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RESEARCH ARTICLE

Estimating Biological Reference Points of the Pink Shrimp, *Farfantepenaeus notialis* (Perez-Farfante, 1967) Targeted by Shrimp Trawlers in Sierra Leone

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Key words:

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Abstract: Time series of catch and effort data for *Farfantepenaeus notialis* were analysed in 'R' using a data limited state-space Bayesian Catch-maximum Sustainbale Yield (CMSY) method for stock assessment from catch (tonnes) and abundance data (t/day). The study categorically compared the status of *F. notialis* in two periods (1981-1996) and (2008-2018) denoted as periods I and II, respectively. Results for management based on Bayesian Schaefer model (BSM) analysis for Period I gave (Prior relative biomass (B/k) = 0.06; MSY = 2.25t , 95% CL = 1.98 - 2.56; Fmsy = 0.379 yr-1 , 95% CL = 0.29 - 0.495; Bmsy = 5.94t , 95% CL = 4.69 - 7.51; Biomass = 4.78t; B/Bmsy = 0.806; Fishing mortality = 0.583yr-1 and Exploitation rate, F/Fmsy = 1.54) while that of Period II showed (Prior relative biomass (B/k) = 0.35; MSY = 0.662t, 95% CL = 0.567 - 0.773; Fmsy = 0.421yr-1 , 95% CL = 0.314 - 0.563; Bmsy = 1.58t , 95% CL = 1.22 - 2.04; Biomass = 1.09t; B/Bmsy = 0.69; Fishing mortality = 0.532yr-1 and Exploitation rate, F/Fmsy = 1.27). By implications, all estimated biological reference points portrayed an overfished status of *F. notialis* in 1989-1996 and in 2008-2018. Stock recovery measures are strongly advised for the stock in Sierra Leone.

Anahtar kelimeler:

Bayesian
Yararlanma oranı
Avcılık baskısı
Referans noktası
Stok
Sürdürülebilirlik

Sierra Leone'de Karides Balıkçıları Tarafından Avlanan Pembe Karides, *Farfantepenaeus notialis* İçin Biyolojik Referans Noktalarının Tahmin Edilmesi

Öz: Av (ton) ve bolluk verilerinden (t/gün) stok tahmini için veri sınırlı durum-alan Bayesian Av-maksimum Sürdürülebilir Ürün (CMSY) yöntemi kullanılarak, *Farfantepenaeus notialis'*in av ve çaba verilerinin zaman serileri 'R'de analiz edildi. Çalışma, *F. notialis*'in durumunu sırasıyla I. dönem (1981-1996) ve II. dönem (2008-2018) olarak belirtilen iki kategoride karşılaştırmıştır. I. dönemde Bayesian Schaefer modeli (BSM) analizine dayalı yönetim için sonuçlar (önceki nisbi biyokütle (B/k) = 0,06; MSY = 2,25t , %95 CL = 1,98 - 2,56; Fmsy = 0,379 yıl-1, %95 CL = 0,29 - 0,495; Bmsy = 5,94t , %95 CL = 4,69 - 7,51; Biyokütle = 4,78t; B/Bmsy = 0,806; Balıkçılık ölüm oranı = 0,583yıl-1 ve Yararlanma oranı, F/Fmsy = 1,54) verirken, II. dönem için sonuçlar (önceki nisbi biyokütle (B/k) = 0,35; MSY = 0,662t, %95 CL = 0,567 - 0,773; Fmsy = 0,421yıl-1, %95 CL = 0,314 - 0,563; Bmsy = 1,58t, %95 CL = 1.22 - 2.04; Biyokütle = 1.09t; B/Bmsy = 0.69; Balıkçılık ölüm oranı = 0.532yr-1 ve Yararlanma oranı, F/Fmsy = 1.27) göstermiştir. Sonuç olarak, tüm tahmini biyolojik referans noktaları, 1989-1996 ve 2008-2018 yıllarında *F. notialis*'in aşırı avcılık durumunu göstermiştir. Sierra Leone'deki stoklar için stok iyileştirme önlemleri şiddetli olarak tavsiye edilmektedir.

