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Catch-based multi-model assessment of *Acetes* fishery along the Gujarat coast of India

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Abstract

The North-west coast of India is a unique marine ecosystem characterised by sustained productivity and a wide continental shelf. The region is known for several unique resources with restricted latitudinal distribution. *Acetes* are one of the major fishery resource of the Gujarat coast and are often considered the keystone species for the region's marine ecosystem. Despite its ecological and fishery importance, a minimal assessment has been done of the area. The present study uses a multi-model approach towards the evaluation of the stock status of *Acetes*. Four models, namely CMSY, BSM, zBRT, and OCOM, were applied to the time series catch data to arrive at the stock status indicators. Artificial intelligence or machine learning tools like boosted regression trees and neural networks are used in model fitting. Output was compared across all the four models. CMSY and BSM gave the most comparable and conservative estimates and are adopted in the present study. The stock can be classified as sustainable or fully exploited (B/B_{MSY} = 1.19-1.20, F/F_{MSY} = 0.79-0.80; B/B_0 = 0.59-0.65). Continuous monitoring of the resource is recommended for its r-selected life history traits.

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Introduction

The Arabian Sea is one of the most productive Large Marine Ecosystems (Satyendranath *et al.*, 1996; Prakash and Ramesh, 2007). The north-west of India along the north-eastern Arabian Sea forms a unique sub-ecosystem of the Arabian Sea characterised by a wide continental shelf (Yadava, 2001; Solanki *et al.*, 2017). The coastal ecosystem along the NW coast of India has characteristic winter cooling and convective mixing, leading to sustained productivity and a rich assemblage of marine fishery resources (Solanki *et al.,* 1998; Madhupratap *et al.,* 2001). The region harbours several unique resources with restricted latitudinal distribution *viz.* golden anchovies, Bombay duck and paste shrimps (Pradhan *et al.*, 2020; Vase *et al.,* 2019, 2021).

Non-penaeid shrimps contribute around 1.40 lakh t to the marine fish landings of Gujarat, which is almost 1/5th of the total marine fish landings of the state (https://www.cmfri.org.in/gujarat2018). *Acetes* form the most dominant component of non-penaeid shrimp fishery (>80%). The fishery can be characterised as high-volume low-value resource as the bulk of these are for drying and subsequent human consumption or drying, followed by pulverisation for animal feed. Despite several potential value addition technologies available, their adoption in the region is minimal (Zynudheen *et al.,* 2004; Vase *et al.,* 2021). Vase *et al.* (2021) based on a multi-species diet species matrix proclaimed *Acetes* as a keystone species whose sustainability holds the key for the wellbeing of the overall commercial fishery of the region. The species is the major prey item of most of the predatory high-value fishery resources of the region and hence exerts a bottom-up control (Hunt and Mckinnell, 2006) towards the production at the higher trophic level.

The species under genus *Acetes* are characterised by fast growth with short generation time and hence warrant a periodic assessment of their stock and abundance. Despite the ecological importance of the species in the region and its inherent biological traits (r-selected species), very limited attempts have been made towards the assessment of the health of the stock (Deshmukh, 1993; Vase *et al.,* 2021). Vase *et al.* (2021) applied the surplus production model over the time series catch and effort data (2004-2008) and found the resource sustainable as the catches were almost equal to the estimated MSY. However, in cases where limited inputs are used in the analysis (data limited), a multi-model approach (MMA) is always recommended. As catches are the most available data over a longer temporal scale, a surge in the catch-based assessment models is seen in recent times. Also, there is an incorporation of artificial intelligence and machine learning techniques in model fitting and parameter estimations in the recently developed methods of stock assessment. In the present study, we applied four recently developed models *viz.* CMSY (Monte-Carlo Catch-MSY), BSM (Bayesian State-space Schaefer surplus production model), zBRT (Zhou Boosted Regression Tree) and OCOM (Optimised catch-only assessment method) (Froese *et al.*, 2017; Zhou *et al.*, 2017a, b) to the time series catch data to evaluate the stock status of *Acetes* fisheries of Gujarat coast. These methods use artificial intelligence and machine learning techniques like neural networks and boosted regression to estimate the parameters of the underlying models, which makes them computationally advanced than their predecessors. Article 6 of FAO-CCRF (Code of Conduct for Responsible Fisheries) advocates the adoption of precautionary principles in fisheries management in case of uncertainty. We compared the outputs of all four models and adopted the most conservative estimate considering the underlying uncertainty associated with data-limited methods.

