Fisheries New Zealand

Tini a Tangaroa

Considering ecosystem aspects when setting management targets for New Zealand's fisheries: Insights from simulations and application to snapper and gurnard in FMA 7

New Zealand Fisheries Assessment Report 2025/40

P. Neubauer,
K. Kim,
T. Hill-Moana,
A. Langley

ISSN 1179-5352 (online)
ISBN 978-1-991380-80-7 (online)

August 2025

Te Kāwanatanga o Aotearoa
New Zealand Government

Requests for further copies should be directed to:

Fisheries Science Editor
Fisheries New Zealand
Ministry for Primary Industries
PO Box 2526
Wellington 6140
NEW ZEALAND

Email: Fisheries-Science.Editor@mpi.govt.nz
Telephone: 0800 00 83 33

This publication is also available on the Ministry for Primary Industries websites at:
http://www.mpi.govt.nz/news-and-resources/publications
http://fs.fish.govt.nz go to Document library/Research reports

Please cite this report as:

Neubauer, P.; Kim, K.; Hill-Moana, T.; Langley, A. (2025). Considering ecosystem aspects when setting management targets for New Zealand’s fisheries: Insights from simulations and application to snapper and gurnard in FMA 7. *New Zealand Fisheries Assessment Report 2025/40*. 62 p.

TABLE OF CONTENTS

PLAIN LANGUAGE SUMMARY

We studied the implications of managing fish stocks in New Zealand by considering the wider ecosystem, instead of only focusing on individual fish species. We examined snapper and gurnard fisheries in the Tasman Bay Golden Bay areas to see what happens when fishing targets are set higher than traditional levels. Using computer simulations, we tested different management approaches that would leave more fish in the ocean than current practices typically require.

We found that keeping fish populations at higher levels led to more and bigger fish. However, this approach also meant fishers could catch 20 to 45% fewer fish, potentially reducing economic returns. Whether higher fish population targets made economic sense depended strongly on fishing costs—expensive operations benefited because they needed less effort to catch quotas, whereas cheaper operations lost money due to smaller catches.

We showed that snapper and gurnard fisheries are closely connected, with over half of snapper catches happening when boats were declaring gurnard target fishing. Managing one species differently affects the other, showing that it is important to consider multiple species together.

Our study suggested that while keeping more fish in the ocean helps marine ecosystems stay productive and diverse, managers need to carefully balance environmental benefits against economic impacts on fishing communities.

EXECUTIVE SUMMARY

Neubauer, P.[1]; Kim, K.[1]; Hill-Moana, T.[1]; Langley, A.[2] (2025). Considering ecosystem aspects when setting management targets for New Zealand's fisheries: Insights from simulations and application to snapper and gurnard in FMA 7

***New Zealand Fisheries Assessment Report 2025/40*. 62 p.**

Fisheries management in Aotearoa/New Zealand has historically focused on single-species models, supplemented by considerations about changes in the ecosystem affecting stocks, as well as bycatch and habitat impact considerations. The present project explored the incorporation of ecosystem considerations into fisheries management for single species in New Zealan's fisheries, with a case-study focusing on snapper (SNA; *Pagrus auratus*) and gurnard (GUR; *Cheliodonichthys kumu*) in the Tasman Bay Golden Bay region (Fisheries Management area (FMA) 7). Using simulation models and empirical analyses, we evaluated implications of setting management targets above traditional Maximum Sustainable Yield (SSB_{MSY}) proxies, and utilising dynamic reference points to account for ecosystem dynamics. For dynamic reference points, we explored the utility of varying target reference points, while maintaining fixed limit reference points.

Two simulation models were developed: a single-species framework evaluating management at or above default targets (40%, 55%, and 70% of unfished spawning stock biomass, SSB_0) and a multispecies case study for FMA 7 focusing on higher catch limits for snapper (SNA 7) and the indirect effects of setting higher snapper catch limits for gurnard fishery performance. Key performance metrics across simulations included catch, catch-per-unit-effort (CPUE), stock status, economic value (Net Present Value), and age/length composition of stocks. Fishing mortality-based harvest control rules were applied in all scenarios.