Introduction

Marine capture fisheries are of far-reaching relevance to local and national economic development through their enormous protein source and economic viability (Meissa et al., 2021). However, despite their critical contributions to human well-being, there is an increasing threat to their very existence particularized in developing nations owing to an upsurge in their human populations and efficient fisheries management conundrums (Amorim et al., 2019; Alam et al., 2021).

Farfantepenaeus notialis (Perez-Farfante, 1967) inhabits tropical and subtropical shallow waters of the continental shelf (May-Kú et al., 2006), and constitutes a critically important bio-economic resource in the shrimp fisheries (King, 2007; Gillett, 2008). This species attains

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maximum carapace length of 4.1 cm (males) and 4.8 cm (females), and occurs at depths of 3-700 m, but commonly at 10 -75 m (Konoyima, 2021).

Shrimp trawling has a long history and tradition in Sierra Leone fisheries and catch estimates from the present study showed greater annual catch in 2016 (11,152 tonnes) while catch in other years fluctuated between 1000 tonnes and 6,500 tonnes between 2008-2018. Four species of the Penaeidae including *F. notialis* are of commercial interest in Sierra Leone, with *F. notialis* accounting for more than 80 % of all coastal shrimp landings in the country (Showers, 2012).

It is proven that science-based fish stock assessment could heighten knowledge and information for effective management in lieu of sustainability of significant fish stocks (Alam et al., 2021). Other authors have argued that stock assessments are eminent in dispensing sound footing or rationale for effectiveness in subsisting sustainable management strategies for fish stocks (Froese et al., 2012; Pauly and Zeller, 2016; Alam et al., 2021; Zhang, 2021). Catch Maximum Sustainable Yield (CMSY) model is a state-space Bayesian method for stock assessment that estimates fisheries reference points (MSY, Fmsy, Bmsy) as well as status or relative stock size (B/Bmsy) and fishing pressure or exploitation (F/Fmsy) from catch-only and/or catch and abundance data (Froese, 2018; Froese et al., 2021), a prior for resilience or productivity (r), and broad priors for the ratio of biomass to unfished biomass (B/k: Froese et al., 2021).

Applcation of a state-space data limited fish stock assessment approach for the Sierra Leone fisheries has yet to fully dazzle scientific interest, and *F. notialis*, being a major target shrimp stock by foreign commercial fleets, deserves the need for a closer look into its fishery status using modern-day reference point indicators applied for data-limited fisheries.

The objective of the present study was to categorically compare the status of *F. notialis* during two periods (1981-1996) and (2008-2018) denoted as periods I and II respectively, in relation to estimated biological reference points of *F. notialis* exploited in Sierra Leone using a Bayesian Catch Maximum Sustainable Yield (CMSY) data limited approach and the management implications of its fisheries in Sierra Leone. The information provided could foster informed management decisions and incentives for rational exploitation of the assessed stock in Sierra Leone. The study will also be invaluable to future researchers.

Material and Methods

Study area

Sierra Leone lies between latitudes 7° and 10' N and longitudes 10° and 14° W on the west coast of Africa, covering an area of 71740 km2. The country is bounded on the north and east by Guinea, on the southeast by Liberia and on the southwest and west by the Atlantic Ocean. The climate is comprised of two seasons: the dry season (November-April) and the monsoonal rainy season, which lasts from May-October (Coutin and Payne, 1989). Figure 1 illustrates the Exclusion Zone of Sierra Leone within which the 2018 data were collected onboard a shrimper.

