

Stock Assessment of *Panulirus Homarus* in Southeastern Madagascar Using A Rectified Virtual Population Analysis

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Abstract

Effective stock assessment is fundamental for the sustainable management of data-limited fisheries. This study assessed the stock status of the spiny lobster (*Panulirus homarus*) in southeastern Madagascar using a Rectified Virtual Population Analysis (VPA), a pseudo-cohort approach suitable for fisheries with limited age-structured data. Biological measurements of 5,624 individuals collected from artisanal fishery landings between 2018 and 2020 were combined with historical catch and fishing effort data from 2014 to 2020. Carapace length measurements were converted into annual age classes to reconstruct population abundance, estimate age-specific fishing mortality, and evaluate stock status through a yield-per-recruit (YPR) model. The reconstructed population consisted of ten age classes, with catches dominated by individuals aged two to three years. Fishing mortality was highest among lobsters aged two to five years, while population abundance declined progressively with increasing age. The YPR analysis indicated that the current exploitation level exceeds the biological reference point corresponding to the Maximum Sustainable Yield (MSY), demonstrating that the stock is already overexploited. These findings highlight the need to reduce fishing effort, strengthen compliance with minimum legal-size regulations and seasonal closures, promote selective fishing gears, and implement continuous biological monitoring. The study demonstrates that Rectified VPA provides a practical and reliable framework for assessing data-limited lobster fisheries and supports evidence-based management for the sustainable exploitation of *P. homarus* in southeastern Madagascar.

Keywords: *stock; lobster; assessment; exploitation; Madagascar.*

Introduction

Spiny lobsters (Family *Palinuridae*) are among the most valuable marine fisheries resources worldwide because of their high commercial value and strong demand in international seafood markets (Radhakrishnan et al., 2021; Haddon, 2011). Throughout the Indo-Pacific region, lobster fisheries provide substantial economic benefits for coastal communities while contributing significantly to national export revenues. However, the high market value of lobsters has also intensified fishing pressure in many regions, resulting in declining stock abundance, reduced biomass, and concerns regarding the long-term sustainability of exploited populations (Phillips et al., 1980; Beverton & Holt, 1966).

Madagascar supports one of the most productive spiny lobster fisheries in the Western Indian Ocean. Five species have been reported from Malagasy waters, namely *Panulirus homarus*, *P. longipes*, *P. penicillatus*, *P. versicolor*, and *P. ornatus* (Mara, 1993; Remanevy, 1993). Among these, *P. homarus* is one of the dominant species harvested along the southeastern coast, particularly in the Anosy Region around Fort-Dauphin, where lobster fishing represents an essential source of income and employment for artisanal fishing

communities (Dizano, 2021). Because *P. homarus* exhibits relatively slow growth, delayed sexual maturity, and a lifespan that may exceed 15 years, its populations are especially vulnerable to excessive fishing mortality and habitat disturbance (Phillips et al., 1980; Singh et al., 2018).

The lobster fishery in southeastern Madagascar is predominantly artisanal and employs several fishing techniques, including traps (pots), gillnets, hook-and-line, and the recently introduced flou fishing method. National management measures include a minimum legal size of 20 cm total length (approximately 6.2 cm carapace length) and seasonal fishing closures that differ between the southern and northern coasts of Madagascar. In addition, some local fishing communities, such as those in Sainte-Luce, have established temporary community-based fishing closures to enhance stock recovery (Antonique, 2016). Despite these management initiatives, increasing fishing effort and continued exploitation of immature individuals raise concerns about the sustainability of lobster populations in the region.

Reliable stock assessment is fundamental for developing effective fisheries management strategies. Conventional age-based stock assessment models, including standard Virtual Population Analysis (VPA), generally require long-term catch-at-age datasets that are unavailable for many small-scale fisheries in developing countries (Sparre et al., 1989). Consequently, many tropical fisheries, including those of Madagascar, are considered data-limited, where only relatively short time series of catch, fishing effort, and biological observations are available (Amorim et al., 2019; Froese et al., 2018). Data-limited assessment methods have therefore become increasingly important for evaluating stock status and supporting evidence-based fisheries management (Palomares et al., 2018).

The Rectified Virtual Population Analysis (VPA), also referred to as pseudo-cohort analysis, offers a practical alternative for assessing exploited stocks when complete age-structured data are lacking. Unlike conventional VPA, the rectified approach integrates historical catch information with biological parameters and estimates of fishing mortality through iterative procedures, allowing the reconstruction of group abundance by age under limited data conditions (Fatemi, 1998; Kagwade, 1993). Previous studies have demonstrated the usefulness of VPA-based approaches for evaluating lobster populations in several regions of the Indian Ocean (Valle et al., 1993; Eric et al., 2025). Nevertheless, no published study has applied a rectified VPA framework to assess the stock status of *P. homarus* in southeastern Madagascar.