Simulations showed significant trade-offs in managing stocks above traditional SSB_{MSY} targets. Higher targets (e.g., 55% and 70% of SSB_0) resulted in improved CPUE and increased numbers of larger and older fish, reflecting potential ecosystem and conservation benefits. However, catches decreased by 20% to 45% at these higher targets, potentially impacting economic returns. The economic performance of higher targets depended on operational costs, with high-cost scenarios benefiting from higher biomass levels requiring lower levels of effort to catch the available quota, whereas relatively low-cost fisheries had diminished profitability due to the lower catches associated with higher biomass targets.

While dynamic target reference points allowed for additional responsiveness to environmental changes (e.g., recruitment shifts) over the application of a static harvest control rule, our simulations showed little actual benefit in adopting dynamic targets while maintaining static limit reference points in view of regime shifts. For stocks with declining productivity, under static limit reference points, a higher average catch than under static target reference points was balanced by periodic reductions in catch due to breaching limit reference points, necessitating more frequent reductions in catch to balance higher average catches. In contrast, for stocks with increasing productivity, dynamic and fixed targets resulted in comparable outcomes, as the simulated harvest control rule effectively adjusted fishing mortality to reflect higher stock biomass regardless of the dynamic nature of the target reference point.

The FMA 7 multispecies case study revealed that recent high recruitment for snapper and gurnard has moved biomass above SSB_{MSY}. Projecting stock dynamics under higher targets highlighted notable differences in response times and length compositions, with snapper showing more substantial increases in larger fish numbers at higher targets. Economic outcomes for both species reflected broader trends, with low-cost fisheries benefiting from lower biomass targets, while fisheries with higher costs benefit from increased CPUE under higher biomass targets.

[1]Dragonfly Data Science, Wellington, New Zealand.
[2]Trophia Ltd., Nelson, New Zealand.

Balancing ecological and economic outcomes requires nuanced approaches. Higher biomass targets enhance ecosystem resilience and conservation outcomes but reduce short-term catch volumes. In a multispecies management context, management decisions for any single species will impact on associated fisheries. Our multispecies characterisation focused on the spatial and seasonal overlap of species in Tasman Bay Golden Bay, with a focus on overlap of snapper and gurnard. Snapper was found more frequently in shallower waters during summer, while gurnard was more evenly distributed year-round. Nevertheless, the multispecies characterisation identified significant overlaps in snapper and gurnard fisheries. Approximately 58% of snapper catch has been associated with gurnard-targeted tows in recent years, highlighting the interdependence of these stocks. Managing snapper at higher targets would likely reduce gurnard catches, but increase CPUE and biomass for both species.

Incorporating ecosystem considerations into management targets can offer tangible benefits for stock sustainability and biodiversity conservation (e.g., maintaining a more diverse age structure, and lower effort leading to reduced indirect impacts), but requires careful trade-off analyses in terms of its potential socio-economic impacts on the fisheries sector. Given the difficulty of predicting, quantitatively, the outcome of these single-species management decisions in a multispecies context, multispecies characterisations such as provided for this project can help establish scenarios based on current fishing practice, which then can be discussed with stakeholders, and used to guide management decisions in an ecosystem context.

1. INTRODUCTION

Considering ecosystem effects when managing fisheries is an increasingly important focus for fisheries managers worldwide. It is well-known that fisheries have a non-negligible impact on marine ecosystems (e.g., Jennings & Kaiser 1998). Conversely, fisheries are embedded in ecosystems that change continuously, often determing regime-like behaviours that can lead to new states of productivity in fish species (e.g., King et al. 2015). Fisheries affect ecosystems, and ecosystems affect fisheries. Consideration of the complex interplay between fisheries and ecosystems in fisheries management has been slow, in part due to the complexity of explicitly describing multispecies and ecosystem dynamics with models that are deemed suitable for tactical management.