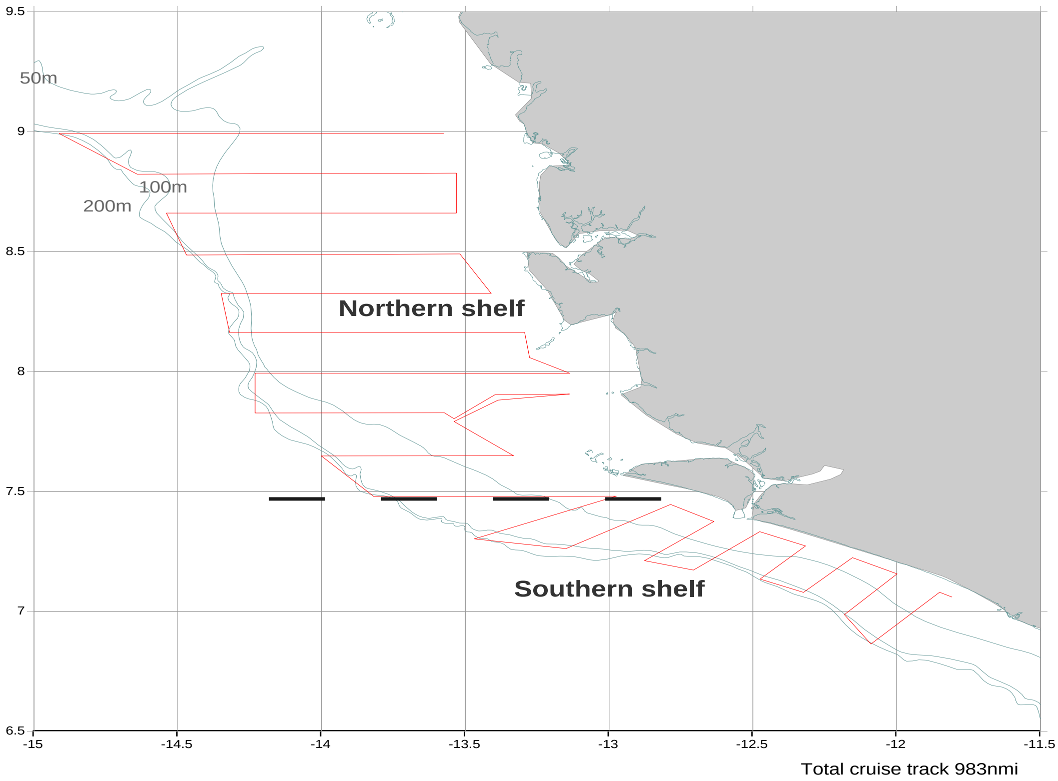

Figure 1. The EEZ of Sierra Leone showing the 10-200 m isobaths

Data collection and analysis

Source of data: indirect enumeration

Two periods (Period I: 1981-1996 and Period II: 2008-2018) of time-series catch and effort data sets (tonnes/day) recorded by fishery observers placed on-board commercial industrial fishing fleets were accessed from the Industrial Fisheries Database (IFDAS) of the Fisheries Ministry in Sierra Leone as indirect enumeration method of data acquisition for the estimation of biological reference points of *F. notialis*.

CMSY estimators: bayesian schaefer model (BSM)

The study applied a state-space data limited Bayesian Schaefer Model (BSM) approach in CMSY analsyis using uninterrupted time-series catch (tonnes) and abundance (catch rate, t/day) data as key input paramaters implemented in the computerized R Packages described in Froese et al.(2021). This methed gives the desired fisheries reference points such as MSY (Maximum Sustainable Yield Point), Bmsy (stock size that can produce maximum sustainable yield when it is fished at a level equal to Fmsy) and Fmsy (fishing mortality rate at the level that would produce maximum sustainable yield from a stock that has a size of Bmsy); gives the ecological reference points such as prior for resilience or productivity (r), and broad priors for the ratio of biomass to unfished biomass (B/k); gives stock size in terms of biomass (B) and status as B/Bmsy and gives exploitation as F and F/Fmsy (Froese, 2018; Froese et al., 2021).

