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QUANTIFYING THE IMPACTS OF FLEET SELECTIVITY PATTERNS ON MAXIMUM SUSTAINABLE YIELDS FOR TROPICAL BIGEYE AND YELLOWFIN TUNAS

Nathan Vaughan[1], Shannon Cass-Calay[2], Guillermo A. Diaz[2]

SUMMARY

*Yellowfin tuna (*Thunnus albacares*) (YFT) and bigeye tuna (*Thunnus obesus*) (BET) fisheries are each exploited by fishing fleets with varied selectivity patterns. This study quantifies fleet-specific maximum sustainable yield (MSY) estimates for these fisheries to inform managers on the potential impact of reallocating landings quotas between fleets. The most recent reference models for each species were used to project a 50-year equilibrium MSY for a status quo relative effort base scenario and individual MSY scenarios where landings were taken by only a single fleet. Results show that fleets dependent on fish aggregation devices (FAD) routinely supported significantly lower individual MSY estimates of around half the baseline MSY. These fleets accounted for only 15–20% of base case landings, while causing almost half of the total population depletion. Many fleets targeting larger individuals supported substantially larger individual MSYs from 3 to 5 times those of the FAD fleets. These results suggest that significant increases in MSY for BET and YFT could be achieved through the reallocation of landings quotas.*

RÉSUMÉ

*Les pêcheries d'albacore (*Thunnus albacares*) (YFT) et de thon obèse (*Thunnus obesus*) (BET) sont chacune exploitées par des flottilles de pêche avec divers schémas de sélectivité. Cette étude quantifie les estimations de la Production maximale équilibrée (PME) spécifiques aux flottilles pour ces pêcheries afin d'informer les gestionnaires sur l'impact potentiel de la réallocation des quotas de débarquements entre les flottilles. Les modèles de référence les plus récents pour chaque espèce ont été utilisés afin de projeter une PME en conditions d'équilibre sur 50 ans pour un scénario basé sur l'effort par rapport au statu quo et des scénarios de PME individuelles lorsque les débarquements étaient réalisés par une seule flottille. Les résultats indiquent que les flottilles qui dépendent des dispositifs de concentration de poissons (DCP) soutiennent régulièrement des estimations de PME individuelles bien inférieures, de près de la moitié de la PME de référence. Ces flottilles ne représentaient que 15–20% des débarquements du cas de base, tout en causant la moitié environ de la raréfaction de la population totale. De nombreuses flottilles ciblant de plus grands spécimens soutenaient des PME individuelles bien supérieures, de 3 à 5 fois celles des flottilles sous DCP. Ces résultats suggèrent que d'importantes augmentations de la PME de BET et de YFT pourraient être obtenues par le biais d'une réallocation des quotas de débarquements.*

RESUMEN

*Las pesquerías de rabil (*Thunnus albacares*) (YFT) y patudo (*Thunnus obesus*) (BET) son explotadas por flotas pesqueras con patrones de selectividad variados. Este estudio cuantifica las estimaciones del rendimiento máximo sostenible (RMS) específicas de cada flota para estas pesquerías con el fin de informar a los gestores sobre el impacto potencial de la reasignación de cuotas de desembarque entre flotas. Los modelos de referencia más recientes para cada especie se utilizaron para proyectar un RMS en equilibrio a 50 años para un escenario basado en el esfuerzo frente al statu quo y escenarios individuales de RMS en los que los desembarques fueron realizados por una sola flota. Los resultados muestran que las flotas dependientes de los dispositivos de concentración de peces (DCP) soportaban rutinariamente estimaciones individuales de RMS significativamente inferiores, en torno a la mitad del RMS de referencia. Estas flotas representaban sólo el 15-20 % de los desembarques del caso base, mientras que*

[1] Vaughan Analytics, supporting NOAA: SEFSC. Miami, FL, USA. nathan.vaughan@noaa.gov
[2] NOAA Southeast Fisheries Science Center, Miami, FL, USA.

causaban casi la mitad de la merma total de la población. Muchas flotas que se dirigen a ejemplares de mayor tamaño soportaron RMS individuales sustancialmente mayores, de 3 a 5 veces los de las flotas con DCP. Estos resultados sugieren que podrían lograrse aumentos significativos del RMS para el BET y el YFT mediante la reasignación de las cuotas de desembarque.

KEYWORDS

Maximum Sustainable Yield, Fleet Allocations, Gear Selectivity, Tuna Fisheries

1. Introduction

Tuna fisheries, particularly those targeting yellowfin tuna (*Thunnus albacares*) (YFT) and bigeye tuna (*Thunnus obesus*) (BET), are essential contributors to global food security and economic prosperity. Tuna fisheries in the Atlantic Ocean are managed by the International Commission for the Conservation of Atlantic Tunas (ICCAT). Achieving sustainable management of these species is a complex challenge for ICCAT due to the intricate interplay of ecological factors, market demands, shifting effort between fleets and nations, and the dynamics of the tuna populations themselves. One critical aspect at the core of sustainable management is the determination of Maximum Sustainable Yield (MSY), a fundamental concept that represents the highest level of fishing effort that can be maintained indefinitely without depleting a population. This study investigates how changes in effort allocation among fleets, with distinct age cohort selectivities, could impact the estimated MSY of these fisheries.

Traditional fisheries management often assumes a static allocation of effort across different fleets or fishing gears. However, effort allocation can vary substantially as it is influenced by factors such as market demand, technological advancements, and regulatory changes. Such shifts in allocation can have consequences for the sustainability of fisheries, particularly when different fleets exhibit varying selectivity such as in the YFT and BET fisheries. This study focuses specifically on quantifying the relative efficiency of each fleet with respect to its individual MSY, therefore, helping to anticipate the future potential impact on MSY of any regulated change in allocation between existing fishing fleets with respect to the current status-quo.

Within the realm of ICCAT-managed tuna fisheries, there exists a constellation of fishing fleets, each characterized by unique selectivity profiles. These profiles have been established in the 2021 BET and 2019 YFT stock assessments using the Stock Synthesis framework (Anonymous, 209, 2021). For comparison, these fleets can be categorized into 6 main groups based on the gear used;

Purse Seine fleets fishing on Fish Aggregation Device (FAD): These fleets employ FADs to create artificial floating habitats, primarily targeting smaller Skipjack tuna (*Katsuwonus pelamis*). YFT and BET, being bycatch species in FAD fisheries, experience varying levels of incidental capture.

Free school Purse-Seine (PS) Fleets: Purse-seine vessels deploy expansive nets to encircle schools of tuna, targeting a broad range of age cohorts, from juveniles to adults. These fleets can capture a wide spectrum of the tuna population and final selectivity is often dependent on the location of deployment and fisher preference.

Bait Boat (BB) Fleets: Bait boat fleets are characterized by vessels equipped with baited hooks that are deployed to attract and capture tuna. This fleet type targets a specific segment of the population, often focusing on larger individuals though with considerable spatial and interfleet variability.

Handline and Rod and Reel (HL) Fleets: Utilizing traditional angling methods, some of these fleets engage in recreational fishing for tuna while others are commercial in nature. Their selectivity is influenced by angler preferences and size limits, which may vary among jurisdictions.

Longline (LL) Fleets: Longline vessels employ extensive lines with baited hooks, primarily targeting older and larger tuna specimens, frequently associated with more mature age classes. These fleets generally aim to capture larger and more valuable individuals.

The allocation of fishing effort among these diverse fleet types plays a pivotal role in shaping the final aggregate age structure of harvested tuna populations and, consequently, the sustainability of these fisheries. This study will explore various effort allocation scenarios, including a base status-quo case and cases where all fishing effort is exclusively directed toward each individual fleet. Using the 2019 YFT and the 2021 BET stock synthesis assessment models, we will estimate MSY for both YFT and BET under each of the effort allocation scenarios.

These individual fleet scenarios will encompass the full spectrum of allocation decisions that could be enacted, providing a nuanced understanding of how shifting effort allocation influences the sustainable exploitation of these species. The research findings will contribute valuable insights into the consequences of shifting fishing effort among fleets with distinct age cohort selectivity's. These insights can be instrumental in informing policy discussions within ICCAT and guiding the development of science-based management strategies that balance ecological conservation and economic interests across a diverse stakeholder base.