Arguments have been put forward to use multispecies and ecosystem models for tactical fisheries management (e.g., Craig & Link 2023), and to use multispecies reference points to reflect ecological interactions (Fogarty 2014, Moffitt et al. 2016). New Zealand has, to date, opted for an approach that combines single-species fisheries management with management of bycatch, habitat impacts, and other ecosystem effects as considerations when applying single-species management (Cryer et al. 2016).

Extending beyond the present system of qualitative incorporation of ecosystem effects into fisheries management in New Zealand would require an explicit acknowledgement of these effects in the management objectives and targets. An explicit application of ecosystem considerations in fisheries management will, therefore, require a quantitative understanding of trade-offs for single- and multispecies fisheries, possibly supported by operationalised multispecies models (e.g., Plagányi et al. 2014, Townsend et al. 2019, Craig & Link 2023). To maximise multispecies yield in an ecosystem context, for example, typically involves reducing fishing pressure on key components of the ecosystem (e.g., keystone species such as key prey species) to maintain production of other species in the ecosystem (Walters et al. 2005). In contrast, aiming to maintain all species at or above target reference points in a multispecies context may forgo overall ecosystem-level yield (Hilborn 2011), and reduce achievable yields for species of economic interest.

Challenges with changing abundance in multispecies fisheries are expected to increase as changing climate and weather lead to changes in productivity of certain components of fisheries, possibly at the expense of the productivity of other stocks. For example, recent increases in both snapper (*Pagrus auratus*) and gurnard (*Cheliodonichthys kumu*) abundance in Tasman Bay Golden Bay in New Zealand have led to difficulties for fishers trying to avoid catching snapper; the allowable catch of this species constrained overall effort in the fishery. In this context, managing snapper at a higher relative biomass level than required may lead to implied higher targets for other species, and constrain overall take and economic performance of the multispecies trawl fishery operating in Tasman Bay Golden Bay.

To provide guidance on some of the trade-offs to consider when incorporating ecosystem effects into fisheries management targets in New Zealand, the present study aimed to evaluate the performance of alternative fishery management targets. Specifically, we evaluated the trade-offs associated with i) managing a specific stock at a level above B_{MSY} in the context of single-species management and multispecies constraints and, ii) applying dynamic reference points that reflect a dynamic environment. While necessarily incomplete, the simulations developed within this project, and applications to the Tasman Bay Golden Bay inshore fisheries for snapper and gurnard, provide a starting point for considerations for particular stocks or ecosystems.

2. METHODS

The project was structured into two main components, using simulations and also empirical data to evaluate trade-offs in single-stock and multispecies fisheries management in the context of applying ecosystem considerations in single-species management targets.

First, idealised simulations were set up to evaluate single-stock aspects of managing stocks at or above the default MSY-proxy target biomass (i.e., 40% of SSB_0), and managing stock to dynamic target reference points (i.e. using dynamic SSB_0). These simulations were then evaluated in terms of catch, catch-per-unit-effort (CPUE), length and age compositions, and net-present value (i.e., an integrated measure of economic trade-offs).

Second, a case study was developed to highlight multispecies aspects of managing species to a higher target in FMA 7. To this end, we first developed a multispecies characterisation to inform management trade-offs in multispecies fisheries. A case study on snapper and gurnard in Fisheries Management Area (FMA) 7 was then set up to evaluate trade-offs between stocks when managing one stock (i.e., SNA 7) above the current default biomass limit, combining aspects of the simulations with rationale from the multispecies characterisation.

2.1 Simulation framework

A basic age-structured simulation model was developed (Appendix A) to illustrate potential trade-offs across a range of fisheries performance indicators under alternative targets and under dynamic versus static reference points. The model incorporated recruitment variability (σ_R = 0.4) and autocorrelation (ρ = 0.6). Randomness in the simulations was introduced by using Monte-Carlo draws from the distribution of recruitment variability, leading to 500 individual stock trajectories per scenario.

Initial depletion was set to the target spawning stock biomass (40% of SSB_0) for each scenario. The population was initialised in this state, assuming a population at equilibrium with the corresponding fishing mortality. To allow recruitment variability to influence simulations and performance indicators from the first year of the simulations, the simulations were then run for A_{mat} (age-at-maturity) years with fixed fishing mortality but variable recruitment before alternative management targets were implemented.