This study therefore aims to assess the stock status of *Panulirus homarus* in southeastern Madagascar using a Rectified Virtual Population Analysis (VPA). Specifically, the study estimates age-specific fishing mortality, reconstructs population abundance by age, and evaluates stock status through yield-per-recruit analysis. The findings are expected to provide scientific evidence for improving the sustainable management of the lobster fishery in Madagascar and to support management measures aimed at preventing further overexploitation of this economically important marine resource.

Methodology

This study used a quantitative approach using a retrospective stock assessment design to evaluate the status of the spiny lobster (*Panulirus homarus*) groups in southeastern Madagascar. The assessment was conducted using the Rectified Virtual Population Analysis (VPA), also known as *pseudo-cohort* analysis, which is suitable for data-limited fisheries where long-term age-structured datasets are unavailable. The study focused on reconstructing age-specific population abundance, estimating fishing mortality, and evaluating stock status through yield-per-recruit analysis. The research was carried out in the artisanal fishing grounds of Fort-Dauphin (Taolagnaro), Anosy Region, southeastern Madagascar, one of the country's principal lobster fishing areas.

The target population comprised all *P. homarus* groups harvested by artisanal fishers operating in the study area. Samples were obtained from the commercial landings of local fishers using the principal fishing gears employed in the region, including lobster traps (pots), gillnets, and hook-and-line. Monthly biological sampling was conducted from January 2018 to December 2020, while historical fishery information covering the period from 2014 to 2020 was incorporated into the stock assessment model. A total of 5,624 individual lobsters were randomly sampled from landing sites throughout the study period. Only *P. homarus* specimens were included in the analysis, whereas other lobster species landed in the fishery were excluded.

Primary data consisted of individual biological measurements collected directly at fish landing sites. The carapace length (CL) of each lobster was measured to the nearest 0.1 cm using a stainless-steel Vernier caliper with a measuring precision of ± 0.02 mm. Information on fishing gear, capture date, landing site, and catch composition was recorded simultaneously using standardized data collection sheets. Secondary data, including annual catch statistics, fishing effort, recruitment indices, biological parameters, and growth information, were compiled from the Directorate of Fisheries and Blue Economy, previous scientific studies, and fisheries monitoring records. These datasets provided the historical information required for reconstructing population dynamics through the Rectified VPA.

The stock assessment procedure consisted of several analytical steps. First, the observed carapace length frequency distribution was converted into corresponding age classes using the available growth parameters for *P. homarus*. Because the maximum lifespan of the species exceeds the available monitoring period, individuals were classified into ten annual age classes to facilitate pseudo-cohort reconstruction. An iterative Rectified Virtual Population Analysis was then performed using R statistical software to estimate age-specific fishing mortality (F), catchability coefficients (q), and population abundance (N) for each age class. The iterative procedure minimized inconsistencies between observed catches and reconstructed population abundance, thereby improving the reliability of stock estimates under limited data conditions.

The outputs generated from the Rectified VPA served as input parameters for the Yield-per-Recruit (YPR) model based on the Beverton and Holt analytical framework. The YPR analysis was used to estimate the Maximum Sustainable Yield (MSY) reference point and to evaluate whether the current exploitation level exceeded biologically sustainable limits. Stock status was determined by comparing the current fishing mortality and yield-per-recruit estimates with the biological reference points derived from the model. A stock was considered overexploited when the observed exploitation level exceeded the optimum reference level corresponding to maximum sustainable yield.

The reliability of the stock assessment depended on the consistency of the biological measurements, historical catch records, and fisheries monitoring data. Therefore, all field measurements followed standardized sampling procedures, and data verification was conducted before analysis to eliminate incomplete records and measurement errors. The combination of biological observations, historical fisheries information, and the Rectified Virtual Population Analysis provided a robust framework for assessing the exploitation status of *Panulirus homarus* under data-limited conditions and for generating scientific evidence to support sustainable fisheries management in southeastern Madagascar.

