# Spatial Diversity of Small Pelagic Species Caught in Bali Strait and Adjacent Indonesian Waters

Ledhyane Ika Harlyan[1*], Farisa Mardiana Rahma[1], Denny Wijaya Kusuma[2], Abu Bakar Sambah[1], Takashi Fritz Matsuishi[3] and Supapong Pattarapongpan[4]

## ABSTRACT

Bali Strait fisheries have experienced overexploitation of certain small pelagic species, such as Bali sardinella (*Sardinella lemuru*) due to limited species-specific geographic information. The lack of information on pelagic species distribution may hamper fishers in locating suitable fishing grounds, and also in avoiding areas where rebuilding or overfished species inhabit. Spatial diversity clustering can provide an accurate depiction of fishing grounds by species. This study aimed to discover spatial diversity in species composition data and fishing coordinates gathered from commercial fisheries operated in the Bali Strait and landed in Pengambengan fishing port and Muncar fishing port from January to May 2021. All fishing locations and their associated species compositions were digitized into two spatial diversity analyses, conducted by applying Shannon-Wiener's index (H') and Margalef's richness index (S), and a hierarchical cluster with bootstrap p-value analysis. These results were compiled to determine fishing ground patterns. Two clusters, one dominated by Bali sardinella and the other by scads (*Decapterus* spp.), were evident in even distribution. Therefore, during this time of year, more localized management of pelagic fisheries could be applied in the Bali Strait to encourage fishers to target other species in order to avoid over-exploitation of Bali sardinella.

**Keywords:** Fisheries management, Multispecies fishery, Spatial distribution, Species composition

## INTRODUCTION

During the last couple of decades, fisheries management has improved substantially to maintain fishing pressure at levels capable of maintaining stock productivity (Nakatsuka, 2017; Harlyan *et al*., 2021a). In some cases, multiple management measures have been employed to preserve stocks to strengthen the resilience of fishing communities facing growing economic and environmental problems (Salas *et al*., 2007; Purcell and Pomeroy, 2015). However, an increase in overfishing and overcapacity has occurred, especially in Southeast Asian fisheries, and consequently threatens fisheries sustainability (FAO, 2004; Amornpiyakrit and Siriraksophon, 2016; SEAFDEC, 2017).

Bali Strait is a part of the Indonesian Fisheries Area (FMA)-573, separating Java and Bali Island. It has high primary productivity as indicated by the high concentration of chlorophyll-*a* (Arianto *et al*., 2014) and is covered by upwelling activity during the monsoon season (from June to October) (Ningsih *et al*., 2013). Owing to the rich supply of nutrients, this area possesses high productivity and potential for its small-pelagic

[1]Department of Fisheries Resource Utilization, Faculty of Fisheries and Marine Science, Brawijaya University, Malang, Indonesia
[2]Institute for Marine Research and Observation, Bali, Indonesia
[3]Faculty of Fisheries Sciences, Hokkaido University, Hokkaido, Japan
[4]Southeast Asian Fisheries Development Center, Training Department, Samutprakan, Thailand
* Corresponding author. E-mail address: ledhyane@ub.ac.id
Received 2 June 2022 / Accepted 23 December 2022

fishery (Hendiarti *et al*., 2015). For decades, Bali sardinella (*Sardinella lemuru*) has been the most dominant small-pelagic species caught in Bali Strait (Himelda *et al*., 2011; Puspasari *et al*., 2016), followed by scads (*Decapterus* spp.) and mackerels (*Rastrelliger* spp.) (Sartimbul *et al*., 2018). Recently, however, some species have experienced over-exploitation and are threatened by high fishing pressure (Wujdi and Wudianto, 2015; Wujdi *et al*., 2016; Tampubolon *et al*., 2021).

In order to avoid over-exploitation of certain species or groups of species, it is important to obtain information on the spatial pattern of fishing grounds used to target them (Harlyan *et al*., 2021a; 2021b). This information may also guide fishers to avoid catching species in stock rebuilding or over-exploited conditions (Harlyan *et al*., 2021a). In Indonesia, the Institute of Marine Research and Observation-Bali (BROL-Bali) has created a map of fishing grounds to support fishery management and planning. The map is produced as the result of environmental factor approaches, remote sensing technology and empirical prediction of fishing areas (Sumadhiharga, 2009). However, the current map might only predict fishing grounds for a group of species rather than being species-specific (Sambah *et al*., 2016; Wiryawan *et al*., 2020; Harlyan *et al*., 2021b) data are only available for particular species. Because of these limitations, a more detailed species distribution map for managing both of target and non-target species pelagic fisheries is still needed (Southall *et al*., 2016; Harlyan *et al*., 2021a; 2021b).

Tropical pelagic fisheries, as in Bali Strait, are multispecies and multi-gear fisheries (Harlyan *et al*., 2022a) that may result in heterogeneous systems (Najmudeen and Sathiadhas, 2008), and thus may require complex management (Pascoe and Greboval, 2003; Kato, 2008; Harlyan *et al*., 2019). Therefore, spatial analysis is helpful to interpret target and non-target species habitats from the distribution of fishing operations. Spatial diversity distribution analysis is a tool to map the fishing catch based on spatial diversity indices combined with Euclidean distance analysis within fishing areas (Sambah *et al*., 2020; Harlyan *et al*., 2021a; 2021b).

As spatial diversity distribution might reflect fishing ground patterns, it is imperative that managers be provided with this information to use as a reference for pelagic fisheries management. Therefore, the present study aimed to explore whether there is grouping or pattern of fishing locations of the pelagic fishery that can be used as baseline data for future studies.

## MATERIALS AND METHODS

*Study area*

In the Bali Strait, there are two dominant fishing ports available for local fishers to land their catches: Pengambengan Fishing Port in Jembrana, Bali and Muncar Fishing Port in Banyuwangi, East Java (Figure 1). The field surveys for this study were conducted at both fishing ports to gather fishing and landing information in the period from January to May 2021, which represents the fishing season in the Bali Strait.