In summary, this research endeavors to illuminate the complex dynamics of international tuna fisheries, focusing on the interactions between fleet selectivity's, effort allocation strategies, and the sustainability of yellowfin and bigeye tuna stocks. By addressing these objectives, our study aims to contribute to the ongoing efforts to secure the future of these species and the communities that rely on them, within the framework of responsible and science-driven fisheries management.

2. Methods

These methods were designed to quantify the potential changes in equilibrium MSY that could be expected due to a future change in the proportion of total landings removed by each fleet. To achieve this, multiple MSY projections were performed for both BET and YFT using the most recently completed Stock Synthesis 3.30 (SS3) stock assessment reference models (2021 Model M20_h0.8_sigmaR0.4 for BET and 2019 Model 3 for YFT). Equilibrium results were approximated using the final years result from a 50-year projection for both species. A reference MSY for each species was defined by performing projections assuming the recent average relative effort between fleets remains constant. Individual MSY estimates were produced for each fleet by performing projections assuming all other fleets effort was reduced to zero. All projections were performed to target an equilibrium MSY proxy of 30% spawning stock biomass (SSB) relative to unfished conditions which is close to the SSB ratio achieved in the direct MSY estimates from the most recent assessments (0.2962 for BET and 0.2933 for YFT). This was done to place all individual fleet MSY estimates on equal footing with respect to equilibrium stock depletion, which reflects the realistic implementation scenario where all fleets are harvesting a single stock and so cannot optimize independently for population depletion. These scenarios resulted in 23 BET projections and 26 YFT projections, one for the base and one for each fleet defined in the stock assessments. All projections were run for 50 years with the fleet specific F iteratively adjusted in each year, for which recent catches were unavailable (2023 and onward for BET and 2019 and onward for YFT), until the SSB in year 50 was equal to 30% of the unfished SSB and annual fishing mortality rate (F) was equal in all years. Four key metrics were collected for each species/fleet:

1) Estimated equilibrium landings for each fleet under the base scenario of recent average effort allocation between fleets. These are the expected landings under status quo conditions and reflect a similar assumption to the original stock assessment results.
2) Estimated equilibrium landings/MSY for each fleet under the scenario that they are the only fleet exploiting the stock. These MSY estimates represent the relative efficiency of each fishery in its capacity to sustainably extract biomass from the population.
3) The base scenario landings for each fleet as a proportion of their fleet specific MSY. These represent the true relative status quo impact of each fleet on population. These results sum to approximately 1 across all fleets with some margin of error due to model rounding and seasonal effects not accounted for in the simulations.
4) The ratios of individual fleet MSY estimates to each other (i.e., MSY for fleet B / MSY for fleet A). These results express a general exchange rate for considering allocation shifts between fleets. For example a ratio of (FleetB/FleetA=2) would suggest that reducing allocation by 1MT for FleetA and increasing the allocation for FleetB by 2 metric tons would result in a 1MT increase in total MSY.

3. Results

3.1 BET

Base scenario results for BET estimated an equilibrium MSY of ~79,200 MT under the current effort allocation scenario (**Figure 1**, **Table 1**). In this base scenario, 80% of the total landings are harvested by 6 fleets FAD_1 (~19%), LL_9 (~17%), LL_4 (~14%), LL_6 (~11%), PS_4 (~9%), and BB_5 (~8%) with the remaining 20% distributed among 13 active fleets and 3 historic inactive fleets (**Figure 2**, **Table 1**).

The individual MSY analyses reveal that a substantial range of MSY values are supported by the different fleets, ranging from approximately 33,800 MT to 165,900 MT, and representing between 0.43 and 2.1 times the base MSY (**Figures 3** and **4**, **Table 1**).

By comparing the estimated base scenario landings for each fleet to their fleet specific MSY estimates we can calculate the real impact on each fleet on stock status. The results show that ~45% of the population depletion is being driven by the FAD_1 fleet and no other fleet contributing more than ~10% (**Figure 5**, **Table 1**).
Comparing the ratio of individual fleet MSY estimates also shows a relative exchange rate in landings between fleets with respect to MSY. If quota is shifted according to these ratios, it is expected that new MSY estimates will generally adjust to match the new total landings (**Table 2**).

3.2 YFT

Base scenario results for YFT estimated an equilibrium MSY of ~129,600 MT under the current effort allocation scenario (**Figure 6**, **Table 3**). In this base scenario 55% of the total landings are harvested by 5 fleets BB_4 (~16%), PS_7 (~10%), HL_1(~10%), PS_6 (~10%), and PS_5 (~9%) with the remaining 45% distributed among 17 active fleets and 3 historic inactive fleets (**Figure 7**, **Table 3**).

The individual MSY analyses reveal that a substantial range of MSY values are supported by the different fleets, ranging from approximately 61,500 MT to 236,800 MT, and representing between 0.48 and 1.82 times the base MSY (**Figures 8** and **9**, **Table 3**).

By comparing the estimated base scenario landings for each fleet to their fleet specific MSY estimates we can calculate the real impact on each fleet on stock status. In this case, the relative impact is again broadly distributed across many fleets (**Figure 10**, **Table 3**).

Comparing the ratio of individual fleet MSY estimates also shows a relative exchange rate in landings between fleets with respect to MSY. If quota is shifted according to these ratios it is expected that new MSY estimates will generally adjust to match the new total landings (**Table 4**).

4. Discussion

The results of this study highlight the significant diversity of fleet selectivity patterns currently represented in the ICCAT-managed tropical Bigeye (BET) and Yellowfin Tunas (YFT) fisheries. This diversity in selectivity is a key factor affecting the existing maximum sustainable yield (MSY) estimates for both BET and YFT. Understanding these profiles and their impact is important for making informed management decisions.

In the base scenario, the study estimated an equilibrium MSY of approximately 79,200 MT for BET and 129,600 MT for YFT. These estimates serve as reference points for evaluating the impact and relative efficiency of different fleets and are in close alignment with the most recent stock assessment recommendations for both species. The results also reveal that a limited number of dominant fleets extract most of the landings in both BET and YFT fisheries.

For both BET and YFT, the results identified purse seines fleets fishing on FADs as having the lowest individual MSY estimates and the largest relative impact on the stocks. For BET, the single FAD fleet represented in the stock assessment was responsible for approximately 15,400 MT of equilibrium landings in the base scenario constituting the largest fleet with 19.4% of total estimated MSY. However, because of the small size of the individuals caught by this FAD fleet its individual MSY was estimated at only 33,844 MT which is only 45.5% of the baseline MSY. Because of this low individual MSY, the baseline landings of the FAD fleet result in 42.7% of the total stock depletion observed in the baseline scenario. Similarly, the four FAD fleets in the YFT fishery account for total removals of 26,200 MT which represent 20.2% of the baseline landings. These fleets have similar individual MSY estimates of around 62,000 MT which is 48% of the baseline MSY. Once adjusted for their individual MSY efficiencies, these four fleets account for 41.9% of the baseline scenario depletion.

In contrast the most efficient BB and PS fleets in the BET fishery support individual MSY's of over 100k MT, HL fleets support up to 143,600 MT, and LL fleets support up to 165,900 MT representing 132%, 137%, 181%, and 209% of the baseline MSY, respectively. When combining the 13 most efficient fleets with individual MSY estimates over 100k MT we find that while extracting approximately 70% of the baseline landings they result in only 41% of the baseline depletion. Likewise, for YFT the most efficient HL, BB, PS, and LL fleets have individual

MSY estimates of 145k, 196k, 231k, and 236k MT, respectively, representing between 112% and 182% of the baseline MSY.

These results suggest that significant increases in total MSY are possible if equitable ways to reallocate effort between fleets can be identified in the future. Specifically, fleet exchange rate calculations suggest that, for example, reducing the FAD fleet allocation by 1 MT could allow the allocation for one of the more efficient BB, PS, HL, or LL fleets to be increased by between 3 and 5 MT.