Materials and methods

The time series catch data for the period 2007-19 for *Acetes* forms the major input data for the present analysis. The recent data for the period 2020-22 were not included in the analysis considering the pandemic-induced alteration during 2020-21 and market-related issues during 2022 in the region adulterating the landing pattern of the region. The data was sourced from the National Marine Fishery Resources Data Centre (NMFDC) of the ICAR-Central Marine Fisheries Research Institute, Kochi. The details of the four recently developed models used to arrive at stock status indicators are mentioned below:

CMSY and BSM

CMSY assumes population growth as per Schaefer Production model (Schaefer, 1954) given by:

$B_{t+1} = B_t + r\,(1 - B_t/k)\,B_t - C_t$ ....(1)

where B_t refers to the biomass in year t, r is the intrinsic growth rate of population increase, k is the carrying capacity and C_t is the catch for the year t.

When in addition to catch, abundance data (CPUE in the present case) is provided, a Bayesian state-space implementation of the Schaefer surplus-production model (BSM) is also applied. The methods also require priors for the r and k, which may be calculated based on information on resilience. With information on time series catch, abundance (for BSM) and informative priors, the model applies a Monte-Carlo approach to identify viable population biomass trajectories (Froese *et al.,* 2017). We used time series catch data of *Acetes* along the Gujarat coast (2007-19) for the present study. We provided derived CPUE from dol-nets for the period 2015-19 for facilitating BSM. The gear was selected as the bulk of the catch comes from this gear and the methods are highly unselective (catch can be treated as a function of abundance). The duration of CPUE was restricted to 2015-2019 because during this period there was negligible change in technology, fishing ground and species preference and hence catch rates can be fairly considered as a proxy of abundance. A new version of CMSY package CMSY++ was used for the analysis as it uses more robust artificial intelligence or machine learning algorithms (neural networks) for finding viable biomass priors from catch (http://oeanrep.geomar.de/52147/).

zBRT

Zhou Boosted Regression Tree (zBRT) uses the machine learning technique to predict the target continuous variable (B/K) (Zhou *et al.,* 2017a). The method is based on regression trees. The approach develops a viable model which predicts the stock depletion based on catch history, *i.e.* time series catch data (2007-19) in the present case. In this approach, each model tree has several interior nodes, each corresponding to the input variables. Each node splits into two branches, based on whether a given input variable is greater or less than a value *p* (determined by "tree learning"). Each leaf represents a value of the target variable, given the values of the input variables represented by the branch from the root to the leaf. A tree can be "learned" by splitting each predictor into branches and repeating the sequential splitting process many times referred to as recursive partitioning. The recursion is completed when the subset stocks at a node have all the same saturation value, or when splitting no longer adds value to the predictions. The model uses only the time series catch as input and hence, is the least data intensive. The model outputs are B/B_{MSY} and B/K trajectories (Zhou *et al.,* 2017a). The zBRT was run using the datalimited2 R package (Free, 2018).