Given a time series of catch and CPUE as abundance, the parameters r and k are estimated from:

$B_{t+1} = B_t + r\,B_t\left(1 - \frac{B_t}{k}\right) - C_t$ (Froese, 2018; Froese, et al., 2021) where Ct is catch in year t, B = CPUE / q, q is the catchability coefficient, k is the carrying capacity of the stock, Bt is biomass in year t, r = distribution prior (resilience) for intrinsic growth rate estimation (Froese, 2018).

The size of prior k is inversely proportional to that of ‘r’, and the prior range of ‘k’ expressed as a function of r bequeaths:

k high = 4max (C) /r low

klow = 2max (C) / rhigh

Where Klow and Khigh are the low and high catch limits of the initial biomass, C is the maximum catch; rlow and rhigh are the low and high limits of the resilience factor ‘r’).

Also, If B > 1/2 Bmsy, then the biomass corresponding to MSY is expressed as:

FMSY = 0.5 r and the biomass below which recruitment may be compromised is half of Bmsy thus, B < 1/2 Bmsy for which r and Fmsy are linearly reduced (Ricker, 1975; Schaefer, 1954). Details of the routines in estimating fisheries reference points using CMSY methods are discussed in Froese, (2018) and Froese et al., (2021).

Results and Discussion

Results of the BSM analysis as management parameters from two periods (I and II) are presented in Table 1. Estimates of fisheries reference points (MSY, Fmsy, Bmsy), relative stock size (B/Bmsy), exploitation status (F/Fmsy), resilience (r) and k priors were considerably higher for Period I compared to Period II.

Table 1. Estimated BSM management parameters for *F. notialis* in Sierra Leone

Biological Reference Point Indicators	Period I (1981-1996)	Period II (2008-2018)
MSY (tonnes)	2.25 (95% CL = 1.98-2.56)	0.662 (95% CL = 0.567-0.773)
Fmsy (yr^{-1})	0.379 (95% CL = 0.29-0.495)	0.421 (95% CL = 0.314-0.563)
Biomass (B, tonnes)	4.78	1.09
Bmsy (tonnes)	5.94 (95% CL = 4.69-7.51)	1.58 (95% CL = 1.22-2.04)
B/Bmsy	0.806	0.691
Fishing mortality (F, yr^{-1})	0.583	0.532
Exploitation F/Fmsy	1.54	1.27
r (yr^{-1})	0.758 (95% CL = 0.58-0.989)	0.841 (95% CL = 0.628-1.13)
K (tonnes)	11.9 (95% CL = 9.39-15)	3.15 (95% CL = 2.43-4.08)
B/k	0.40	0.35

Sadly, very scanty literature exist for *F. notialis*, a limitation for robust comparisons of the current findings. However, maintaining optimal stock status would mean that the fishing mortality threshold (Fmsy) should be less than the fishing mortality that would produce Bmsy; that the fishing mortality rate (F) should be less than fishing mortality rate at the level that would produce maximum sustainable yield from a stock that has a size of Bmsy (F < Fmsy) and that the stock size expressed in terms of biomass (B) should be greater than stock size that can produce maximum sustainable yield when it is fished at a level equal to Fmsy (B > Bmsy), and concurred by several, and the reverse of such indicator referenced points implies a stock that is in an overfished state as concurred by several, and the reverse of such indicator referenced points implies a stock that is in an overfished state as concurred by several researchers (Shan et al., 2016; Froese, 2018; Winker et al., 2018; Meissa et al., 2021; Froese et al., 2021). Results from the present study depicted that fishing mortality (F) in the period I was only 8.75% overhead that in period II, and 'F' in both periods vastly climaxed Fmsy. A considerable soaring occurred in all exploitation and biomass levels in period I and II, though at disparate numerals. Therewithal, the exploitation point (F/Fmsy) in both period I and II exceeded their exploitable limit (B/BMSY), indicating dreadful overfished status of the stock during such periods, and a more terrible scenario was observed in Period I. Also, estimated prior relative biomass (B/k) of *F. notialis* showed values in both assesement periods in the range 0.01- 0.4 (Strong), which according to Froese et al. (2021), depicts a stock that is way off safe biological limits, a stock that is in a state of reduced recruitments consequently leading to grave economic losses in its fishery (high cost of fishing and reduced economic rents). Gulland (1971) had proposed a value of 0.5yr-1 for an optimally exploited fish stock. Exploitation rates of both assesent period vastly exceeded the Gulland (1971) limit, buttressing the initial postulate of an overexploited stock of *F. notialis* in Periods I and II. Study by Nwosu (2009) also portrayed overfished status (Exploitation, E > 0.5) of *F. notialis* in the Cross River Estuary, Nigeria.