*Data collection*

The field surveys were performed to collect species information by fishing grounds, fishing gears, landing sites and amount of the landing. During the surveys, a systematized questionnaire was used to collect fishing data including fishing coordinates and catch data through face-to-face interviews with local fishers and enumerators. Consultations were conducted with the Institute of Marine Research and Observation-Indonesia before data collection to develop the questionnaires and collect fishing activity information. The species composition of the landings was gathered from fishing logbooks submitted to the local fishery authorities at the ports of Muncar and Pengambengan. The fishing coordinates were obtained from participatory mapping to assist local fishers (respondents) in identifying and indicating their fishing coordinates. At the time of the survey, there were 682 owners of fishing boats who landed their boats in both fishing ports. For data collection, over 10 % of the boat owners were included as respondents. A total of 80 boat owners were interviewed, comprising 20 gillnet boats sized

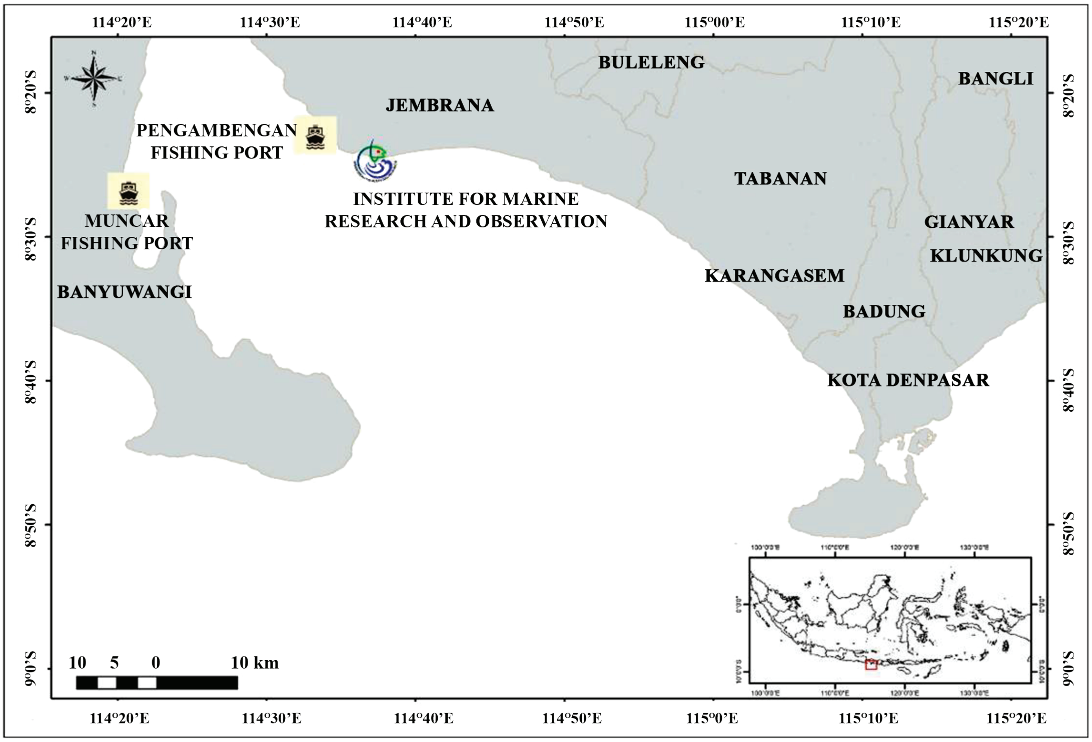


Figure 1. Bali Strait and its two fishing ports.

2-6 gross tonnage (GT), 15 handline boats sized 1-5 GT, 10 lift net boats sized 1-5 GT, 10 "payang" or seine boats sized 6-26 GT, and 25 purse seine boats sized 18-35 GT.

*Data analysis*

To define the spatial patterns of Bali Strait fishing areas, two analyses were conducted, namely species diversity and cluster analysis, as explained in the following sections.

Two diversity indices were applied to illustrate the species diversity in each location within the fishing ground, the Shannon-Wiener index (H') and Margalef's richness index (S) (Zhu *et al*., 2011; Boyle *et al*., 2016):

$$\text{Shannon-Wiener's index } (H') = -\sum_{i=1}^{s} p_i \ln p_i \quad (1)$$

$$\text{Margalef's richness index } (S) = \frac{s-1}{\ln n} \quad (2)$$

In the first equation, $H'$ is the number of equally common species that might produce the same heterogeneity, where $p_i$ is the ratio of the caught species; i denotes species 1,2,3,…,s; and n stands for the weight of all caught individuals. In the second equation, S is the species richness by considering the number of individuals collected, where *s* is the number of species in a sample (Lipps *et al*., 1979).

To explore the specific grouping pattern within pelagic fishery grounds, cluster analysis was conducted based on the Ward's method with bootstrapped p-values in R Package (Maechler *et al*., 2018; R Core Team, 2018). In this study, 80 pairs of fishing coordinates (i.e., locations) were considered as observations that were clustered based on several variables. The 12 species caught and their weights were considered as the variables and observed values, respectively. Cluster analysis was applied to show the similarity among individuals within each cluster and the dissimilarity among clusters. A dendrogram was formed to indicate the hierarchical relationship distance among individuals or clusters of fishing coordinates which were generated by computing the Euclidean distances between vectors x and y, calculated as the following formula (Himmelstein *et al*., 2010; Roy *et al*., 2015):

$$d_{x,y} = \sqrt{\sum_{i=1}^{n}(x_i - y_i)^2} \quad (3)$$

where x and y are points in the Euclidean space, $x_i$ and $y_i$ are the Euclidean vectors in n Euclidean space.