While these results provide valuable quantitative information to managers, many caveats remain. Specifically, the low efficiency of the FAD fleets with respect to BET and YFT landings would need to be weighed against the potential efficiency with which they exploit their smaller primary target species skipjack tuna. Additionally, the apparent efficiency of LL fleets in targeting BET and YFT cannot be viewed in isolation from their potential by-catch impact on species such as ICCAT prohibited sharks, sea turtles, and marine mammals that would be increased if their allocations were raised. These fleets also represent the varied interests and needs of a diverse multi-national user base. In light of these and other issues, while this study provides valuable insights into the impacts of fleet selectivity patterns on MSY, further research is needed to explore the ecological and economic consequences of different allocation scenarios. Additionally, incorporating ecosystem-based models and considering the socio-economic aspects of fisheries management will be crucial for developing holistic and sustainable strategies for the future management of these species.

In conclusion, this study underscores the complexity of managing tropical Bigeye and Yellowfin Tunas in ICCAT-managed fisheries. Ultimately, the challenge for ICCAT and its member nations is to strike a balance between conserving tuna populations and maximizing the economic interests of all constituents. This research contributes to that goal by providing a data-driven foundation for informed decision-making. It also highlights the pivotal role of fleet selectivity patterns and allocation strategies in determining the maximum sustainable yield.

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Table 1. Simulation results for Bigeye tuna. Base landings and MSY are equilibrium (year 50 of projection) results under status quo relative effort between fleets. Individual MSY is the result when all landings are taken by the single named fleet. MSY is estimated by a proxy of achieving 30% of virgin spawning biomass.

Name	*Base Landings*	*Base landings/ Base MSY*	*Individual MSY*	*Individual MSY/ Base MSY*	*Base landings/ Individual MSY*
FAD_1	15400.92	0.19	33844.00	0.43	0.46
BB_1	3085.75	0.04	41372.00	0.52	0.07
BB_2	952.38	0.01	68776.30	0.87	0.01
BB_3	0.00	0.00	69591.60	0.88	0.00
BB_4	332.99	0.00	76150.60	0.96	0.00
BB_5	6536.25	0.08	104478.00	1.32	0.06
PS_1	131.17	0.00	44902.80	0.57	0.00
PS_2	0.00	0.00	55695.60	0.70	0.00
PS_3	0.00	0.00	69627.40	0.88	0.00
PS_4	7090.44	0.09	108568.00	1.37	0.07
HL_1	4038.79	0.05	68673.70	0.87	0.06
HL_2	413.71	0.01	143667.00	1.81	0.00
OTH	1362.15	0.02	132803.00	1.68	0.01
LL_1	1720.10	0.02	116009.00	1.46	0.01
LL_2	108.18	0.00	121844.00	1.54	0.00
LL_3	2605.85	0.03	134656.00	1.70	0.02
LL_4	11269.22	0.14	141271.00	1.78	0.08
LL_5	37.63	0.00	141570.00	1.79	0.00
LL_6	9080.24	0.11	144525.00	1.82	0.06
LL_7	928.98	0.01	151720.00	1.92	0.01
LL_8	435.86	0.01	154349.00	1.95	0.00
LL_9	13688.04	0.17	165912.00	2.09	0.08

Table 2. Fleet quota exchange rates for Bigeye tuna. These represent the approximate relative exchange rates for equilibrium landings quota between fleets. In a hypothetical allocation scenario a 1 MT landings reduction in FAD_1 could be exchanged with a 3.18 MT landings increase for BB_5 with MSY for this allocation scenario increasing by 2.18 MT in response. These estimates are approximate due to unaccounted seasonal effects and dependent on the 30% SSB assumption of the simulation. While these estimates do provide useful guidance on the approximate responses, they should be interpreted with caution.

Fleet A (row) Fleet B (col)	FAD_1	FAD_2	FAD_3	FAD_4	BB_1	BB_2	BB_3	BB_4	BB_5	OTH	HL_1	HL_2	LL_1	LL_2	LL_3	LL_4	LL_5	LL_6	PS_1	PS_2	PS_3	PS_4	PS_5	PS_6	PS_7
FAD_1	1.00	1.00	1.02	1.03	1.51	1.96	1.96	1.98	3.18	2.29	1.96	2.35	2.95	2.95	3.10	3.11	3.46	3.83	2.36	2.86	3.48	3.66	3.68	3.72	3.76
FAD_2	1.00	1.00	1.01	1.03	1.51	1.95	1.95	1.97	3.17	2.29	1.95	2.34	2.94	2.94	3.10	3.10	3.45	3.82	2.36	2.86	3.47	3.65	3.67	3.71	3.75
FAD_3	0.98	0.99	1.00	1.01	1.49	1.93	1.93	1.94	3.13	2.25	1.92	2.31	2.90	2.90	3.05	3.05	3.40	3.76	2.32	2.81	3.42	3.59	3.62	3.66	3.70
FAD_4	0.97	0.97	0.99	1.00	1.47	1.90	1.90	1.92	3.09	2.22	1.90	2.28	2.86	2.86	3.01	3.01	3.35	3.71	2.29	2.78	3.37	3.55	3.57	3.61	3.65
BB_1	0.66	0.66	0.67	0.68	1.00	1.30	1.30	1.31	2.10	1.52	1.29	1.55	1.95	1.95	2.05	2.05	2.29	2.53	1.56	1.89	2.30	2.42	2.44	2.46	2.49
BB_2	0.51	0.51	0.52	0.53	0.77	1.00	1.00	1.01	1.62	1.17	1.00	1.20	1.50	1.50	1.58	1.58	1.76	1.95	1.21	1.46	1.77	1.87	1.88	1.90	1.92
BB_3	0.51	0.51	0.52	0.53	0.77	1.00	1.00	1.01	1.62	1.17	1.00	1.20	1.50	1.50	1.58	1.58	1.76	1.95	1.21	1.46	1.77	1.87	1.88	1.90	1.92
BB_4	0.51	0.51	0.51	0.52	0.77	0.99	0.99	1.00	1.61	1.16	0.99	1.19	1.49	1.49	1.57	1.57	1.75	1.94	1.20	1.45	1.76	1.85	1.86	1.88	1.90
BB_5	0.31	0.32	0.32	0.32	0.48	0.62	0.62	0.62	1.00	0.72	0.62	0.74	0.93	0.93	0.98	0.98	1.09	1.20	0.74	0.90	1.09	1.15	1.16	1.17	1.18
OTH	0.44	0.44	0.44	0.45	0.66	0.86	0.86	0.86	1.39	1.00	0.85	1.03	1.28	1.29	1.35	1.35	1.51	1.67	1.03	1.25	1.52	1.60	1.61	1.62	1.64
HL_1	0.51	0.51	0.52	0.53	0.77	1.00	1.00	1.01	1.63	1.17	1.00	1.20	1.50	1.51	1.59	1.59	1.76	1.96	1.21	1.46	1.78	1.87	1.88	1.90	1.92
HL_2	0.43	0.43	0.43	0.44	0.64	0.83	0.83	0.84	1.35	0.98	0.83	1.00	1.25	1.25	1.32	1.32	1.47	1.63	1.00	1.22	1.48	1.56	1.57	1.58	1.60
LL_1	0.34	0.34	0.35	0.35	0.51	0.67	0.67	0.67	1.08	0.78	0.66	0.80	1.00	1.00	1.05	1.05	1.17	1.30	0.80	0.97	1.18	1.24	1.25	1.26	1.28
LL_2	0.34	0.34	0.35	0.35	0.51	0.66	0.66	0.67	1.08	0.78	0.66	0.80	1.00	1.00	1.05	1.05	1.17	1.30	0.80	0.97	1.18	1.24	1.25	1.26	1.28
LL_3	0.32	0.32	0.33	0.33	0.49	0.63	0.63	0.64	1.03	0.74	0.63	0.76	0.95	0.95	1.00	1.00	1.11	1.23	0.76	0.92	1.12	1.18	1.19	1.20	1.21
LL_4	0.32	0.32	0.33	0.33	0.49	0.63	0.63	0.64	1.03	0.74	0.63	0.76	0.95	0.95	1.00	1.00	1.11	1.23	0.76	0.92	1.12	1.18	1.19	1.20	1.21
LL_5	0.29	0.29	0.29	0.30	0.44	0.57	0.57	0.57	0.92	0.66	0.57	0.68	0.85	0.85	0.90	0.90	1.00	1.11	0.68	0.83	1.01	1.06	1.07	1.08	1.09
LL_6	0.26	0.26	0.27	0.27	0.39	0.51	0.51	0.52	0.83	0.60	0.51	0.61	0.77	0.77	0.81	0.81	0.90	1.00	0.62	0.75	0.91	0.96	0.96	0.97	0.98
PS_1	0.42	0.42	0.43	0.44	0.64	0.83	0.83	0.84	1.35	0.97	0.83	1.00	1.25	1.25	1.31	1.31	1.46	1.62	1.00	1.21	1.47	1.55	1.56	1.58	1.59
PS_2	0.35	0.35	0.36	0.36	0.53	0.68	0.68	0.69	1.11	0.80	0.68	0.82	1.03	1.03	1.08	1.08	1.21	1.34	0.83	1.00	1.21	1.28	1.29	1.30	1.31
PS_3	0.29	0.29	0.29	0.30	0.43	0.56	0.56	0.57	0.91	0.66	0.56	0.68	0.85	0.85	0.89	0.89	0.99	1.10	0.68	0.82	1.00	1.05	1.06	1.07	1.08
PS_4	0.27	0.27	0.28	0.28	0.41	0.54	0.54	0.54	0.87	0.63	0.54	0.64	0.81	0.81	0.85	0.85	0.94	1.05	0.65	0.78	0.95	1.00	1.01	1.02	1.03
PS_5	0.27	0.27	0.28	0.28	0.41	0.53	0.53	0.54	0.86	0.62	0.53	0.64	0.80	0.80	0.84	0.84	0.94	1.04	0.64	0.78	0.94	0.99	1.00	1.01	1.02
PS_6	0.27	0.27	0.27	0.28	0.41	0.53	0.53	0.53	0.85	0.62	0.53	0.63	0.79	0.79	0.83	0.83	0.93	1.03	0.63	0.77	0.93	0.98	0.99	1.00	1.01
PS_7	0.27	0.27	0.27	0.27	0.40	0.52	0.52	0.53	0.85	0.61	0.52	0.62	0.78	0.78	0.82	0.82	0.92	1.02	0.63	0.76	0.92	0.97	0.98	0.99	1.00

