The average annual catch rate derived for *C. smithii* was 0.01 kg. The average biomass calculated for *C. hoplites* in the fished part of the fishing ground polygon was 322.17 t. The catch rate of *C. hoplites* was as high as 36 kg/hour in certain parts of the fishing ground (fig. 5). Even though trawling was not possible, looking at the distribution of the species in the similar depth zone of the fishing ground, its distribution is apparent in non-trawled areas also, which may be instrumental in getting this species a natural protection from the heavy fishing pressure. Due to the seasonal nature of its presence and the patchy occurrence in its distribution area, the annual biomass of *C. smithii* was not estimated: it just could not reliably be established. The estimated average annual fishing effort from the Mangalore fisheries harbour during the period of study was about 1 487 892 hours and it is estimated that about 2803 t of *C. hoplites* were caught and discarded annually by the trawlers during 2009-2012. For *C. smithii*, the estimated annual catch was a mere 15 t.

DISCUSSION

Along the western Indian Ocean, *Charybdis hoplites* and *C. smithii* were earlier reported as major contributors to the local brachyuran biodiversity, and also as contributing to the fishery ecosystem (Apel & Spiridonov, 1998). *C. smithii* was reported as occupying the semi-pelagic realm and *C. hoplites* as having benthic affinities, with an occasional distributional overlap between the two (Türkay & Spiridonov, 2006). There have been studies on the distribution and biology of *C. smithii* from Indian waters (Balasubramanian & Suseelan, 2001), but the information on the presence and abundance of *C. hoplites* in the trawl fishing grounds of the SEAS were fairly unknown (Dineshbabu et al., 2012). With trophic studies on the benthic fauna, Philip (1998) and Xue et al. (2005) observed that crabs formed one of the major food components, responsible for sustaining a high production of commercially important demersal fishes. Similarly, with the ecopath modelling of SEAS, Abdurahiman et al. (2010) highlighted the trophic significance of benthic crabs specifically in the ecosystem where the present study was conducted. The use of GIS in understanding the distribution and abundance of the marine resources is gaining importance globally (Booth, 1998; Nishida & Booth, 2001) and biomass estimation of commercially less important species with spatial data analysis (Wazevbok & Gassner, 2000) is becoming a part of the "ecospace" concept (Walters et al., 2000) in ecopath modelling. The methodology of application of GIS in EBFM demonstrated by Meaden et al. (2010) in the eastern English Channel is applied in the present study for strengthening EBFM in the SEAS area. In the light of the information on the trophic dependency of demersal fishes on benthic crabs (Abdurahiman et al., 2010) the biomass of *C. hoplites*

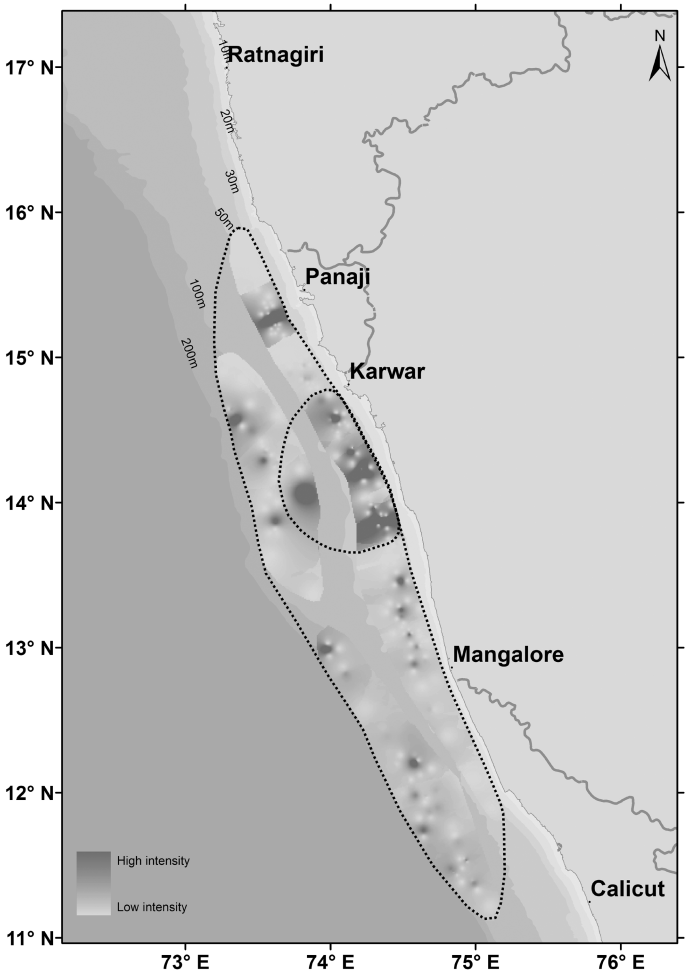

Fig. 5. GIS aided biomass estimation of *Charybdis hoplites* (Wood-Mason, 1877).