OCOM

Like CMY and BSM, OCOM (Optimised Catch-Only assessment Method) uses the Schaefer surplus production function. The function has two unknown parameters, r (intrinsic rate of population growth) and k (carrying capacity). The depletion d is related to carrying capacity k as:

$d = 1 - S = 1 - B_t/K$ ....(2)

Where S refers to stock saturation (Zhou *et al.,* 2017a), B_t refers to biomass at time t. If the prior information on r and S (or d) is available, k in the equation 1 can be estimated. In addition to time series catch data, the model requires M (instantaneous natural mortality) as an additional input. Zhou *et al.* (2012) have established a relationship between F_{MSY} and natural mortality (M) based on a global meta-analysis. Assuming $r = 2\,F_{MSY}$, as is the case for the Schaefer model, we can obtain prior for r from M. The prior for S in the model is based on the parameterised relationship between $Se = B_e/B_0$ from Zhou *et al.* (2017b), where S_e and B_e are stock saturation and biomass at the end of time series and B_0 is the model-based estimate of unfished biomass. The OCOM was run using datalimited2 R package (Free, 2018). The stock is categorised based on Palomares *et al.* (2018) and Zhang *et al.* (2020).

Results and discussion

Along the Gujarat coast, 72.39% of the total crustacean landings comprise non-penaeid shrimps (CMFRI, 2019). *Acetes* spp. forms the bulk of the non-penaeid shrimp landings with a share of 81.8 to 88.3% during the last five years (2015-19) (Fig. 1).

The commercial exploitation of *Acetes* has registered significant growth in the last decade with catch increasing from 60000 t close to over 1 lakh t during the last few years (2016-2019) (Fig. 1). The operation of dol-net (DN) forms the major means of harvest for *Acetes* spp. The relative contribution of dol-nets has recorded an increase from around 60% in 2007 to over 90% in 2018. The trawl accounts for less than 20% of the total *Acetes* landings during the last few years with the lowest recorded during 2018 (6.4%) (Fig. 2).

The declining share in trawls towards *Acetes* landings was mostly due to decreasing contribution from multi-day trawlers (MDTN). On the contrary, the share of mechanised trawlers (MTN) operating for a single day in the *Acetes* landings was more or less the same over the study period (2007-19), despite a gradual decline in effort. A decline of over 81% in total effort spent by single-day trawlers in hours was recorded throughout 2007-19. The targeted *Acetes* trawling during some months along the Gujarat coast by the MTN could be attributed to the higher proportion of *Acetes* landings. However, over the years, multi-day trawl operators are more interested in resources like ribbonfishes and cephalopods for their high export value and hence the major share of multi-day trawl efforts are dedicated towards these resources (Rahangdale *et al.*, 2022a, b; Kumar *et al.,* 2023) leading to poor catch or retention of *Acetes* in MDTN. As far as *Acetes* fishery is considered, the least change in fishing grounds and species preference was observed in multi-day trawlers. An insight into the catch rates (CPUE) reveals a general increasing trend with inter-annual fluctuation (expected for the short-lived fast-growing fishes) (Fig. 1). The catch rates from dol-nets hinted at an increasing abundance of the resource, which can be attributed to the climate change or decreasing predators.

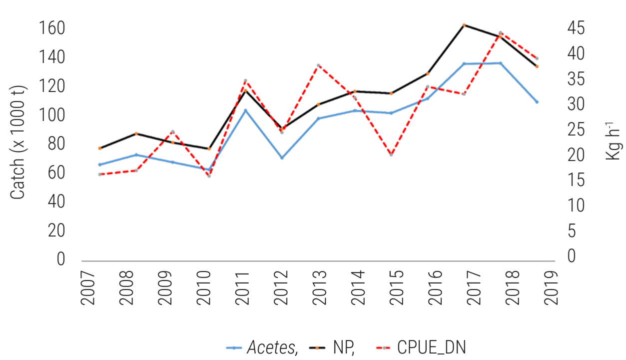

Fig. 1. Time series catch trend of *Acetes* and non-penaeid shrimps (NP) and abundance indices (CPUE_DN) for *Acetes* along Gujarat coast