Table 3. Simulation results for Yellowfin tuna. Base landings and MSY are equilibrium (year 50 of projection) results under status quo relative effort between fleets. Individual MSY is the result when all landings are taken by the single named fleet. MSY is estimated by a proxy of achieving 30% of virgin spawning biomass.

Name	*Base Landings*	*Base landings/ Base MSY*	*Individual MSY*	*Individual MSY/ Base MSY*	*Base landings/ Individual MSY*
FAD_1	4096.43	0.03	61568.00	0.48	0.07
FAD_2	7212.92	0.06	61740.00	0.48	0.12
FAD_3	7226.45	0.06	62650.10	0.48	0.12
FAD_4	7666.06	0.06	63507.60	0.49	0.12
BB_1	0.00	0.00	93111.80	0.72	0.00
BB_2	213.79	0.00	120696.00	0.93	0.00
BB_3	2168.33	0.02	120698.00	0.93	0.02
BB_4	20659.21	0.16	121699.00	0.94	0.17
BB_5	1406.01	0.01	195977.00	1.51	0.01
OTH	2757.25	0.02	141159.00	1.09	0.02
HL_1	13095.44	0.10	120575.00	0.93	0.11
HL_2	1635.19	0.01	144775.00	1.12	0.01
LL_1	1432.24	0.01	181373.00	1.40	0.01
LL_2	8.62	0.00	181526.00	1.40	0.00
LL_3	3290.71	0.03	191115.00	1.48	0.02
LL_4	174.74	0.00	191181.00	1.48	0.00
LL_5	8121.50	0.06	212810.00	1.64	0.04
LL_6	2107.96	0.02	235778.00	1.82	0.01
PS_1	2890.38	0.02	145483.00	1.12	0.02
PS_2	0.00	0.00	176335.00	1.36	0.00
PS_3	0.00	0.00	214225.00	1.65	0.00
PS_4	6501.64	0.05	225219.00	1.74	0.03
PS_5	11060.00	0.09	226842.00	1.75	0.05
PS_6	12529.60	0.10	229297.00	1.77	0.05
PS_7	13302.40	0.10	231753.00	1.79	0.06

Table 4. Fleet quota exchange rates for Yellowfin tuna. These represent the approximate relative exchange rates for equilibrium landings quota between fleets. In a hypothetical allocation scenario a 1 MT landings reduction in FAD_1 could be exchanged with a 3.18 MT landings increase for BB_5 with MSY for this allocation scenario increasing by 2.18 MT in response. These estimates are approximate due to unaccounted seasonal effects and dependent on the 30% SSB assumption of the simulation. While these estimates do provide useful guidance on the approximate responses, they should be interpreted with caution.

Fleet A (row) Fleet B (col)	FAD_1	BB_1	BB_2	BB_3	BB_4	BB_5	PS_1	PS_2	PS_3	PS_4	HL_1	HL_2	OTH	LL_1	LL_2	LL_3	LL_4	LL_5	LL_6	LL_7	LL_8	LL_9
FAD_1	1.00	1.22	2.03	2.06	2.25	3.09	1.33	1.65	2.06	3.21	2.03	4.24	3.92	3.43	3.60	3.98	4.17	4.18	4.27	4.48	4.56	4.90
BB_1	0.82	1.00	1.66	1.68	1.84	2.53	1.09	1.35	1.68	2.62	1.66	3.47	3.21	2.80	2.95	3.25	3.41	3.42	3.49	3.67	3.73	4.01
BB_2	0.49	0.60	1.00	1.01	1.11	1.52	0.65	0.81	1.01	1.58	1.00	2.09	1.93	1.69	1.77	1.96	2.05	2.06	2.10	2.21	2.24	2.41
BB_3	0.49	0.59	0.99	1.00	1.09	1.50	0.65	0.80	1.00	1.56	0.99	2.06	1.91	1.67	1.75	1.93	2.03	2.03	2.08	2.18	2.22	2.38
BB_4	0.44	0.54	0.90	0.91	1.00	1.37	0.59	0.73	0.91	1.43	0.90	1.89	1.74	1.52	1.60	1.77	1.86	1.86	1.90	1.99	2.03	2.18
BB_5	0.32	0.40	0.66	0.67	0.73	1.00	0.43	0.53	0.67	1.04	0.66	1.38	1.27	1.11	1.17	1.29	1.35	1.36	1.38	1.45	1.48	1.59
PS_1	0.75	0.92	1.53	1.55	1.70	2.33	1.00	1.24	1.55	2.42	1.53	3.20	2.96	2.58	2.71	3.00	3.15	3.15	3.22	3.38	3.44	3.69
PS_2	0.61	0.74	1.23	1.25	1.37	1.88	0.81	1.00	1.25	1.95	1.23	2.58	2.38	2.08	2.19	2.42	2.54	2.54	2.59	2.72	2.77	2.98
PS_3	0.49	0.59	0.99	1.00	1.09	1.50	0.64	0.80	1.00	1.56	0.99	2.06	1.91	1.67	1.75	1.93	2.03	2.03	2.08	2.18	2.22	2.38
PS_4	0.31	0.38	0.63	0.64	0.70	0.96	0.41	0.51	0.64	1.00	0.63	1.32	1.22	1.07	1.12	1.24	1.30	1.30	1.33	1.40	1.42	1.53
HL_1	0.49	0.60	1.00	1.01	1.11	1.52	0.65	0.81	1.01	1.58	1.00	2.09	1.93	1.69	1.77	1.96	2.06	2.06	2.10	2.21	2.25	2.42
HL_2	0.24	0.29	0.48	0.48	0.53	0.73	0.31	0.39	0.48	0.76	0.48	1.00	0.92	0.81	0.85	0.94	0.98	0.99	1.01	1.06	1.07	1.15
OTH	0.25	0.31	0.52	0.52	0.57	0.79	0.34	0.42	0.52	0.82	0.52	1.08	1.00	0.87	0.92	1.01	1.06	1.07	1.09	1.14	1.16	1.25
LL_1	0.29	0.36	0.59	0.60	0.66	0.90	0.39	0.48	0.60	0.94	0.59	1.24	1.14	1.00	1.05	1.16	1.22	1.22	1.25	1.31	1.33	1.43
LL_2	0.28	0.34	0.56	0.57	0.62	0.86	0.37	0.46	0.57	0.89	0.56	1.18	1.09	0.95	1.00	1.11	1.16	1.16	1.19	1.25	1.27	1.36
LL_3	0.25	0.31	0.51	0.52	0.57	0.78	0.33	0.41	0.52	0.81	0.51	1.07	0.99	0.86	0.90	1.00	1.05	1.05	1.07	1.13	1.15	1.23
LL_4	0.24	0.29	0.49	0.49	0.54	0.74	0.32	0.39	0.49	0.77	0.49	1.02	0.94	0.82	0.86	0.95	1.00	1.00	1.02	1.07	1.09	1.17
LL_5	0.24	0.29	0.49	0.49	0.54	0.74	0.32	0.39	0.49	0.77	0.49	1.01	0.94	0.82	0.86	0.95	1.00	1.00	1.02	1.07	1.09	1.17
LL_6	0.23	0.29	0.48	0.48	0.53	0.72	0.31	0.39	0.48	0.75	0.48	0.99	0.92	0.80	0.84	0.93	0.98	0.98	1.00	1.05	1.07	1.15
LL_7	0.22	0.27	0.45	0.46	0.50	0.69	0.30	0.37	0.46	0.72	0.45	0.95	0.88	0.76	0.80	0.89	0.93	0.93	0.95	1.00	1.02	1.09
LL_8	0.22	0.27	0.45	0.45	0.49	0.68	0.29	0.36	0.45	0.70	0.44	0.93	0.86	0.75	0.79	0.87	0.92	0.92	0.94	0.98	1.00	1.07
LL_9	0.20	0.25	0.41	0.42	0.46	0.63	0.27	0.34	0.42	0.65	0.41	0.87	0.80	0.70	0.73	0.81	0.85	0.85	0.87	0.91	0.93	1.00