Graphical outputs of CMSY analysis in Figure 2 and Figure 3 depict the status of the assessed stock for the various time frames. As described in Froese et al., (2021), the catch curves (upper left) show catches relative to MSY (indicated by dotted lines), and the yield (tonnes) of *F. notialis* exceeded MSY in 1985, 1990 and 1995-6 (Period I) and 2008 and 2016 in Period II with the light grey colour band indicating the confidence level (95% confidence limits-Table 1) of MSY estimation (Figure 2). The top right curve of Period I shows estimated time series of total biomass relative to Bmsy (dashed lines), and B/Bmsy was highest in1981 through early 1990s before transcending in later years (1990s) to the boundary of diminished recruitment (indicated by dotted line), with the light grey colour band specifying uncertainty (Figure 2). Period II shows a consistently lower estimated time series of total biomass relative to Bmsy throughout the assessment years (2008-2018), and the biomass state was much closer to the boundary indicating a transfiguration juncture that may transcend into collapse hereinafter if current fishing mortality does not regress to its pristine FMSY or BMSY status (Figure 3). The graph in the lower left of both periods portray relative exploitation (F/Fmsy), while that in the lower-right panel indicates the trajectory of relative stock size (B/Bmsy) as a function of fishing pressure (F/Fmsy), both of which corroborate earlier postulates of an impoverished status of the assessed stock, and the "banana" shape around the assessment of the final year (Period I-1996; Period II-2018) triangle indicates uncertainty with yellow for 50%, grey for 80% and dark grey for 95% confidence levels (Froese et al., 2021). Showers (1999) had estimated optimum yield (MSY) for shrimps in industrial fishery in Sierra Leone at 2.686.8 t, and catch for 1996 was 2,788 t, indicating an escalation in exploitation which, if prolonged, could bring reduced productivity, he inferred.