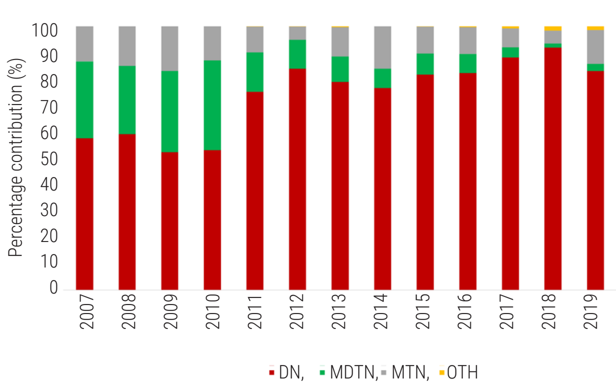

Fig. 2. Relative share of *Acetes* catches in different gears operated along Gujarat coast (2007-19)

The dedicated studies on the health of the stocks are limited in the study region (Deshmukh, 1993; Vase *et al.,* 2021). The most recent assessment was by Vase *et al.* (2021) who used catch and standardised effort from 2004 to 2018 to arrive at parameters like MSY and B_{MSY}. The study categorised the species as healthy as the current catch (Y_{curr}) was found less than the estimated MSY. However, in their assessment, they did not consider the changing species preference in multi-day trawl operations during effort standardisation. The estimated CPUE from MDTN may not be a reliable index of abundance, especially in the context of Gujarat. Hence, the current study focused on the application of recently developed catch-only models to evaluate the status of the *Acetes* fishery along the Gujarat coast. We applied CMSY, zBRT and OCOM, which primarily uses time series catch data and additional information on resilience (CMSY) and natural mortality coefficient, M (OCOM). It was indicative that catch rates (CPUE) from dol-nets would be a better index of the abundance of *Acetes* in the context of Gujarat. A derived CPUE for the period 2015-19 from dol-nets was used as an index of abundance to run BSM as an altitudinal approach to estimate stock status. A multimodal approach is always advisable in case of a data limited scenario. The estimated B/B_{MSY} ranged between 1.19 and 1.55. The F/F_{MSY} varied from 0.38 to 0.80. The estimates of B/B_0 were found most consistent across the models and ranged between 0.59 and 0.79 (Table 1).

The outputs from CMSY and BSM were highly comparable and gave almost similar outputs (Fig. 3), which reinforces the reliability of CPUE from dol-nets as an indicator of the abundance of the resource. Hence, dolnets can be considered as the indicator gear for monitoring *Acetes* resources.

Both CMSY and BSM categorise the stock as fully exploited (sustainable). The other two methods, zBRT and OCOM, put the resource under the category of being under-exploited. We recommend the adoption of more conservative estimates from CMSY and BSM for management advisories. The KOBE plot from BSM (Fig. 4) shows that the resource has been in the green zone for the last few years, which is a good sign for the resource and overall marine ecosystem of the region. Though there is a marginal scope for increasing the harvest of *Acetes*, the non-selective nature of the dol-nets does not permit further escalation of effort to ensure the sustainability of other resources landed along with *Acetes*.

The exploitation rate for the *Acetes* resource along the coast has increased over the years, indicated both by increasing catch and exploitation indices. The current multi-modal comparison of stock status categorises the stock as sustainable. CMSY and BSM approach gives the most conservative stock status and should be given preference over the other two models in the situation of limited data availability. Considering short generation time and fast growth with multiple intra-annual recruits, regular monitoring of the resource is recommended. It is also advised to have an

Table 1. Estimates of stock status indices from different models and comparison with previous studies

Present/Previous	Method	Data	B/B_{MSY}	F/F_{MSY}	B/B_0	E	Y_{curr}/MSY	Stock status
Previous (1993)	Length based	LF (1980-82)		0.04		0.19-0.23		Under-exploited
Previous (2021)	Schaefer Model	Catch (2004-18) Effort (2004-18)					0.93	Fully exploited (sustainable)
Present	CMSY	Catch (2007-19) Resilience (High)	1.19	0.79	0.65			Fully exploited (sustainable)
Present	BSM	Catch (2007-19) Abundance (2015-19) Resilience (High)	1.20	0.80	0.59			Fully exploited (sustainable)
Present	zBRT	Catch (2007-19)	1.46		0.73			Under-exploited
Present	OCOM	Catch (2007-19) M (9.5 $^{yr-1}$)	1.55	0.38				Under-exploited