Two life history strategies were simulated: A moderately long-lived (Moderate; A_{max} = 20, h = 0.90, M = 0.20, where A_{max} is maximum age, h is the steepness of the stock-recruit relationship and M is natural mortality), and a long-lived (Long; A_{max} = 60, h = 0.85, M = 0.075) species. We ran the model for 20 or 70 years for moderate and long-lived species, respectively, to evaluate the long-term performance of any target or other fishing policy. Selectivity was assumed to be knife-edge at the age of maturity.

2.1.1 Defining alternative targets and management settings

The management targets were defined as a proportion of the unfished spawning stock biomass (SSB_0), with the default target set at 40% of SSB_0. We evaluated the performance of alternative targets, including 55% and 70% of SSB_0. For stocks to be maintained at this level, we applied a harvest control rule that adjusted fishing mortality based on the current stock status relative to the target biomass level (e.g., target biomass, soft limit, and hard limit; Figure 1). The target-20-10 rule reduces fishing mortality linearly between the target and 20% of unfished biomass, and a second linear reduction between 20 and 10%, where the intercept at 10% of SSB_0 is set to zero. The fishing mortality at 20% of SSB_0 is a parameter that can be set to provide for increased fishing opportunity above the soft limit, while restricting fishing more severely between the soft and hard limit. For the purpose of the simulations herein, this parameter was set to 2/3 of the fishing mortality at the target biomass level.