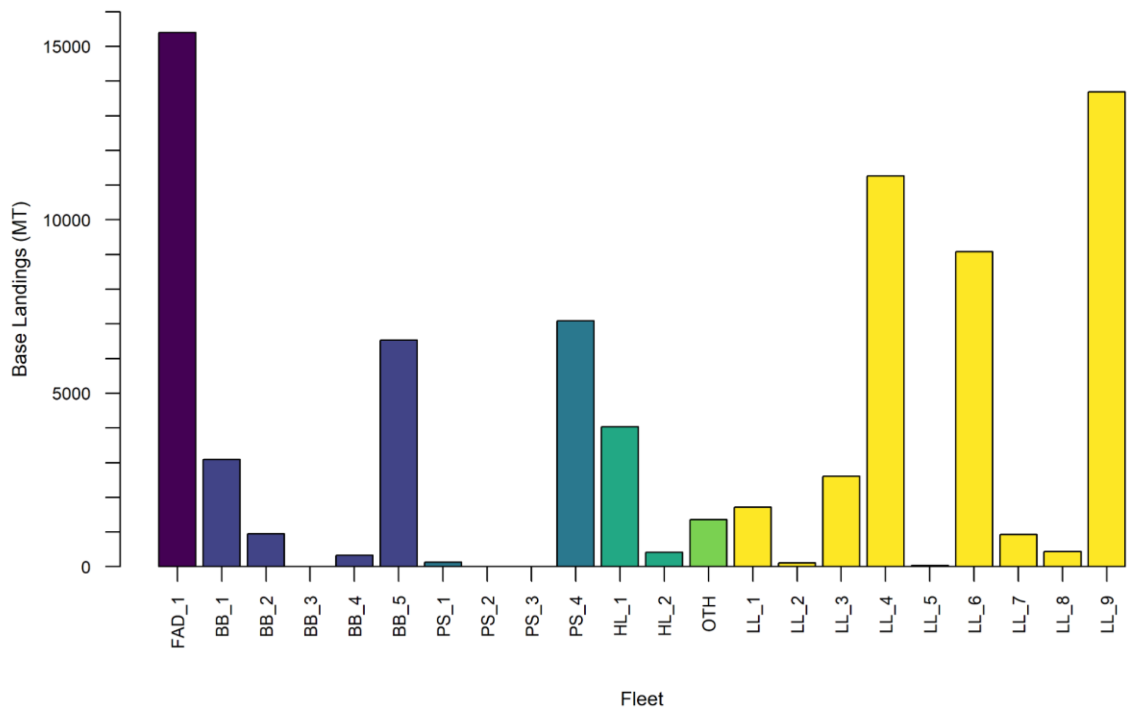

Figure 1. BET fleet landings estimates at equilibrium under base allocation assumptions of constant relative effort at the average of observed effort between 2017 and 2019 and a target MSY proxy of SSB equal to 30% of unfished SSB. The different color bars identify different gear types.

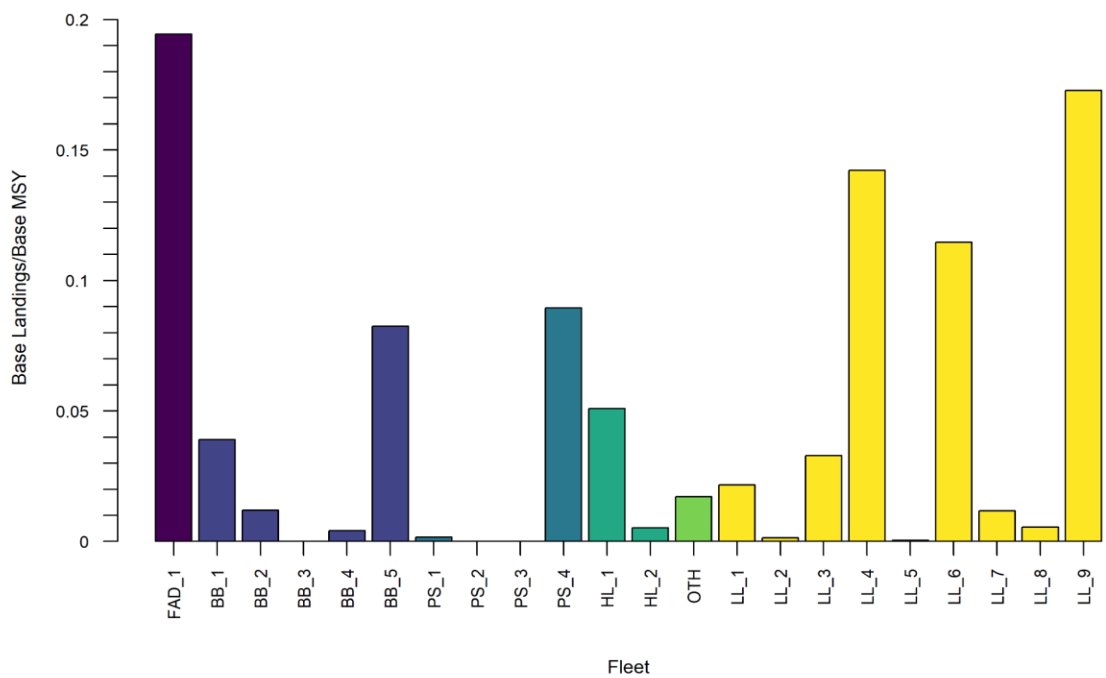

Figure 2. BET fleet landings estimates as a proportion of MSY at equilibrium under base allocation assumptions of constant relative effort at the average of observed effort between 2017 and 2019 and a target MSY proxy of SSB equal to 30% of unfished SSB.