Using Euclidean distances, 80 fishing coordinates were clustered by species composition based on 12 species. For the dendrogram, the approximated unbiased probability value (AU value) and bootstrap probability value (BP value) were generated through multi-scale bootstrap resampling and normal bootstrap resampling, respectively. The AU values have a better approximation than the BP values. A cluster with AU value of more than 0.95 indicates that the cluster may exist due to the stable number of observations (Suzuki and Shimodaira, 2017). To display the clustering of potential fishing grounds, the fishing coordinate clusters, together with their species composition, were digitized.

## RESULTS AND DISCUSSION

*Species composition*

There were 12 species landed during the fishery surveys, which were categorized into seven species groups (Figure 2). Six of the groups comprised 94 % of the total weight of the samples (71,857 kg).

The catch was dominated by *Sardinella lemuru* (43 %), *Decapterus* spp. (22 %) and *Auxis rochei* (17 %), with lesser percentages for other species groups. Some categories were aggregations of multiple species (e.g., *Decapterus* spp., *Rastrelliger* spp.), and these groups comprised nearly 33 % of the weight of landings.

*Species diversity*

Based on the field surveys during January–May 2021, 80 sets of fishing coordinates were mapped together with the composition of the associated landings (Figure 3). Several species were widely distributed and found at each fishing ground.

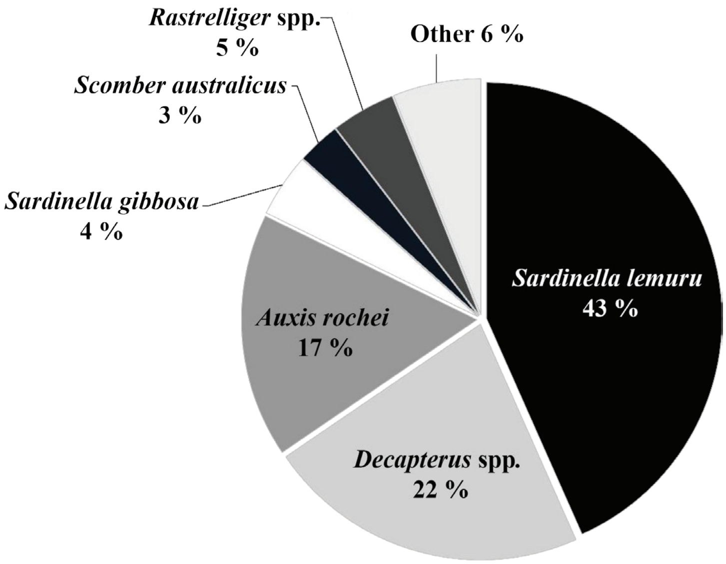


Figure 2. Landing composition at two ports of Bali Strait, Indonesia, based on survey data in January–May 2021.

Species diversity and richness were calculated to portray the pelagic fishery resources in the Bali Strait. Species diversity (H') ranged from 0 to 1.5, while species richness (S) at the fishing grounds ranged from 0 to 5 (Figure 4). Some overlaps were found between fishing locations with low and high species diversity and richness due to the temporal differences in fishing period. No structured pattern was found either for species diversity or richness.

These indices reflect the pelagic multispecies fishery conditions in the Bali Strait, and show both low and high species diversity within an area. This might be due to the differences in the species selectivity of fishing gears operated in the areas, which resulted in different species composition in the catch (Oliveira *et al*., 2014; Islam *et al*., 2016).

*Cluster analysis*

The fishing locations of the multispecies pelagic fishery in the Bali Strait were grouped by cluster analysis (Figure 5). There were two clusters found in this fishery based on each species' similarity distance, and the clusters showed a similar pattern as the diversity analyses. More of the samples (i.e., fishing locations) were placed in Cluster II than in Cluster I.

Cluster II, which is indicated as the dominant cluster, includes locations widely distributed across the Bali Strait to the Indian Ocean, while samples in cluster I are mostly from within the Bali Strait (Figure 6). The difference in fishing grounds may be related to the type of fishing gears, which also affects the species composition of the catch. The landing composition of these two