Results and Discussion

The application of the Rectified Virtual Population Analysis (VPA) enabled the reconstruction of the age structure and exploitation pattern of *Panulirus homarus* in southeastern Madagascar. Using biological measurements collected between 2018 and 2020 together with historical fisheries information from 2014 to 2020, the analysis generated estimates of catch distribution, fishing mortality, population abundance, and yield-per-

recruit. These indicators provide a comprehensive understanding of the current exploitation status of the stock and its implications for sustainable fisheries management.

Following the conversion of carapace length measurements into age classes using the species' growth parameters, ten annual age classes were identified in the exploited population. The age-frequency distribution revealed that the fishery was largely dominated by individuals belonging to the two- and three-year age classes, whereas both younger recruits and older individuals were comparatively less abundant (Fig. 1). The predominance of intermediate age classes indicates that fishing activities are concentrated on lobsters shortly after recruitment to the fishery and before a substantial proportion of the population reaches older ages.

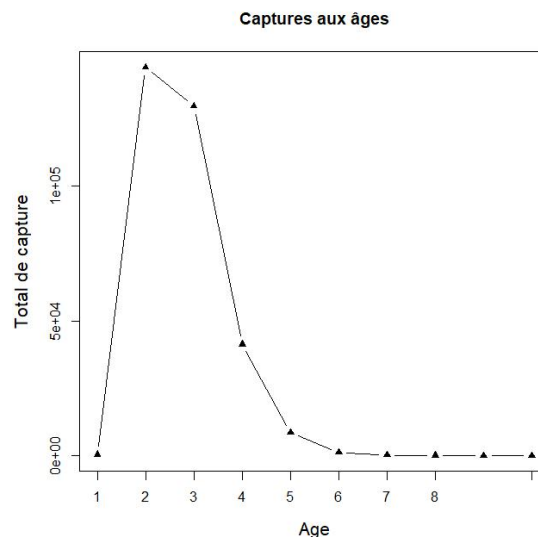


Figure 1. Age composition of the exploited *Panulirus homarus* groups

The dominance of young adults in the catch suggests a truncated age structure, a characteristic commonly observed in heavily exploited crustacean fisheries. Under moderate exploitation, lobster populations generally exhibit a broader distribution of age classes, including a greater proportion of mature individuals. Conversely, intensive fishing pressure selectively removes larger and older lobsters, resulting in an age distribution skewed toward younger individuals. Similar patterns have been reported for *P. homarus* in the Gulf of Aden (Valle et al., 1993), *P. polyphagus* in India (Kagwade, 1993), and several exploited spiny lobster fisheries in the Western Indian Ocean (Singh et al., 2018). The scarcity of older individuals in the present study may therefore reflect prolonged fishing pressure rather than natural demographic variation. Considering that *P. homarus* reaches sexual maturity at approximately six years of age, the predominance of younger age classes also suggests that a considerable proportion of the harvested stock may not have reproduced before capture, potentially reducing reproductive output and long-term recruitment.

The age-specific estimates of fishing mortality obtained from the Rectified VPA further support this interpretation. Fishing mortality increased rapidly after recruitment to the fishery, reaching its highest value among individuals aged two to five years before declining in older age classes (Fig. 2). Although the abundance of younger individuals was relatively high, the corresponding fishing mortality remained comparatively low, indicating that these individuals had only recently entered the fishery. In contrast, the greatest fishing pressure occurred during the intermediate age classes, which constitute the most economically valuable component of the fishery.

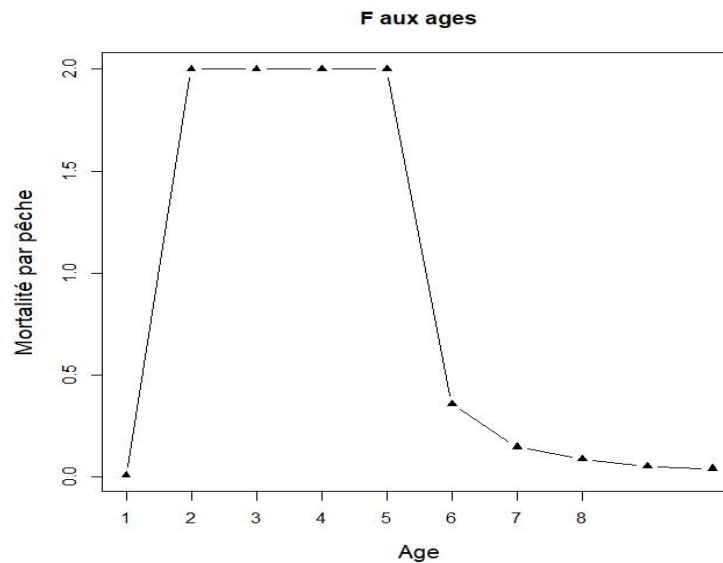


Figure 2. Estimated fishing mortality by age class for *Panulirus homarus*.