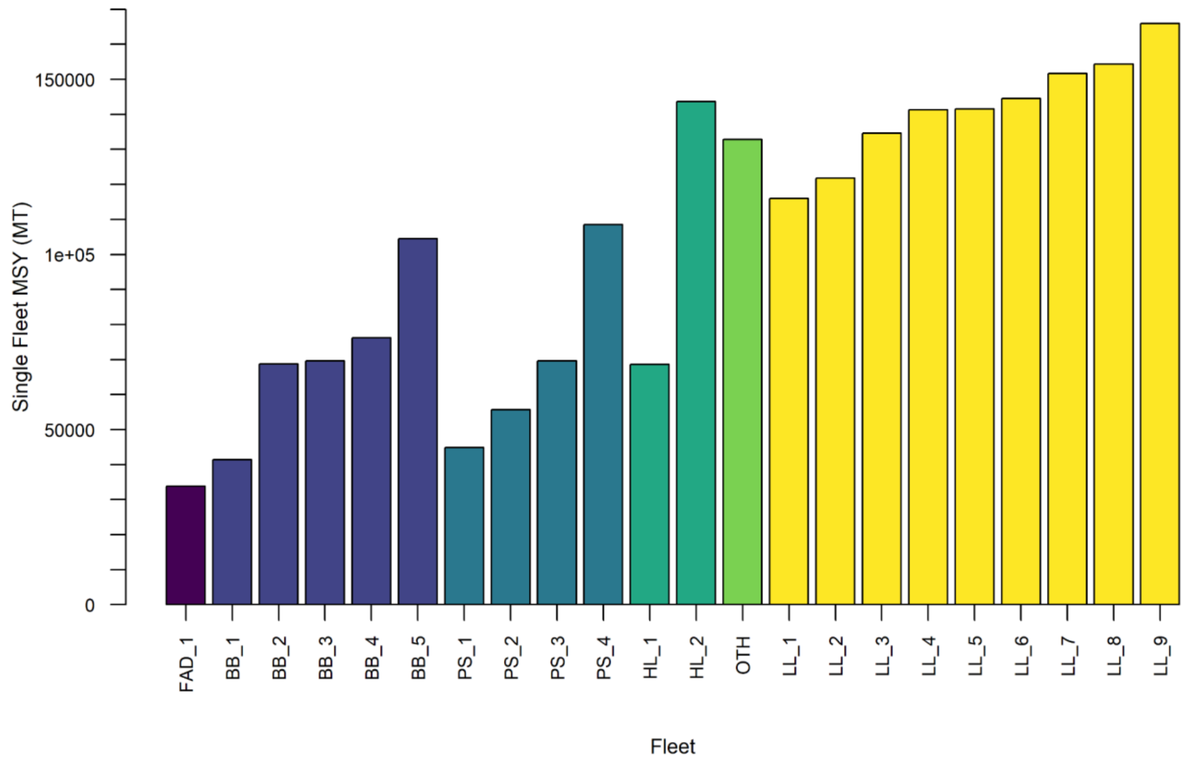

Figure 3. BET equilibrium MSY estimates for each fleet assuming all fishing effort came from that single fleet. MSY proxy assumed of SSB equal to 30% of virgin SSB.

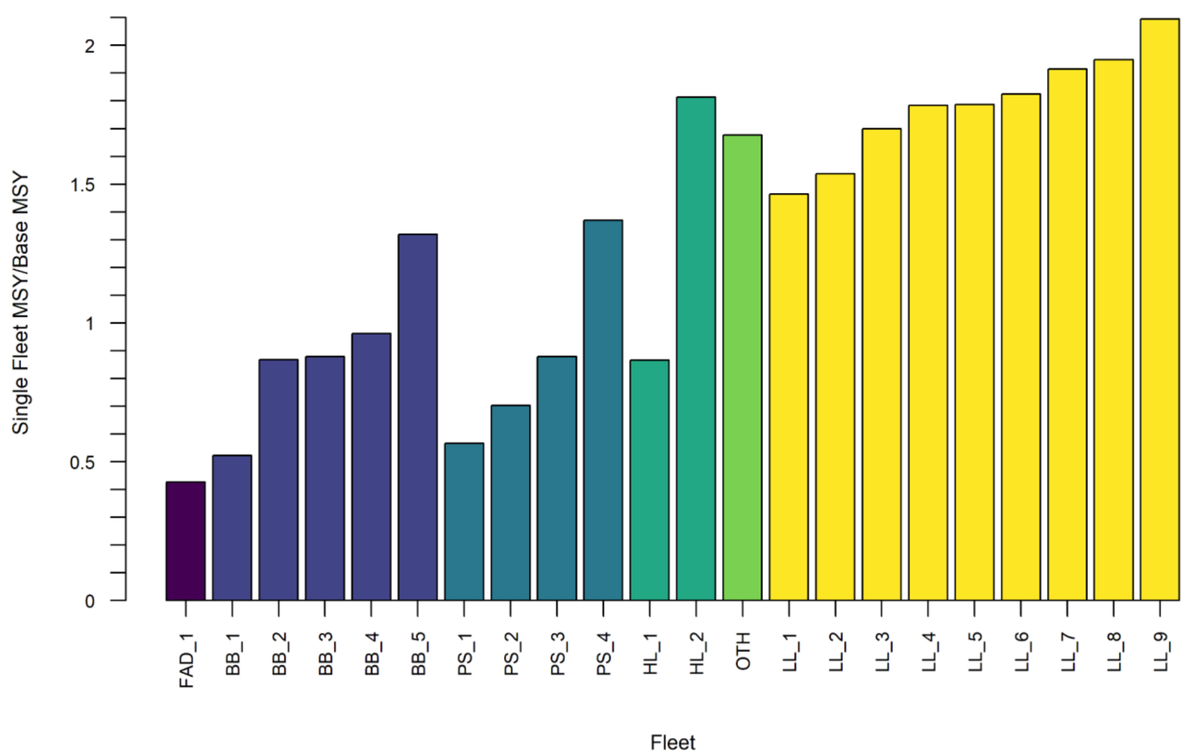

Figure 4. BET equilibrium single fleet MSY estimates as a proportion of base scenario MSY. MSY proxy assumed of SSB equal to 30% of virgin SSB.