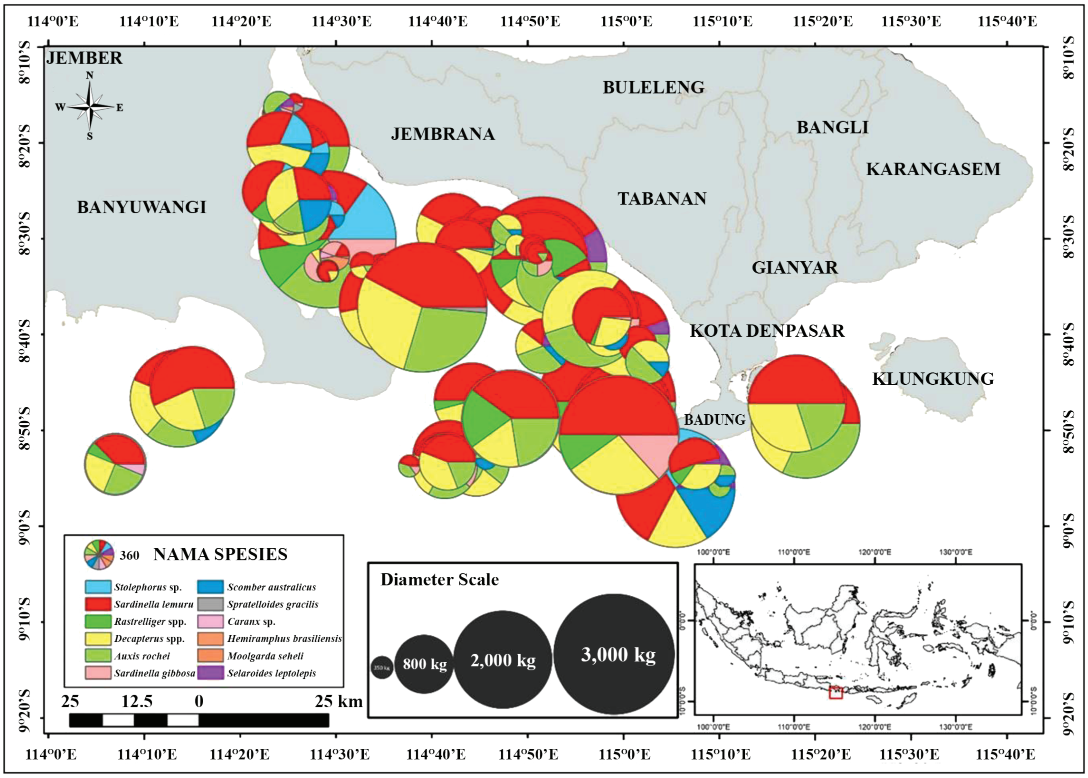


Figure 3. The multispecies condition of small pelagic fisheries in the Bali Strait. Circle diameters are proportional to the overall landings, and colored sections reflect the catch composition.

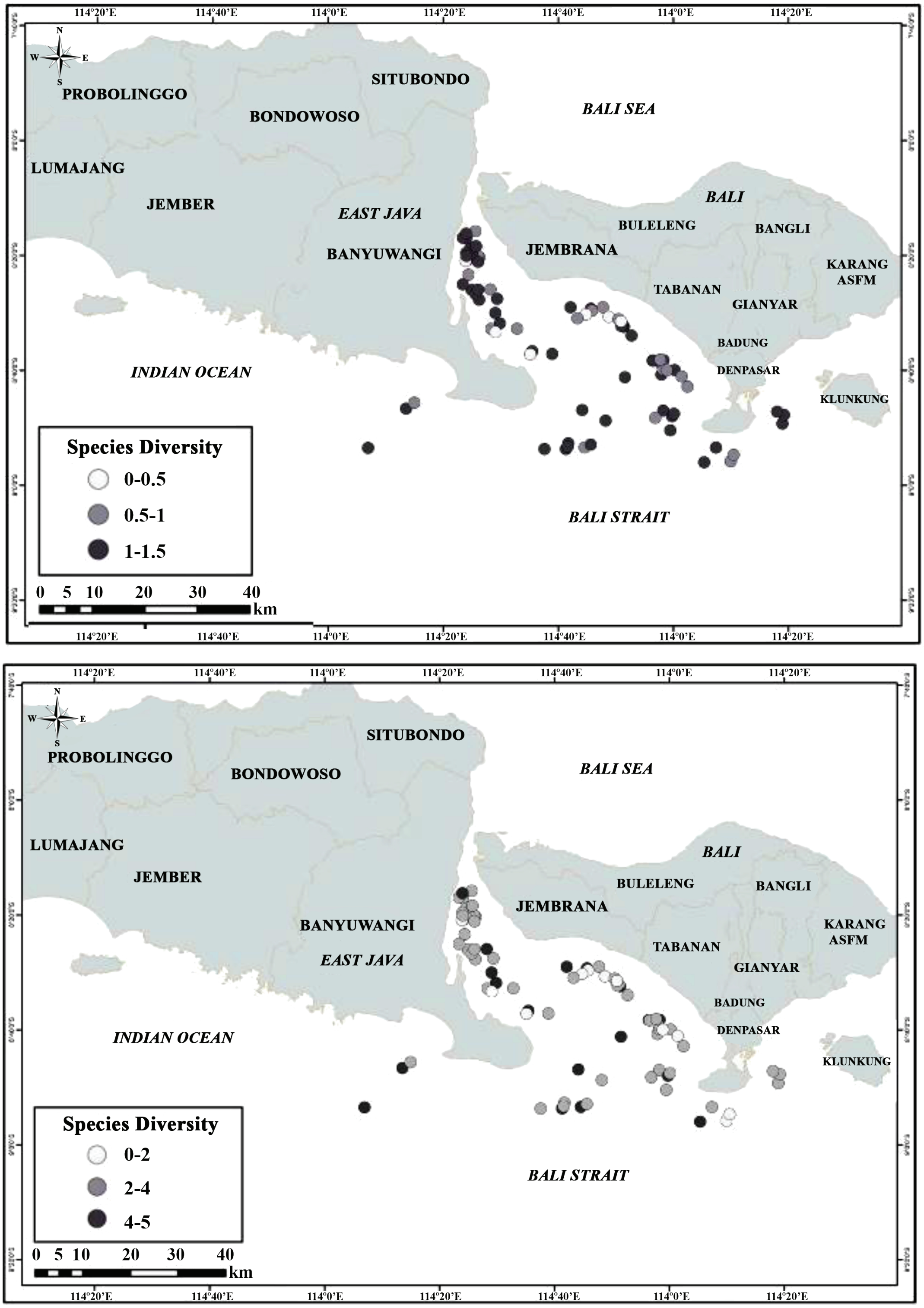


Figure 4. Species diversity (H') and richness (S) in the Bali Strait fishery.