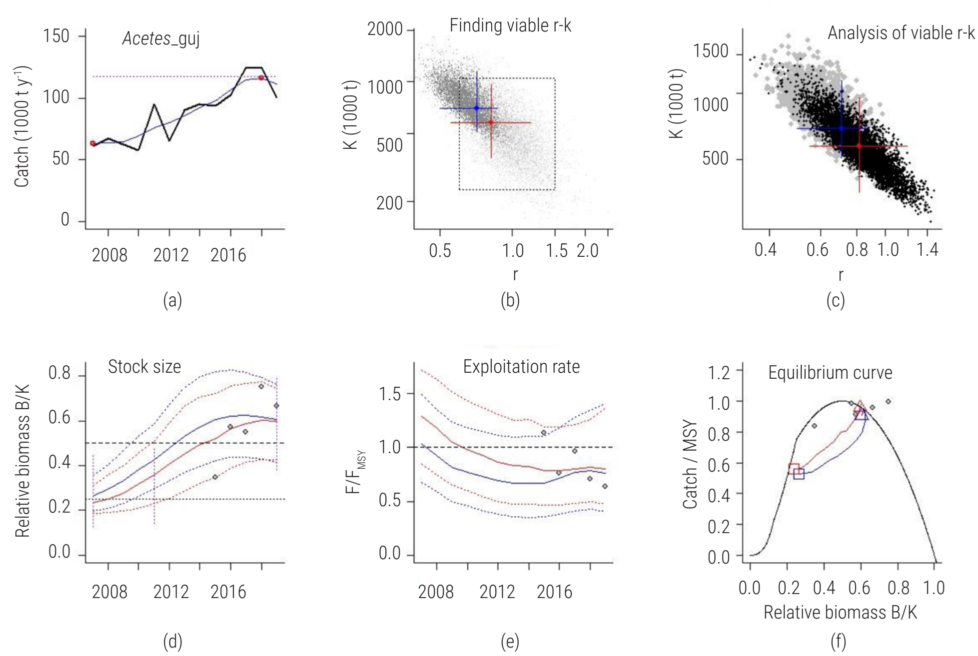

Fig. 3. Output of CMSY and BSM for *Acetes* landed along the Gujarat coast (2007-19)

intermittent fishery-independent survey for the available biomass of the resource. The resource holds the key to the success of other fisheries in the region through prey-predator interaction and hence due priority should be given to research, monitoring and management formulations.

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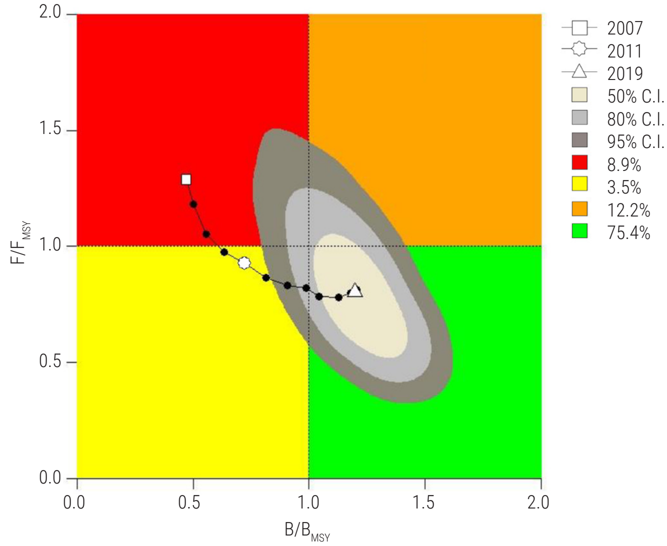

Fig. 4. KOBE plot indicating the stock status of the resource based on BSM analysis

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