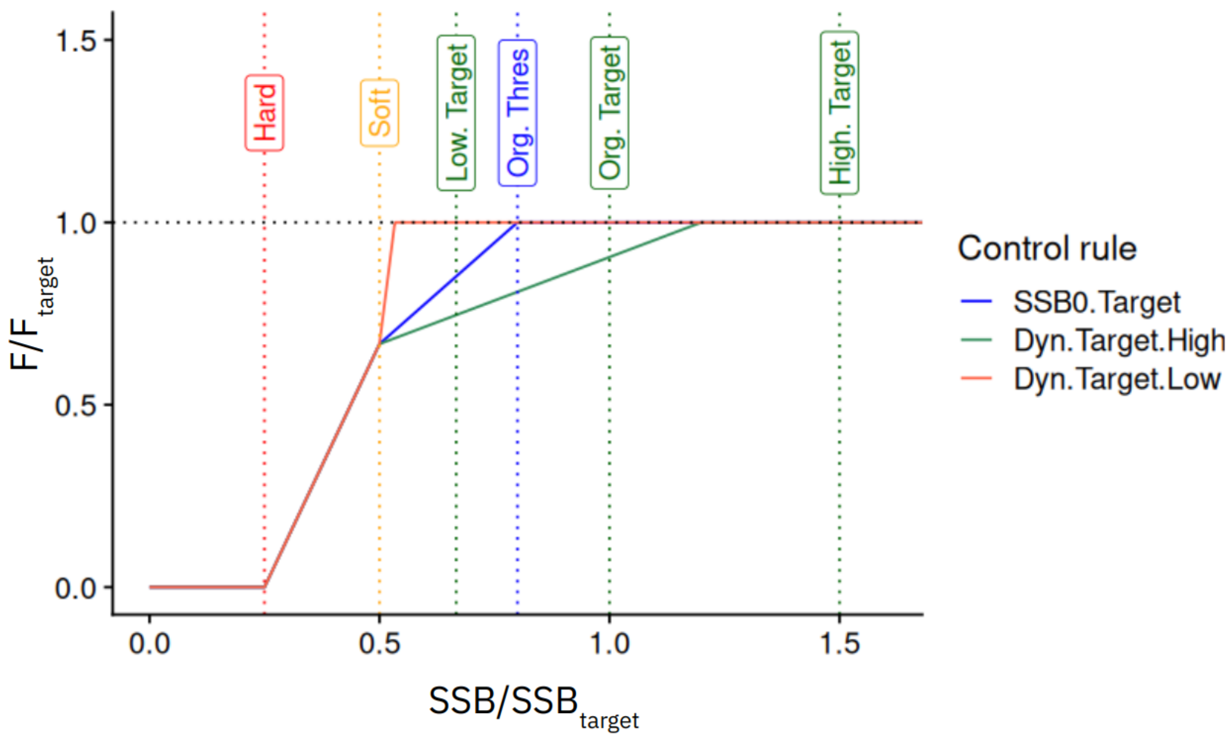


Figure 1: Harvest control rules used to manage fishing mortality levels in simulations; in terms of fishing mortality F relative to F_{target}, the fishing mortality leading to the target stock status, as a function of biomass relative to static (blue; Org. target and threshold) or dynamic biomass reference points (green and red lines for higher and lower targets, respectively). (Note, that the soft and hard limit reference points were set to remain static, i.e., referencing static SSB_0.)

2.1.2 Evaluating performance of dynamic target reference points

Recent changes in snapper and gurnard recruitment in FMA 7 (amongst other stocks) have led to discussions about the appropriateness of static target reference points for these fisheries. With dynamic targets, the target biomass level (SSB_0; treated as a dynamic quantity) was implemented using dynamic B_0 defined as

$$SSB_{F=0}(t) = \sum_{a>=1} R_{t-a} e^{-\sum_y^a M} \sum_{l=1}^{L} \varphi_a^L f_L w_L,$$

where R_{t-a} is the recruitment of the age a cohort in year $t-a$, M is the natural mortality rate, φ_a^L is length at age a, f_L is the proportion of the population at age L that is mature, and w_L is the weight at age L (Bessell-Browne et al. 2022). The target biomass level is then defined as a proportion of the dynamic $SSB_{F=0}(t)$, with the default target set at 40% of $SSB_{F=0}$(t).

To explore differences in performance between static and dynamic targets, we applied a common harvest control rule where only the target changed dynamically, but the soft and hard limits remained static.

We simulated three sets of stock trajectories to explore the utility of dynamic target reference points. Stocks were projected with either a 50% increase (or decrease) of recruitment in log-space, leading to a smooth but steady increase (decline) in $SSB_{F=0}(t)$ to reflect the increase (decrease) in recruitment.

We simulated three strategies for management for this set of simulations (Figure 2):

1. Reference points were treated as static,
2. $SSB_{F=0}(t)$ was calculated on an ongoing basis, or
3. $SSB_{F=0}(t)$ was used as reference point only when recruitment increased over a ten-year period, otherwise it remained fixed at the previous value.