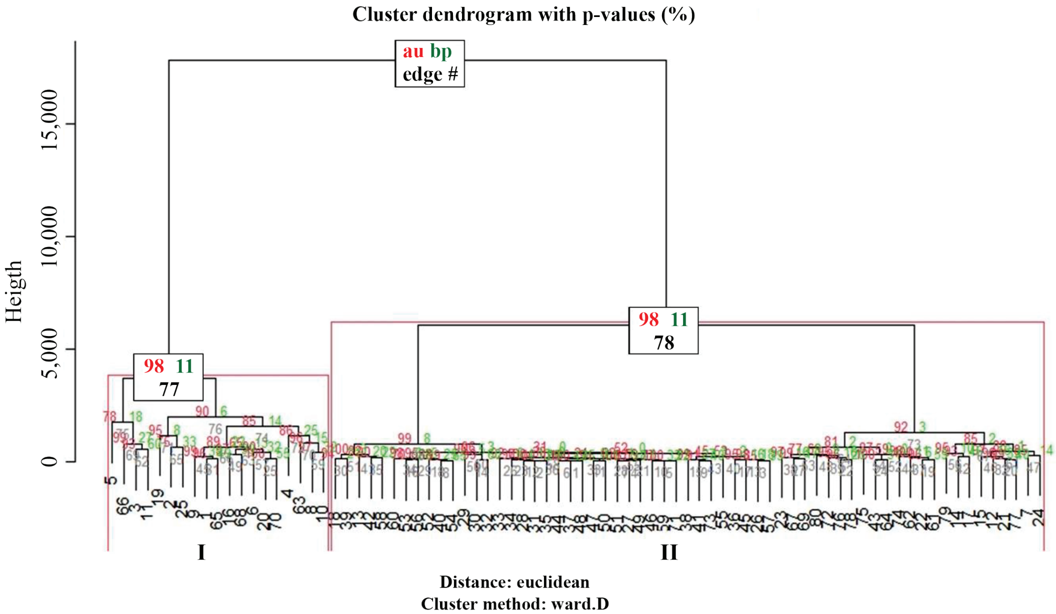


Figure 5. Dendrogram of clustered fishing locations. The approximated unbiased probability (AU) values are in red, while bootstrap probability values are in green. The red frames specify clusters with AU values more than 0.95.

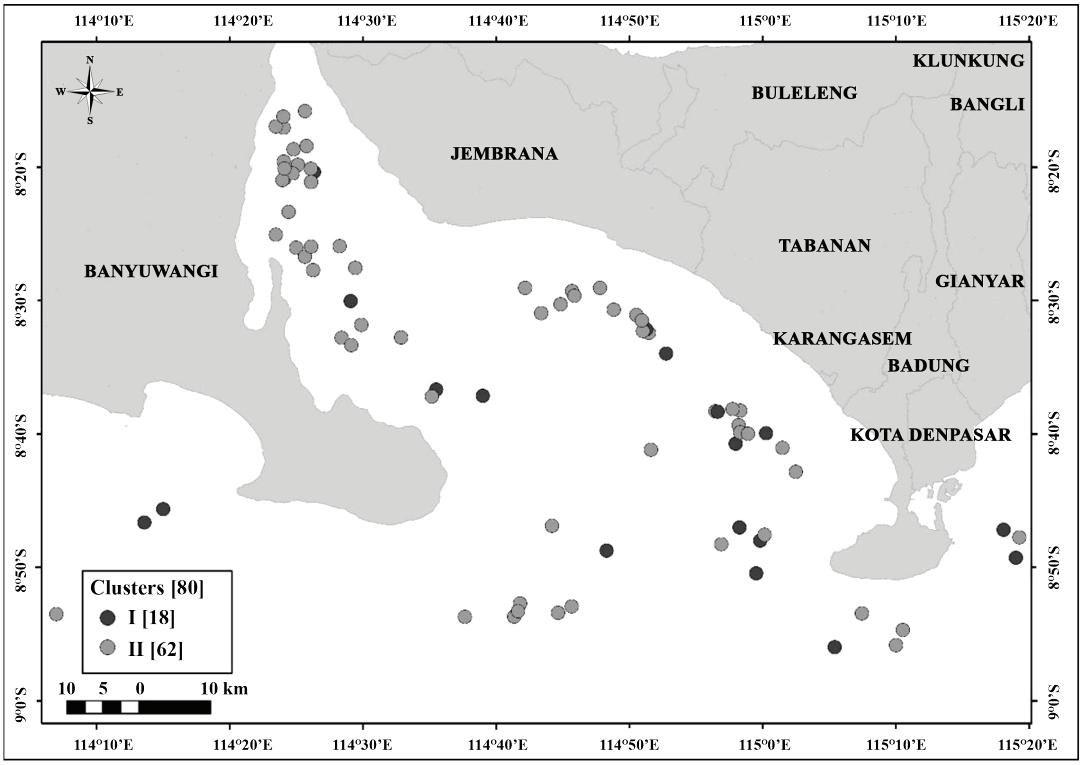


Figure 6. Distribution of fishing locations in Cluster I and Cluster II of the multispecies fishery in the Bali Strait.

clusters were relatively similar (Figure 7). The dominant species was *Sardinella lemuru* (43 %), followed by *Decapterus* spp. (22 %), *Auxis rochei* (14-19 %), *Sardinella gibbosa* (4-5 %), *Rastrelliger* spp. (3.7-5 %), and *Scomber australicus* (3 %).

The distribution pattern of fishing locations in the Bali Strait indicated that fishing pressure is spread evenly, especially for the two dominant species, *Sardinella lemuru* and *Decapterus* spp. *Sardinella lemuru* is one of the small pelagic species in the Bali Strait, with high productivity since 1972 (Wujdi, 2013). An increase in fish processors may have amplified the magnitude of demand and fishing pressure for this species (Wujdi and Wudianto, 2015; Wujdi *et al*., 2016).

Like *Sardinella lemuru*, *Decapterus* spp. are small pelagic fishes with high vulnerability to capture and high growth rate. Plankton, the main diet of *Decapterus* spp. are widely distributed in the Bali Strait (Puspasari *et al*., 2016). The two clusters of samples based on fishing location had similar proportions of the two dominant species. This may be due to differences in the type of fishing gears, fishing season and multispecies characteristics (Harlyan *et al*., 2021a; 2021b; 2022a; 2022b). Their relative abundance within the assemblage of species may reflect their broad spawning period and successive cohort (Peck *et al*., 2012; Harlyan *et al*., 2021a).