This pattern is consistent with the selectivity of artisanal fishing gears used in southeastern Madagascar. Lobster traps, gillnets, and hook-and-line gears preferentially capture medium-sized individuals because of both gear selectivity and fisher preferences for marketable sizes. Similar age-specific mortality patterns have been reported in lobster fisheries from India (Vijayanand et al., 2007) and Iran (Fatemi, 1998), where fishing mortality peaks among intermediate age classes before declining among the oldest individuals. The lower mortality observed among older lobsters does not necessarily indicate reduced fishing pressure but may instead reflect the limited number of individuals surviving to older ages after years of continuous exploitation. Consequently, the observed mortality pattern is characteristic of a stock subjected to sustained fishing pressure.

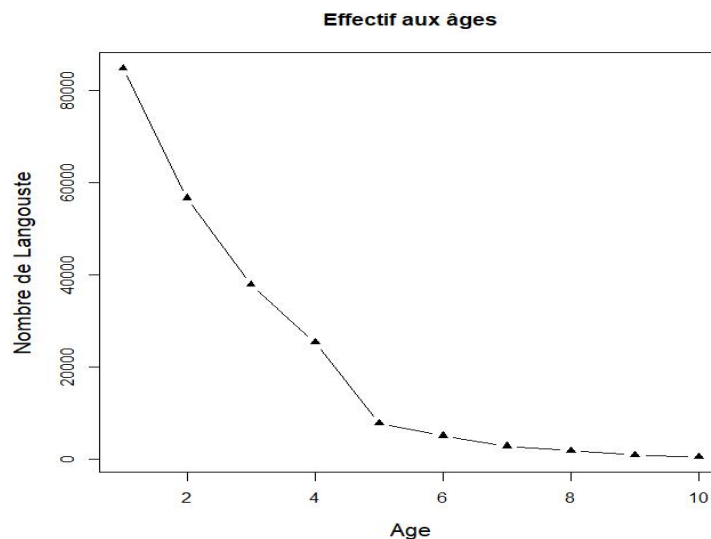


Figure 3. Estimated group abundance of *Panulirus homarus*.

The reconstructed abundance of individuals by age exhibited the expected decline from recruitment to the oldest age classes (Fig. 3). Population abundance decreased progressively with age, indicating cumulative losses resulting from both natural mortality and fishing mortality. The sharp reduction in abundance after recruitment suggests that exploitation contributes substantially to population decline before many individuals attain advanced ages. Moreover, the relatively small number of individuals older than six years

indicates that mature breeding lobsters are poorly represented within the exploited population.

The decline in abundance with increasing age is typical of exploited marine populations; however, the steepness of the decline observed in the present study suggests that fishing mortality represents an important component of total mortality. Previous investigations have demonstrated that healthy lobster populations generally maintain a sufficient proportion of mature individuals capable of sustaining recruitment through regular spawning. In contrast, populations dominated by immature individuals may experience reduced reproductive potential and become increasingly vulnerable to recruitment overfishing (Beverton & Holt, 1966; Phillips & Cobb, 1980). The present findings therefore indicate that the current age structure may compromise the long-term resilience of the lobster population if current exploitation rates continue.

The Yield-per-Recruit (YPR) analysis provided additional evidence regarding the exploitation status of the stock (Fig. 4). The relationship between fishing mortality, biomass, and yield demonstrated that the current exploitation level exceeded the biological reference point corresponding to the Maximum Sustainable Yield (MSY). Although increasing fishing effort may produce short-term increases in harvest, the analysis indicates that additional exploitation would result in declining biomass and reduced long-term productivity.