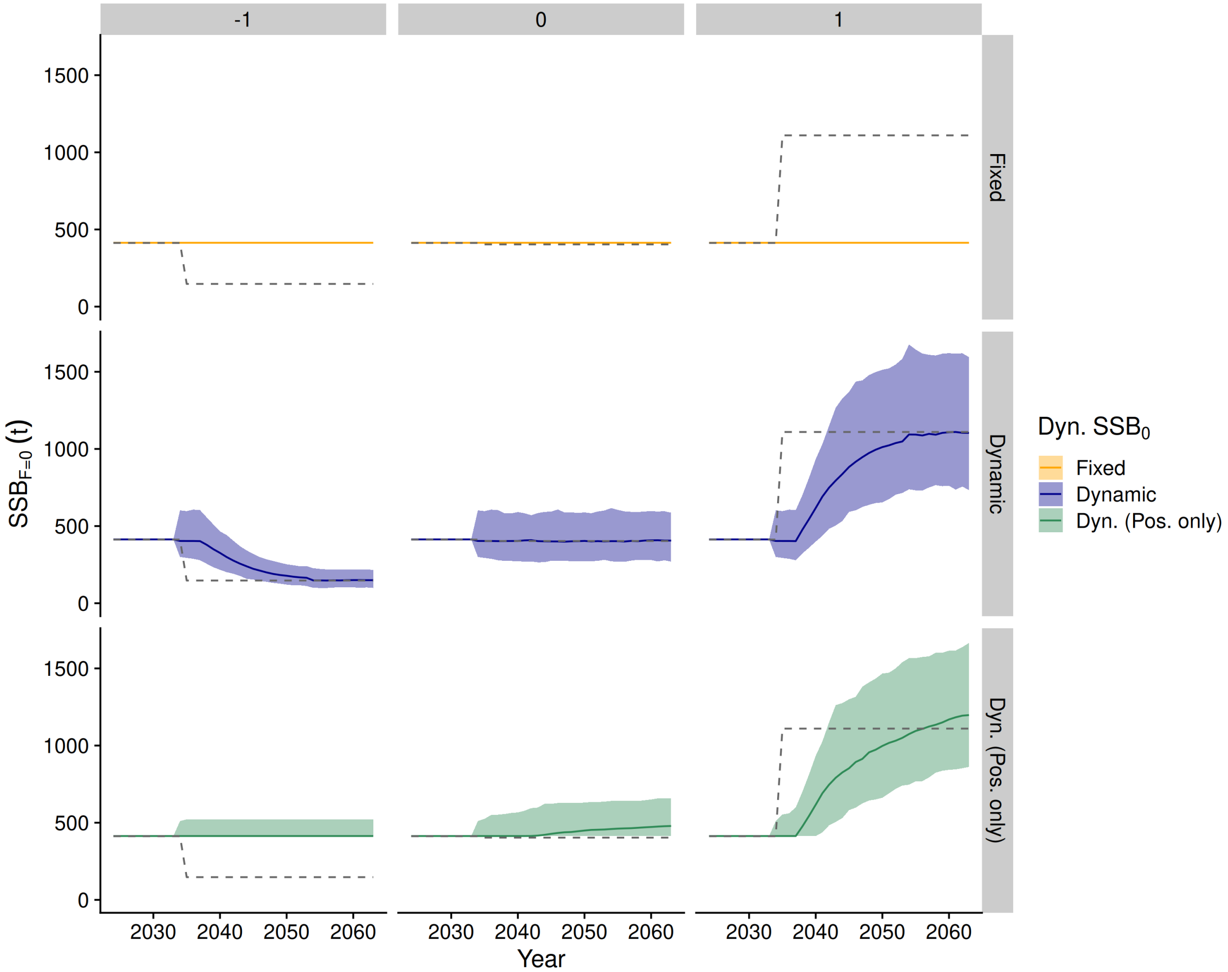


Figure 2: Simulated recruitment trend (dashed line) and reference point ($SSB_{F=0}(t)$; median and 95% variability across 500 simulation replicates) for stocks with declining (left column), stable (middle column), and increasing (right column) recruitment. Rows correspond to fixed reference points (top), dynamic reference points (middle) and dynamic reference points for positive recruitment trends only (bottom row). (Note, the reference point in the top row does not change as recruitment is assumed to be average for the purpose of defining the reference point.)

2.1.3 Performance metrics

We evaluated alternative management targets based on several performance metrics:

- Catch, CPUE and fishing mortality.
- Risk of falling below 10% of SSB_0.
- Ratio of old (or large) fish at alternative reference points, where large fish were defined as being larger than 80% of L_∞.
- Net present value (*NPV*) of the fishery during the rebuilding period, including the components of *NPV* expressed as relative costs and profit over time.

Net present value is an (idealised) way to integrate over time, and illustrate economic trade-offs. For this study, a simple version of NPV was used: Following Clark (1973), we assumed a (potentially non-linear) relationship between yield (Y) per unit effort (E) and available biomass:

$$Y(t)/E(t) = q^\beta B^{avail};$$

with a fixed cost k per unit of effort, so that the total cost $C(t) = k \cdot E(t)$. The non-linearity in CPUE is determined by the exponent β of the catchability(q), with $\beta < 1$ leading to hyper-stable CPUE, and $\beta > 1$ resulting in hyper-depleted CPUE (CPUE declines faster than abundance). Setting catch to a single unit and rearranging gives the cost per unit yield as a function of available biomass, with costs varying with biomass levels and non-linearity between CPUE and biomass (Figure 3).