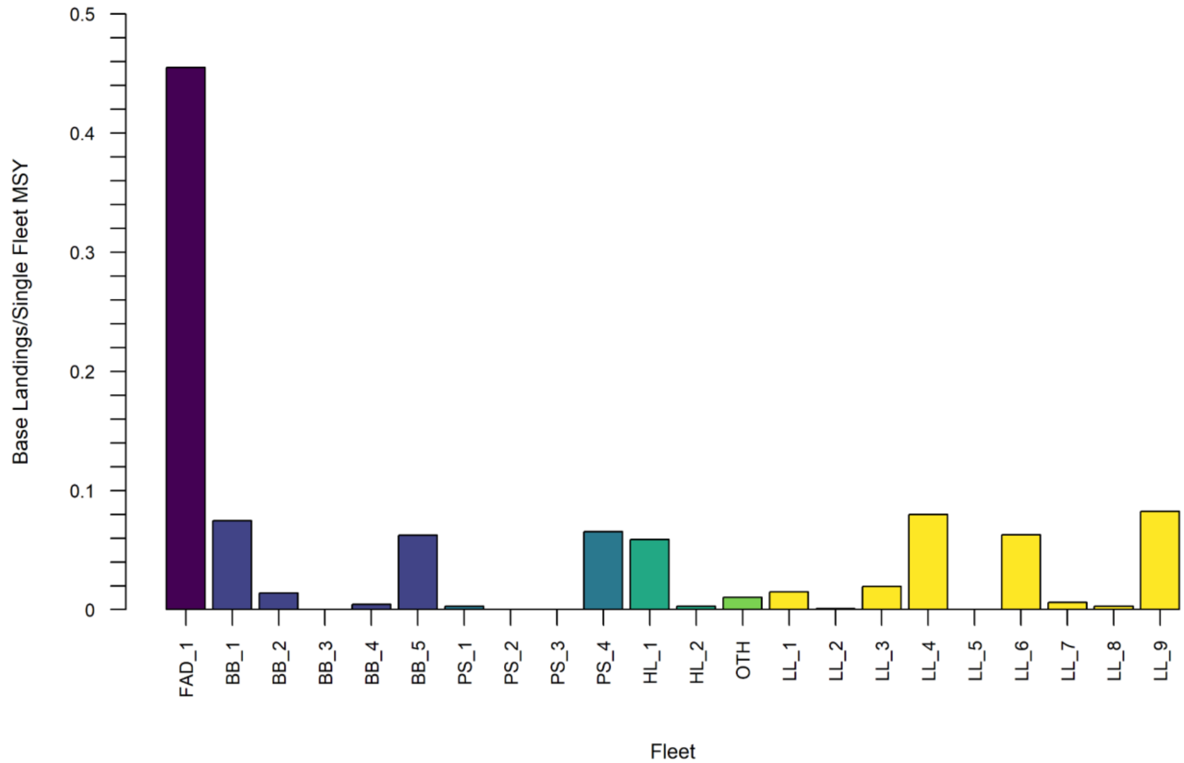

Figure 5. BET base scenario equilibrium fleet landings as a proportion of single fleet MSY estimates.

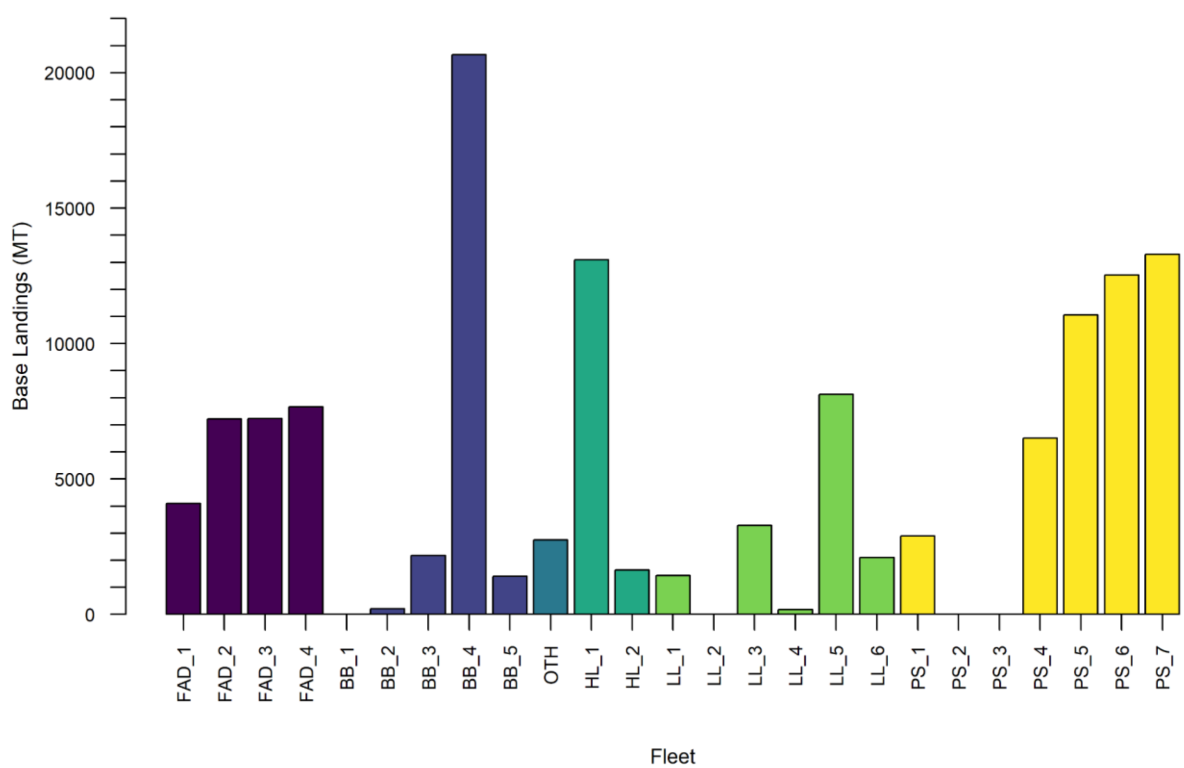

Figure 6. YFT fleet landings estimates at equilibrium under base allocation assumptions of constant relative effort at the average of observed effort between 2017 and 2019 and a target MSY proxy of SSB equal to 30% of unfished SSB.

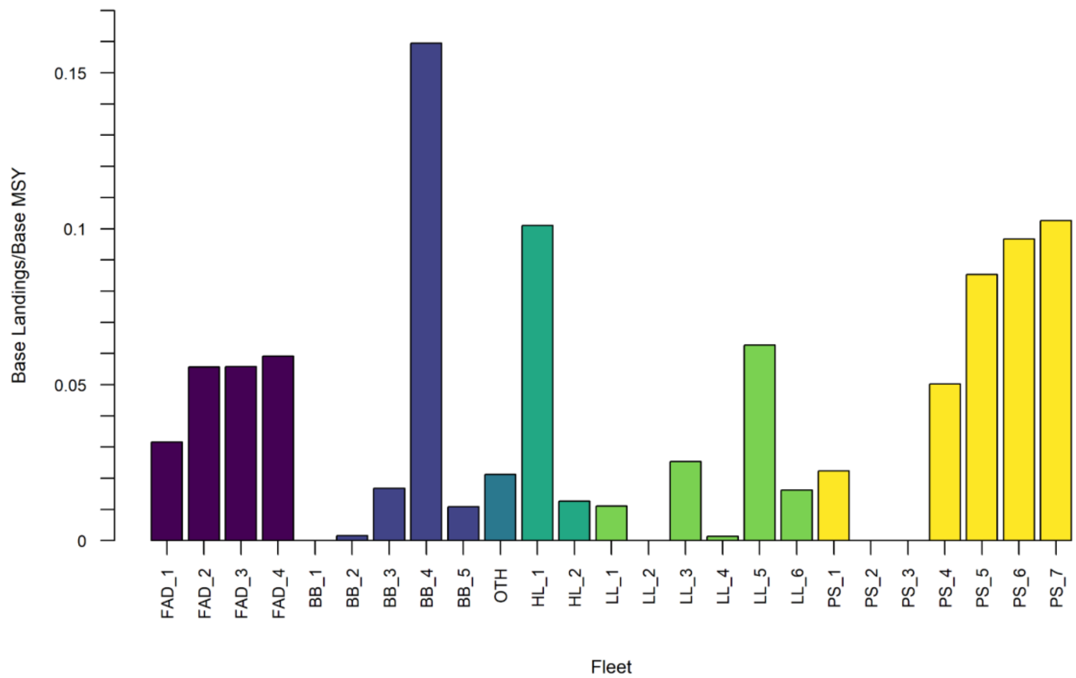

Figure 7. YFT fleet landings estimates as a proportion of MSY at equilibrium under base allocation assumptions of constant relative effort at the average of observed effort between 2017 and 2019 and a target MSY proxy of SSB equal to 30% of unfished SSB.