Some studies found that *Sardinella lemuru* had collapsed for decades (Purwaningsih *et al*., 2011; Puspasari *et al*., 2016; 2018; Sartimbul *et al*., 2021; Setyohadi *et al*., 2021), even though it appeared to be abundant to the south of Java Island in 2019. Given this variability in catch and uncertainty of populations of *Sardinella lemuru*, and also considering the similar composition of the two clustered groups of species, it is suggested that target of pelagic fisheries in the Bali Strait be changed from *Sardinella lemuru* to scads and/or other dominant species (Figure 7). One potential area for fishing is around 114°7´-115°19´E, 9°4´-9°44´S (Figure 6).

By recognizing and understanding the multispecies characteristics of the pelagic fishery in the Bali Strait, fishers have a chance to adjust their target species, since our analysis shows that the species assemblages are distributed evenly in the Bali Strait with a similar composition. A multispecies fishery approach should be used to manage a multispecies fishery. A short-term tactical approach validated for multispecies fisheries,

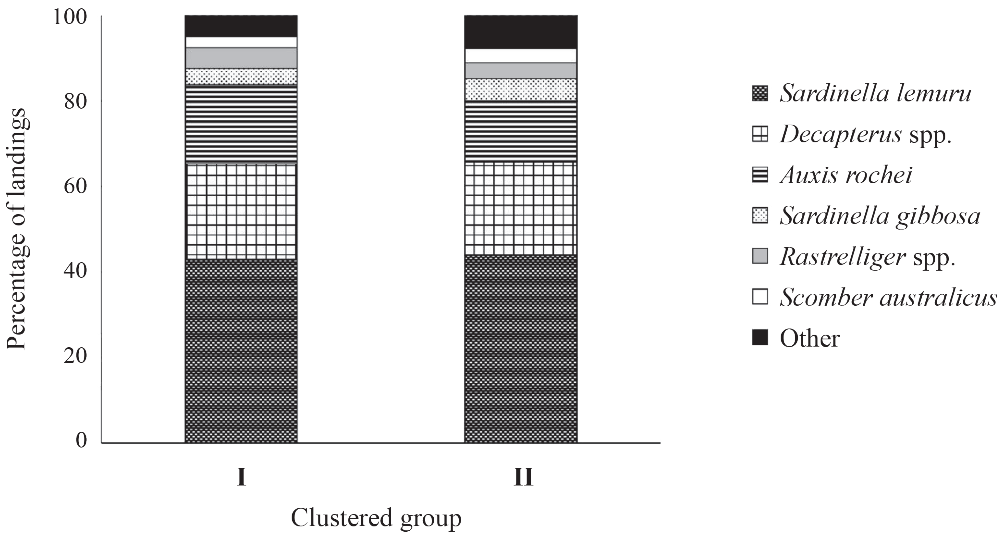


Figure 7. Species composition by weight of Cluster I and Cluster II, based on samples from the Bali Strait fishery.

the feedback harvest control rule (Goethel *et al*., 2019; Harlyan *et al*., 2019; 2022b), suggested that species with similar growth rates can be managed together. The majority of fast-growing pelagic fish in the Bali Strait occupy roughly the same fishing grounds. In this situation, to avoid overexploitation and high catch variability of certain species, fishers may adopt an alternative fishing strategy to also target some of the other pelagic species.

## CONCLUSION

Diversity indices based on catch composition from fishing grounds in the Bali Strait showed no discernible pattern, with high and low diversity locations intermixed. During the survey period, two clusters of fishing locations with similar species composition were identified in the Bali Strait. Therefore, during this period, some alteration of species targets might be beneficial. A limitation of this study was the length of the survey period (January–May); future studies should document fishing patterns and catch composition at other times of the year.

## ACKNOWLEDGEMENTS

We acknowledge the Institute for Marine Research and Observation-Indonesia, Muncar and Pengambengan Fishing Port for supporting our research and for valuable recommendations to improve this manuscript.

## LITERATURE CITED

Amornpiyakrit, T. and S. Siriraksophon. 2016. Management of fishing capacity for sustainable fisheries: RPOA-Capacity. **Fish for the People** 14(2): 18-23.

Arianto, B.Y., S. Subiyanto and Hani'ah. 2014. Analysis of the relationship between lemuru productivity and sea surface temperature and chlorophyll-*a* using Aqua Modis satellite imagery (Case Study: Bali Strait). **Jurnal Geodesi Undip** 3(4): 158-168.

Boyle, K., M. Kaiser, S. Thompson, L. Murray and P. Duncan. 2016. Spatial variation in fish and invertebrate bycatches in a scallop trawl fishery. **Journal of Shellfish Research** 35(1): 7-15. DOI: 10.2983/035.035.0102.

Food and Agriculture Organization (FAO). 2004. **Progress on the Implementation of the International Plan of Action for Management of Fishing Capacity.** Food and Agriculture Organization of the United Nation, Rome, Italy. 44 pp.

Goethel, D.R., S.M. Lucey, A.M. Berger, S.K. Gaichas, M.A. Karp, P.D. Lynch and J.F. Walter. 2019. Recent advances in management strategy evaluation: introduction to the special issue "Under pressure: addressing fisheries challenges with Management Strategy Evaluation." **Canadian Journal of Fisheries and Aquatic Sciences** 76 (10): 1689-1696. DOI: 10.1139/cjfas-2019-0084.

Harlyan, L.I., A.B. Sambah, F. Iranawati and R. Ekawaty. 2021a. Spatial clusterization of tuna diversity in the Southern Java. **Journal of Fisheries Sciences** 23(1): 9-16. DOI: 10.22146/jfs.58917.

Harlyan, L.I., D. Wu, R. Kinashi, M. Kaewnern and T. Matsuishi. 2019. Validation of a feedback harvest control rule in data-limited conditions for managing multispecies fisheries. **Canadian Journal of Fisheries and Aquatic Sciences** 76: 1885-1893. DOI: 10.1139/cjfas-2018-0318.