(332 t), can be considered a prominent contributor to the high production of demersal fishes from SEAS and, as observed by Baran (2002), heavy exploitation of such ecologically sensitive species as bycatch, as in the present case, which is estimated at 700 t annually, may have a detrimental impact on the sustaining high productivity from SEAS. The methodology described in the present paper will be a handy tool for the quantification of many other discarded species, which are generally unrecorded, to ensure efficient management of the marine fishery from SEAS.

There are only a few published accounts on the distribution of non-commercial species in trawling grounds, since most of these catches are discarded at sea. Generally, non-commercial species were found to act as “keystone species” and their absence or reduction in abundance may change the entire trophic fabric of the ecosystem (Link, 2007), but due to the absence of such species in the actual landings, their importance is often neglected. The present study reveals the significant role of non-commercial brachyuran species in the trawl fishing grounds, in terms of distribution and abundance, and emphasize the fact that, while developing plans for management of the commercial fishery, the exploitation of (as yet) non-commercial species also needs to be taken into consideration, first of all for ensuring continued sustainability.

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REFERENCES

ABDURAHIMAN, K. P., T. H. NAYAK, P. U. ZACHARIA & K. S. MOHAMED, 2010. Trophic organization and predator-prey interactions among commercially exploited demersal finfishes in the coastal waters of the Southeastern Arabian Sea. Estuar. Coast. Shelf Sci., **87**: 601-610.

APEL, M. & V. A. SPIRIDONOV, 1998. Taxonomy and zoogeography of the portunid crabs (Crustacea: Decapoda: Brachyura: Portunidae) of the Arabian Gulf and adjacent waters. Fauna of Arabia, **17**: 159-331.

BAIRD, S. J., J. E. HEWITT & B. A. WOOD, 2015. Benthic habitat classes and trawl fishing disturbance in New Zealand waters shallower than 250 m. New Zealand Aquatic Environment and Biodiversity Report, **144**: 1-184.

BALASUBRAMANIAN, C. P. & C. SUSEELAN, 2001. Distribution and population structure of deep-water crab *Charybdis smithii* (Decapoda: Portunidae) in the Arabian Sea and the Bay of Bengal. Bull. Mar. Sci., **68**(3): 435-449.

BARAN, E., 2002. The importance of non-commercial fish. In: P. SAFRAN (ed.), Fisheries and aquaculture: towards sustainable aquatic living resources management: 1-7. (UNESCO Encyclopaedia of Life Support Systems; EOLSS Publishers, Oxford, U.K.).

BOOTH, A. J., 1998. Spatial analysis of fish distribution and abundance patterns: a GIS approach. In: F. FUNK, T. J. QUINN, II, J. HEIFETZ, J. N. IANELLI, J. E. POWERS, J. F. SCHWEIGERT, P. J. SULLIVAN & C. I. ZHANG (eds.), Fisheries stock assessment models: 719-740. (University of Alaska Sea Grant, Fairbanks).

CHRISTENSEN, V. & D. PAULY (eds.), 1993. Trophic models of aquatic ecosystems. ICLARM Conference Proceedings, **26**: 1-390.

DINESHBABU, A. P., S. THOMAS & A. C. DINESH, 2016. Handbook on application of GIS as a decision support tool in marine fisheries: 1-104. (ICAR – Central Marine Fisheries Research Institute, Kochi).

DINESHBABU, A. P., S. THOMAS & E. V. RADHAKRISHNAN, 2012. Spatiotemporal analysis and impact assessment of trawl bycatch of Karnataka to suggest operation based fishery management options. Indian J. Fish., **59**(2): 27-38.

GUNDERSON, D. R., 1993. Surveys of fisheries resources: 1-248. (Wiley, New York).

KLIMA, E. F., 1976. A review of the fishery resources in the western central Atlantic. WECAF Stud., **3**: 1-77.

LINK, J. S., 2007. Underappreciated species in ecology: "ugly fish" in the northwest Atlantic Ocean. Ecological Applications, **17**(7): 2037-2060.

MEADEN, G. J., 1999. Applications of GIS to fisheries management. In: D. WRIGHT & D. BARTLETT (eds.), Marine and coastal geographical information systems: 205-226. (Taylor & Francis, London).

NISHIDA, T. & A. J. BOOTH, 2001. Recent approaches using GIS in the spatial analysis of fish populations. In: G. H. KRUSE, N. BEZ, A. BOOTH, M. W. DORN, S. HILLS, R. N. LIPCIUS, D. PELLETIER, C. ROY, S. J. SMITH & D. WITHERELL (eds.), Spatial processes and management of marine populations: 19-36. (University of Alaska Sea Grant, Fairbanks).