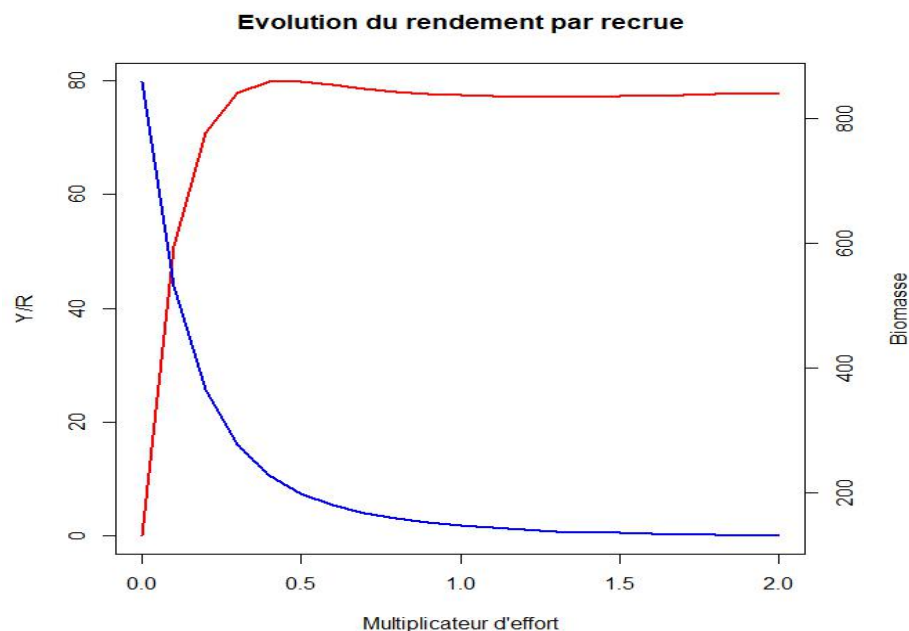


Figure 4. Yield-per-recruit analysis indicating the exploitation status of *Panulirus homarus*.

The position of the current exploitation level beyond the optimum biological reference point indicates that the stock of *P. homarus* in southeastern Madagascar is already overexploited. This conclusion agrees with previous stock assessments of tropical lobster fisheries, which have shown that excessive fishing mortality reduces spawning biomass and ultimately diminishes sustainable yields (Froese et al., 2018). Similar conclusions have also been reported for lobster fisheries in Indonesia (Kembaren & Suman, 2023), India (Vijayanand et al., 2007), and the Gulf of Aden (Valle et al., 1993), where excessive harvesting of commercially valuable age classes has resulted in declining stock productivity.

The combined evidence from the age composition, fishing mortality, abundance estimates, and yield-per-recruit analysis consistently indicates that the current exploitation pattern is unsustainable. Although national management measures, including seasonal closures and minimum legal-size regulations, are already implemented in Madagascar, the

persistence of high fishing mortality among immature and young adult lobsters suggests that existing measures may not be sufficient to ensure long-term stock recovery. Additional management actions should therefore focus on reducing fishing effort, improving compliance with minimum legal-size regulations, strengthening the use of selective fishing gears such as lobster traps, expanding locally managed marine areas, and maintaining continuous biological monitoring. Community-based management initiatives already implemented in parts of the Anosy Region could provide an effective framework for rebuilding the stock while preserving the livelihoods of artisanal fishing communities (Palomares et al., 2018; Emynorane et al., 2026).

In summary, the Rectified Virtual Population Analysis proved to be an effective assessment tool for this data-limited fishery. By integrating biological observations with historical catch information, the model successfully reconstructed population dynamics and provided reliable indicators of stock status. The approach demonstrates considerable potential for supporting fisheries management in Madagascar, where comprehensive age-structured datasets remain scarce. Future assessments should incorporate longer monitoring periods, environmental variability, and fishery-independent surveys to reduce uncertainty and improve estimates of stock productivity. Together, these measures would strengthen science-based management and contribute to the sustainable exploitation of *Panulirus homarus* in southeastern Madagascar.

Conclusion

This study demonstrated the applicability of the Rectified Virtual Population Analysis (VPA) as a reliable stock assessment tool for evaluating the exploitation status of the spiny lobster (*Panulirus homarus*) in southeastern Madagascar under data-limited conditions. The analysis revealed that the exploited population is dominated by young individuals, with the highest fishing mortality occurring among lobsters aged two to five years, resulting in a progressive decline in population abundance with increasing age. Furthermore, the yield-per-recruit analysis indicated that the current level of exploitation exceeds the biological reference point corresponding to the Maximum Sustainable Yield (MSY), confirming that the stock is already overexploited. These findings suggest that continued fishing at the present intensity may further reduce spawning biomass, compromise recruitment, and threaten the long-term sustainability of this economically important fishery. The study therefore highlights the urgent need to strengthen fisheries management through reduced fishing effort, improved compliance with minimum legal size regulations, wider adoption of selective fishing gears, reinforcement of seasonal closures, and expansion of community-based marine management initiatives. Continuous biological monitoring and regular stock assessments are also essential to support adaptive management and ensure the sustainable exploitation and conservation of *P. homarus* resources in southeastern Madagascar.

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