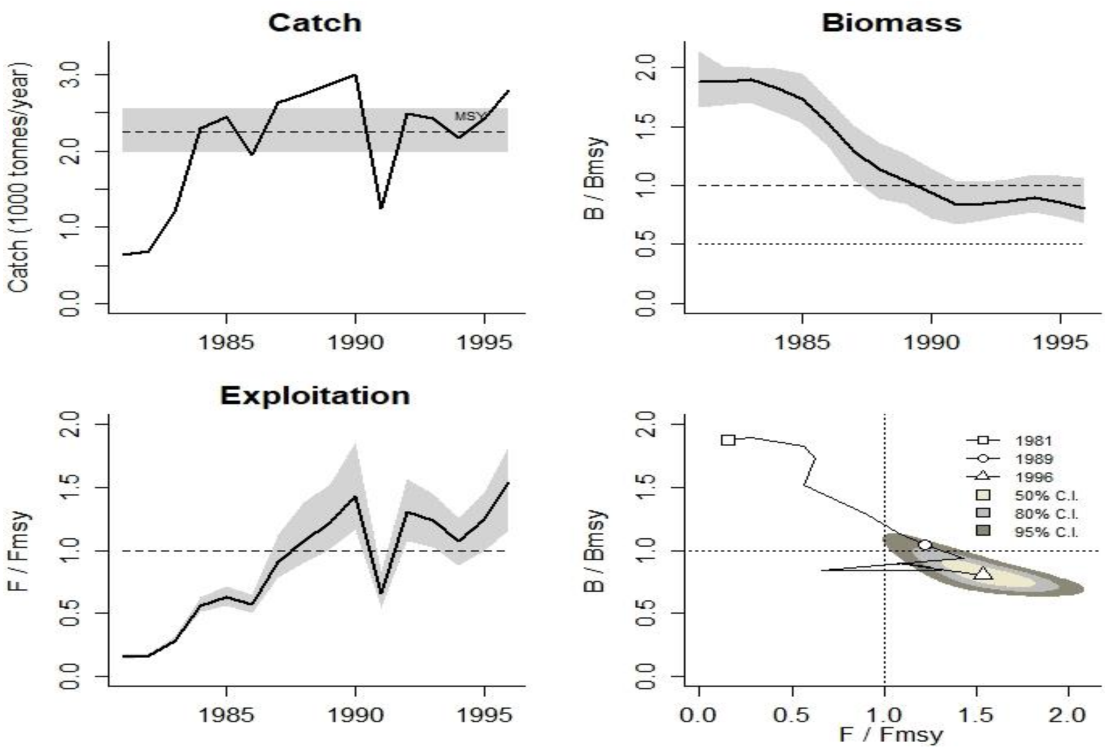

Figure 2. Graphical output of CMSY analysis for *F. notialis*, 1981-1996

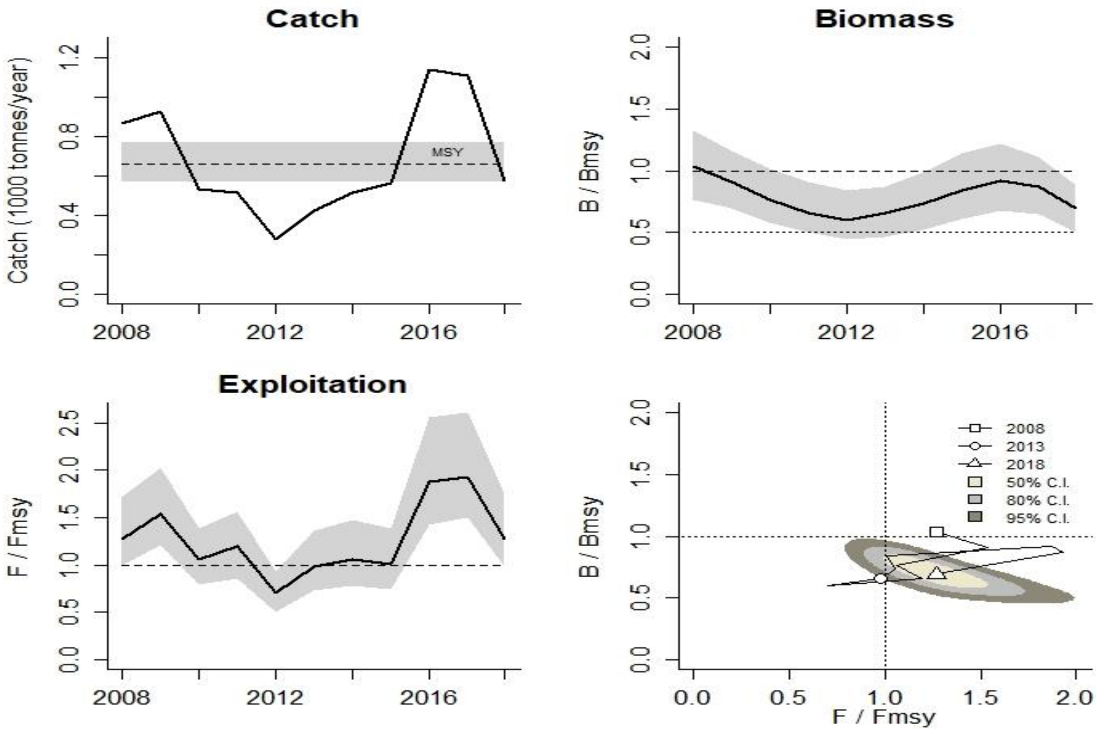

Figure 3. Graphical outputs of CMSY analysis for *F. notialis*, 2008-2018

In the Kobe plots from CMSY analysis (Figure 4), the fishery's safe zone that should bring out surplus production owing to booming spawning stock biomass (as for stock status in 1981) is represented by the green region, while the orange zone suggested a population that was near fishing pressure as described in other studies (Alam et al., 2021; Froese et al., 2021). By implication aside from the booming stock status and surplus production enshrined in spawning stock biomass in 1981, the plots portrayed divesting status of the pink shrimp stock between 1989 and 2018, affirming the dire need for recalibrating management measures for sustainability in the pink shrimp fishery in Sierra Leone.

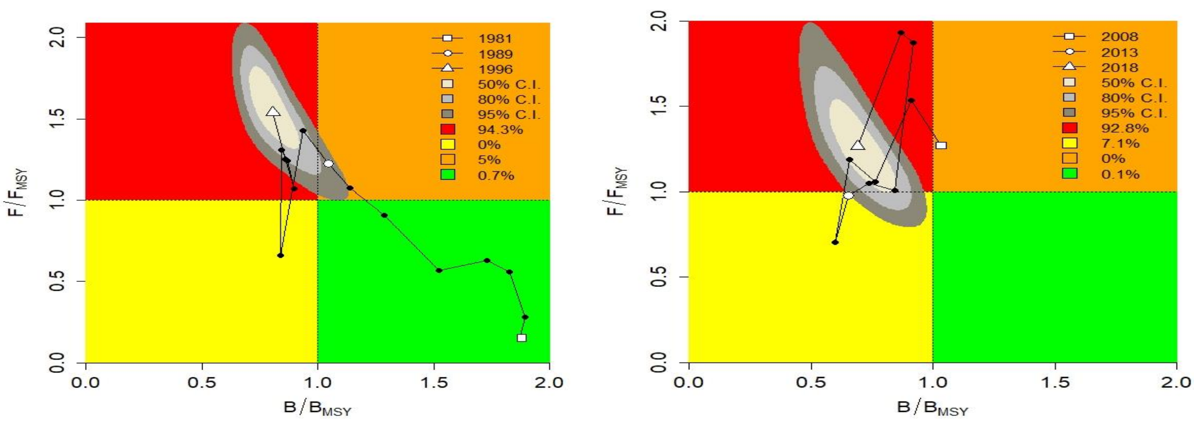

Figure 4. Kobe plots of F/Fmsy and the relative biomass-B/BMmsy connoting heavily fished stock of *F. notialis* in 1981-1996 (left) and in 2008-2018 (right)

Conclusions

Estimated sustainable yield point (MSY) and relative biomass were both considerably higher in Periods I and II (precisely, 1989-2018). The MSY estimate for the period I was almost four times higher than that for Period II. Generally, all estimated reference point indicators from the CMSY analysis were justifiable of extreme fishing pressure on the stock of *F. notialis* beyond sustainably limits in 1989-2018. Stock recovery through strengthening and enforcing input control resource sustainability management measures such as reducing fishing intensity by limiting the number of registered shrimpers in Sierra Leone is substantial, and the pursuit of accurate and efficient data collection routine should continue through training of data collectors and the maintenance of a statistical database.

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Conflict of Interest

The authors declare that there are no conflicts of interest.

Author Contributions

All authors contributed to the results and preparation of manuscript.

Ethics Approval

Industrial Fisheries Database (IFDAS) and invertebrate species are used in the article therefore ethics committee approval is not required for this study.

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