Harlyan, L.I., L. Badriyah, M.A. Rahman, D.O. Sutjipto and W.K. Sari. 2022a. Harvest control rules of pelagic fisheries in the Bali Strait, Indonesia. **Biodiversitas** 23 (2): 947-953. DOI: 10.13057/biodiv/d23 0237.

Harlyan, L.I., S.A. Nabilah, D. Setyohadi, Rahman, M.A. and S. Pattarapongpan. 2022b. Harvest control rules of multispecies scads (*Decapterus* spp.) fishery in Blitar Waters, East Java. **Jurnal Ilmiah Perikanan dan Kelautan** 14(1): 38-47. DOI: 10.20473/jipk.v14i1.30688.

Harlyan, L.I., T.F. Matsuishi and M.F. Md Saleh. 2021b. Feasibility of a single-species quota system for management of the Malaysian multispecies purse-seine fishery. **Fisheries Management and Ecology** 28: 126-137. DOI: 10.1111/fme.12470.

Hendiarti, N., Suwarso, E. Aldrian, K. Amri, R. Andiastuti, S.I. Sachoemar and I.B. Wahyono. 2015. Seasonal variation of pelagic fish catch around Java. **Oceanography** 18(4): 112-123. DOI: 10. 5670/oceanog.2005.12.

Himelda, H., E.S. Wiyono, A. Purbayanto and M. Mustaruddin. 2011. Analysis of the sardine oil (*Sardinella lemuru* Bleeker 1853) resources in Bali Strait. **Marine Fisheries** 2(2): 165-176. DOI: 10.29244/jmf.2.2. 165-176.

Himmelstein, D.S., C. Bi, B.S. Clark, B. Bai and J.D. Kohtz. 2010. **Chapter 4 Measures of distance between samples : Euclidean. BMC Developmental Biology.** http://www.econ.upf.edu/~michael/stanford/maeb4.pdf. Cited 21 April 2022.

Islam, S.M.M., M.B. Rahman, M.R. Alam, B.D. Mithun, A. Bal, M. Azam, and M. Ruma. 2016. A Case study on fishing gears, fish species composition and fisher folk community at Jamuna River of Sirajganj Sadar Fish Landing Site, Bangladesh. **Journal of Aquatic Science** 4(1): 11-19. DOI: 10.12691/jas-4-1-2.

Kato, Y. 2008. Steering the small-scale fisheries of Southeast Asia towards responsible development. **Fish for the People** 6(1): 3-9.

Lipps, J.H., W.H. Berger, M.A. Buzas, R.G. Dauglas and C.A. Ross. 1979. **The measurement of species diversity.** In: Foraminiferal Ecology and Paleocology (ed. J.H. Lipps), pp. 3-10. The Society for Sedimentary Geology, Tulsa, Oklahoma, USA.

Maechler, M., P. Rousseeuw, A. Struyf, M. Hubert and K. Hornik. 2018. **Cluster: Cluster Analysis Basic and Extensions 1.** R Package version 2.0.7-1. https://cran.r-project.org/package=cluster. Cited 4 Jan 2022.

Najmudeen, T.M. and R. Sathiadhas. 2008. Economic impact of juvenile fishing in a tropical multi-gear multispecies fishery. **Fisheries Research** 92(2-3): 322-332. DOI: 10.1016/j.fishres.2008.02.001.

Nakatsuka, S. 2017. Management strategy evaluation in regional fisheries management organisations-How to promote robust fisheries management in international settings. **Fisheries Research** 187: 127-138. DOI: 10.1016/j.fishres.2016.11.018.

Ningsih, N.S., N. Rakhmaputeri and A.B. Harto. 2013. Upwelling variability along the southern coast of Bali and in Nusa Tenggara waters. **Ocean Science Journal** 48: 49-57. DOI: 10.1007/ s12601-013-0004-3.

Oliveira, A.G., L.C. Gomes, J.D. Latini and A.A. Agostinho. 2014. Implications of using a variety of fishing strategies and sampling techniques across different biotopes to determine fish species composition and diversity. **Natureza and Conservação** 12(2): 112-117. DOI: 10.1016/j.ncon.2014. 08.004.

Pascoe, S. and D. Greboval. 2003. **Measuring Capacity in Fisheries.** Food and Agriculture Organization of the United Nations, Rome, Italy. 172 pp.

Peck, M.A., K.B. Huebert and J.K. Llopiz. 2012. **Chapter 3 - Intrinsic and extrinsic factors driving match-mismatch dynamics during the early life history of marine fishes.** In: Global Change in Multispecies Systems Part 2 (eds. G. Woodward, U. Jacob and E.J. O'Gorman), pp. 177-302. Elsevier, Academic Press, London, UK.

Purcell, S.W. and R.S. Pomeroy. 2015. Driving small-scale fisheries in developing countries. **Frontiers in Marine Science** 2(44): 1-7. DOI: 10.3389/fmars.2015. 00044.

Purwaningsih, R., S. Widjaja and S.G. Partiwi. 2011. The effect of marine fish biomass stock reduction to fishers revenue (A case study of *Sardinella lemuru* fisheries on Bali Strait). **IPTEK The Journal for Technology and Science** 22(3): 166-176. DOI: 10.12962/ j20882033.v22i3.73.

Puspasari, R., P. Rachmawati, E. Susilo, W. Wijopriono and N.N. Wiadnyana. 2018. The impact of environmental changing, food availability and anthropogenic pressure on sardine (*Sardinella lemuru*) CPUE in Bali Strait waters. **Jurnal Segara** 14(2): 107-116. DOI: 10.15578/segara.v14i2.7131.

Puspasari, R., P.F. Rachmawati and W. Wijopriono 2016. Vulnerability analysis of small pelagic fishes in Bali Strait and Makassar Strait to the dynamic of sea surface temperature. **Jurnal Penelitian Perikanan Indonesia** 22(1): 33-42. DOI: 10.15578/jppi.22.1.2016.33-42.