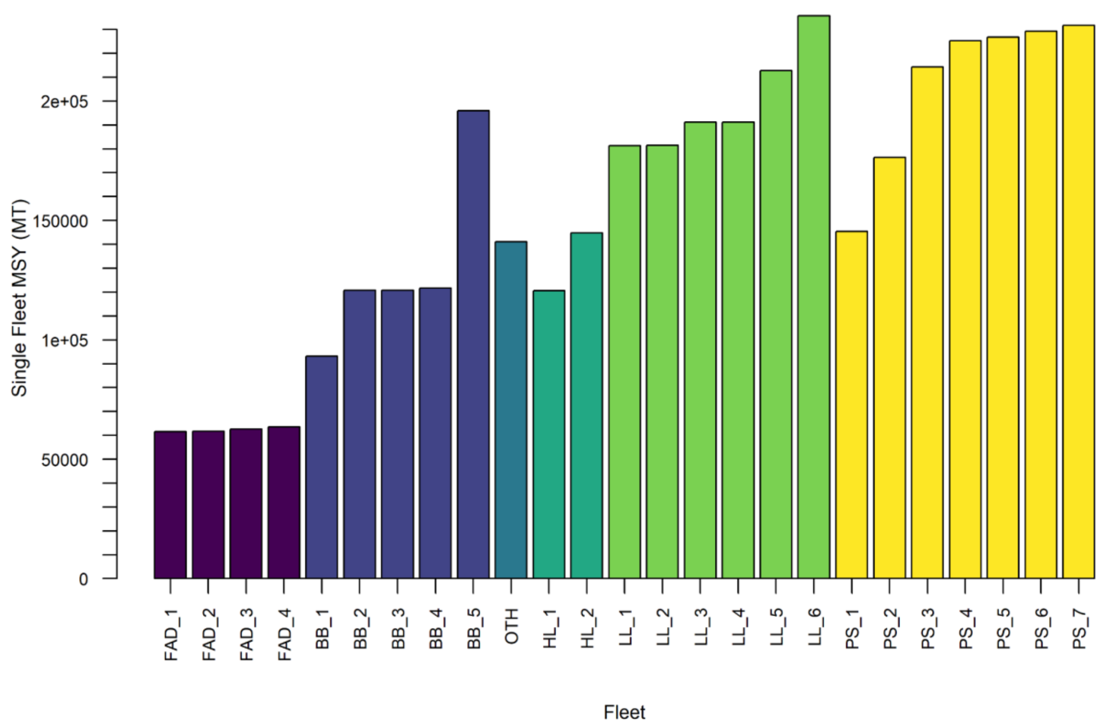

Figure 8. YFT equilibrium MSY estimates for each fleet assuming all fishing effort came from that single fleet. MSY proxy assumed of SSB equal to 30% of virgin SSB.

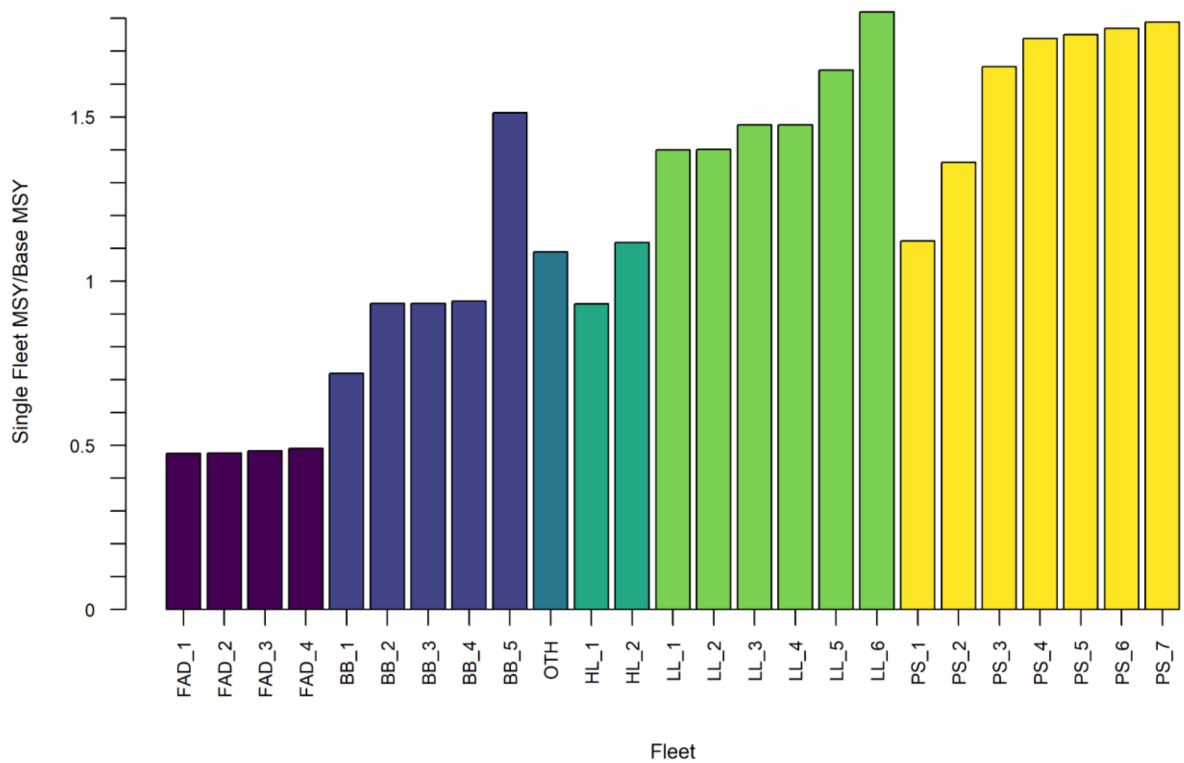

Figure 9. YFT equilibrium single fleet MSY estimates as a proportion of base scenario MSY. MSY proxy assumed of SSB equal to 30% of virgin SSB.

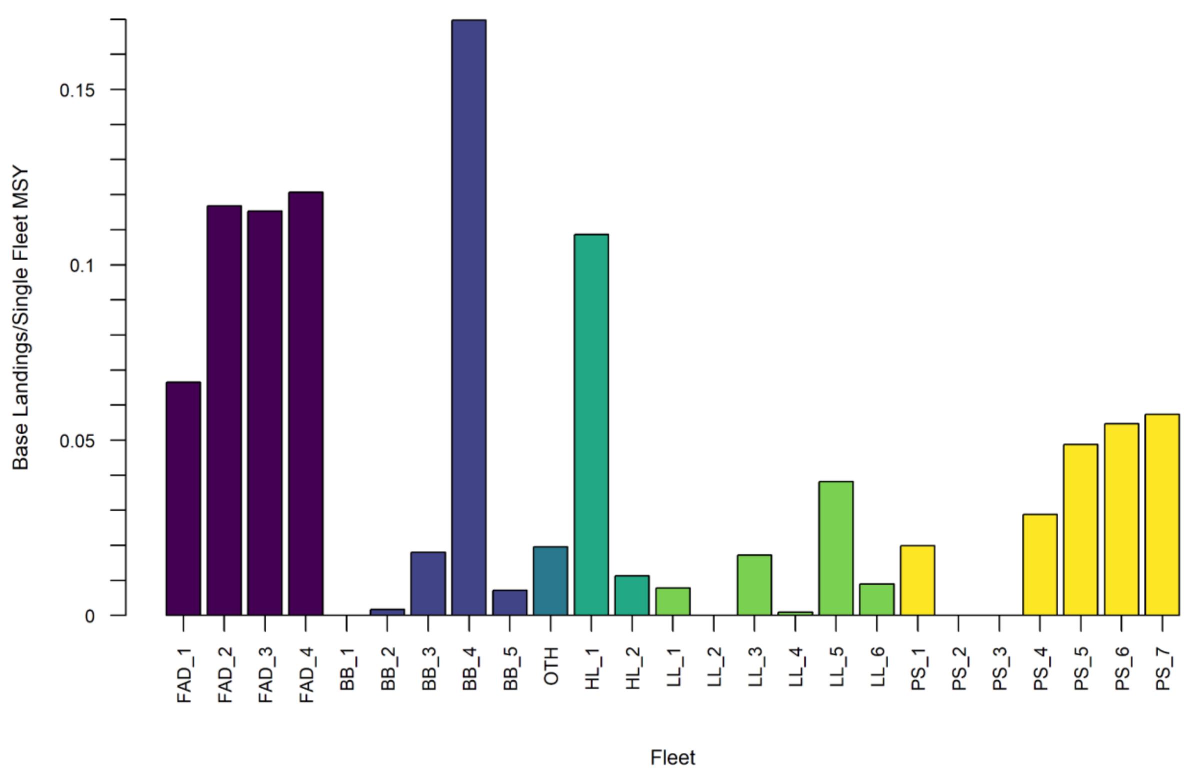

Figure 10. YFT base scenario equilibrium fleet landings as a proportion of single fleet MSY estimates.