PAULY, D., V. CHRISTENSEN & C. WALTERS, 2000. Ecopath, ecosysm and ecospace as tools for evaluating ecosystem impact fisheries. ICES J. Mar. Sci., **57**: 697-706.

PHILIP, K. P., 1998. Food and feeding habits of *Priacanthus hamrur* (Forsskål) from the upper east coast of India. Bull. Fish. Surv. India, **26**: 12-25.

RSTUDIO TEAM, 2015. RStudio: integrated development for R. (RStudio, Inc., Boston, MA). [Available at: http://www.rstudio.com/.]

SPARRE, P. & S. C. VENEMA, 1998. Introduction to tropical fish stock assessment. Part 1. Manual. FAO Fish. Tech. Pap., **306.1** (Rev. 2): 1-407. (FAO, Rome).

SRINATH, M., S. KURIAKOSE & K. G. MINI, 2005. Methodology for the estimation of marine fish landings in India. CMFRI Spec. Publ., **86**: 1-57.

TÜRKAY, M. & V. A. SPIRIDONOV, 2006. Deep water swimming crabs of the subgenus *Charybdis* (*Goniohellenus*) of the western Indian Ocean (Crustacea: Decapoda: Portunidae). Fauna of Arabia, **22**: 199-223.

VIVEKANANDAN, E., 2002. Application of an ecosystem model on the fish stocks in the southwest coast of India. RAP Publication (FAO), **2002/27**: 47-60.

VIVEKANANDAN, E., M. SRINATH, V. N. PILLAI, S. IMMANUEL & K. N. KURUP, 2003. Marine fisheries along the southwest coast of India. In: G. SILVESTRE, L. GARCES, I. STOBUTZKI, C. LUNA, M. AHMAD, R. A. VALMONTE-SANTOS, L. LACHICA-ALIÑO, P. MUNRO, V. CHRISTENSEN & D. PAULY (eds.), Assessment, management and future directions for coastal fisheries in Asian countries. WorldFish Center Conference Proceedings, **67**: 757-792. (Penang).

WALTERS, C., D. PAULY & V. CHRISTENSEN, 2000. Ecospace: prediction of mesoscale spatial patterns in trophic relationships of exploited ecosystems, with emphasis on the impacts of marine protected areas. Ecosystems, **2**: 539-554.

WAZEVBOK, J. & H. GASSNER, 2000. Assessment of fish biomass distribution in Australian lakes and visualisation in 3D GIS. In: T. NISHIDA (ed.), Proceedings of first international symposium on GIS in fisheries science, 2-4 March 1999, Seattle, Washington: 329-335. (GIS Fishery Research Group, Saitama, Japan).

WOOD, B. & S. J. BAIRD, 2010. Mapping bottom-trawl fishing activity in the New Zealand EEZ. In: T. NISHIDA & A. E. CATON (eds.), GIS/spatial analyses in fishery and aquatic sciences, **4**: 443-450. (International Fishery GIS Society, Saitama, Japan).

XUE, Y., X. JIN, B. ZHANG & Z. LIANG, 2005. Seasonal, diel and ontogenetic variation in feeding patterns of small yellow croaker in the central Yellow Sea. J. Fish. Biol., **67**: 33-50.

NOTE FROM THE EDITORS

The name *Charybdis feriata*, as spelled considering the generic name to be of feminine gender (as is in accordance with the guidelines in the ICZN (1964) and also appears from many other specific names in combination with this generic name that show the difference between masculine and feminine gender; as evidenced by the list of species on the website of WoRMS (2018): see http://www.marinespecies.org/aphia.php?p=taxdetails&id=106923), other lists treat the name *Charybdis* as of masculine gender, as, e.g., the website of Sealife Base (2018), at: https://www.sealifebase.ca/summary/Charybdis-feriatus.html, where consequently the name is spelled as *Charybdis feriatus*. Crustaceana follows WoRMS (2018) and Ng et al. (2008), and thus spells the name as *C. feriata*.

ICZN, 1964. International code of zoological nomenclature – adopted by the XV international congress of zoology (2nd ed.): i-xx, 1-177. (International Trust for Zoological Nomenclature, London).

NG, P. K. L., D. GUINOT & P. J. F. DAVIE, 2008. Systema Brachyurorum: Part I. An annotated checklist of extant brachyuran crabs of the world. Raffles Bull. Zool., (Suppl.) **17**: 1-286.

WORMS, 2018. World Register of Marine Species. [Available at: http://www.marinespecies.org/index.php.]

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