R Core Team. 2018. **R: A language and environment for statistical computing.** R Foundation for Statistical Computing, Vienna. https://www.R-project.org. Cited 20 Mar 2022.

Roy, K., S. Kar and R.N. Das. 2015. **Chapter 6 - Selected statistical methods in QSAR.** In: Understanding the Basics of QSAR for Applications in Pharmaceutical Sciences and Risk Assessment (eds. K. Roy, S. Kar and R.N. Das), pp. 191-229. Academic Press, Boston, USA.

Salas, S., R. Chuenpagdee, J.C. Seijo and A. Charles. 2007. Challenges in the assessment and management of small-scale fisheries in Latin America and the Caribbean. **Fisheries Research** 87(1): 5-16. DOI: 10.1016/j.fishres.2007.06.015.

Sambah, A.B., F. Iranawati, S.H.J. Sari, D. Pranoto, L.I. Harlyan and A.F. Ghafiky. 2016. **The spatial analysis in tuna habitat related to the ocean variability in the Indian Ocean BT.** Proceeding of 1st International Conference on Geography and Education (ICGE) 2016: 262-267.

Sambah, A.B., T.D. Oktavia, D.W. Kusuma, F. Iranawati, N. Hidayati and A. Wijaya. 2020. Oceanographic variability and its influence on pelagic fish catch in the Bali Strait. **Berkala Penelitian Hayati** 26(1): 8-16. DOI: 10.23869/bphjbr.26.1.20202.

Sartimbul, A., E. Rohadi, D. Yona, E.Y. Herawati, A.B. Sambah and J. Arleston. 2018. Change in species composition and its implication on climate variation in Bali Strait: Case Study in 2006 and 2010. **Journal of Survey in Fisheries Science** 4(2): 38-46. DOI: 10.17501/icfa.2016.3101.

Sartimbul, A., E. Thrisnayana, E. Rohadi, N. Muslihah, O.M. Luthfi, F. Iranawati, L.I. Harlyan, E. Wulandari and A.B. Sambah. 2021. Plankton's abundance and its implications for *Sardinella lemuru* catch in Prigi waters. **IOP Conference Series: Earth and Environmental Science** 763: 1-9. DOI: 10.1088/1755-1315/763/1/012049.

Setyohadi, D., U. Zakiyah, A.B. Sambah and A. Wijaya. 2021. Upwelling impact on *Sardinella lemuru* during the Indian Ocean Dipole in the Bali Strait, Indonesia. **Fishes** 6(1): 8. DOI: 10.3390/fishes6010008.

South East Asian Fisheries Development Center (SEAFDEC). 2017. **Southeast Asian State of Fisheries and Aquaculture (SEASOFIA) 2017.** Southeast Asian Fisheries Development Center, Bangkok, Thailand. 167 pp.

Southall, T., O. Defeo, M. Tsamenyi, P. Medley, D. Japp, Y. Oloruntuyi, D. Agnew, M. Doddema, S. Good, D. Hoggarth, R. Lefébure, M. Atcheson, S.Y. Liow, C. Leisk, H. Norbury, P. Bianchi, L. Anderson, J. Bostrom and A. Gutteridge. 2016. **Working Towards MSC Certification: A Practical Guide for Fisheries Improving to Sustainability.** Marine Stewardship Council, London, UK. 431 pp.

Sumadhiharga, O.K. 2009. **Tuna**. National Research and Innovation Agency of Indonesia, Jakarta, Indonesia. 129 pp.

Suzuki, R. and H. Shimodaira. 2017. **Pvclust: An R package for hierarchical clustering with p-values. Shimodaira Laboratory Statistics and Machine learning.** http://stat.sys.i.kyoto-u.ac.jp/prog/pvclust/#download. Cited 4 Jan 2022.

Tampubolon, P.A.R.P., N.D. Pertami and A. Wujdi. 2021. Morphoregression and first size at maturity of Goldstripe Sardinella (*Sardinella gibbosa*) from Bali Strait waters. **Indonesian Fisheries Research Journal** 27(1): 17-26. DOI: 10.15578/ifrj.27.1.2021.17-26.

Wiryawan, B., N. Loneragan, U. Mardhiah, S. Kleinertz, P.I. Wahyuningrum, J. Pingkan, W. Wildan, P.S. Timur, D. Duggan and I. Yulianto. 2020. Catch per unit effort dynamic of yellowfin tuna related to sea surface temperature and chlorophyll in southern Indonesia. **Fishes** 5(3): 28. DOI: 10.3390/fishes5030028.

Wujdi, A. 2013. Some population parameters of Bali Sardine (*Sardinella lemuru*) in Bali Strait waters. **Widyariset** 16(2): 211-218. DOI: 10.14203/widyariset.16.2.2013.211-218.

Wujdi, A. and W. Wudianto. 2015. Stock status of bali sardinella (*Sardinella lemuru* Bleeker, 1853) in the Bali Strait Waters. **Jurnal Penelitian Perikanan Indonesia** 21(4): 253-260. DOI: 10.15578/jppi.21.4.2015.253-260.

Wujdi, A., S. Suwarso, W. Wudianto. 2016. Biology reproduction and spawning season of Bali Sardinella (*Sardinella lemuru* Bleeker 1853) in Bali Strait waters. **BAWAL Widya Riset Perikanan Tangkap** 5(1): 49-57. DOI: 10.15578/bawal.5.1.2013.49-57.

Zhu, J., X. Dai, Y. Chen. 2011. Species composition and diversity of pelagic fishes based on a longline fishery catch in the North Pacific Ocean. **Chinese Journal of Oceanology and Limnology** 29: 261-269. DOI: 10.1007/s00343-011-0122-7.