$$C(t) = \frac{k}{q^\beta B^{avail}}.$$

We used a net present value framework to assess the economic performance of different rebuilding strategies:

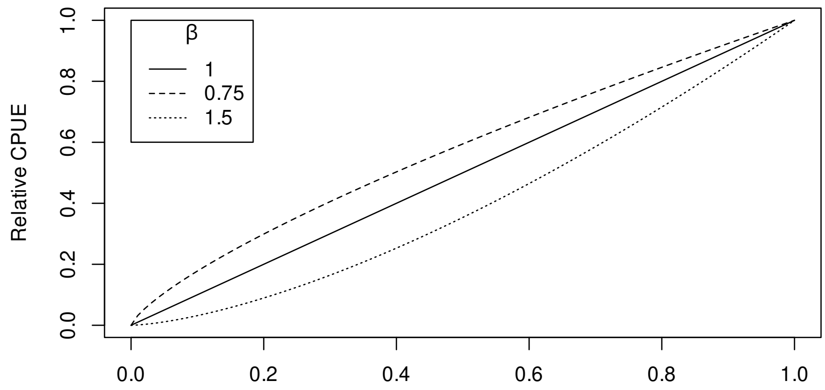
$$NPV = \sum_{t=0}^{T} \frac{Y_t(P - C(t))}{(1+\delta)^t},$$

where P is the price per unit yield, Y_t is the yield at time t, and δ is the discount rate. Substituting the above equation for cost gives the net present value as a function of available biomass:

$$NPV = \sum_{t=0}^{T} \frac{Y_t(P - \frac{k}{q^\beta B^{avail}})}{(1+\delta)^t}.$$

We considered various scenarios with different cost structures and discount rates:

- CPUE hyperstability parameter (β): 0.5, 1.0, 1.5.
- Unit effort cost (k): 0.05, 0.1, 0.2.
- Discount rates: Constant (3%, 6%) and declining (20% to 3%).



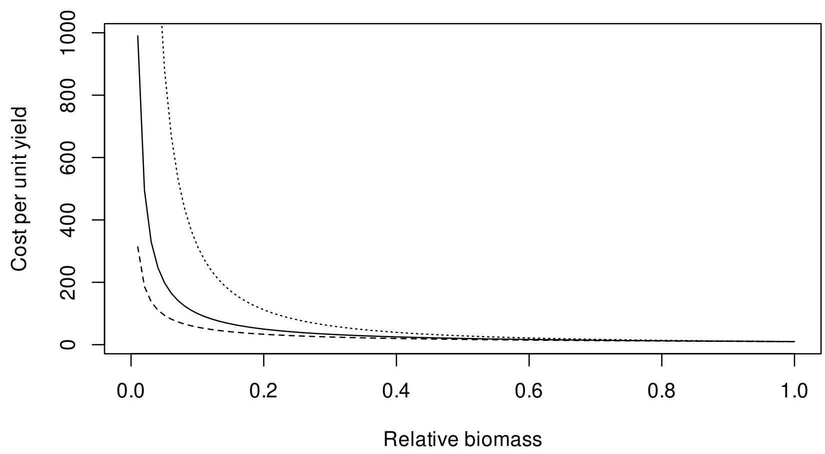


Figure 3: Relative catch-per-unit-effort (CPUE) and cost per unit yield at different levels of available biomass and levels of hyperstability (*β*).

A declining discount rate aimed to reflect high initial costs of rebuilding policies (e.g., the socio-economic costs of reduced catch or fishery closures), while maintaining a long-term, inter-generational view (Arrow et al. 2013, Abelson & Dalton 2024).

2.2 Consequences of alternative management targets in a multispecies fishery: FMA 7 inshore bottom trawl case study

2.2.1 Snapper and gurnard in FMA 7: projecting trade-offs for managing individual stocks above SSB_{MSY}

Both recent SNA 7 and GUR 7 stock assessments found high recruitment in recent years, leading to increases in biomass above SSB_{MSY}. To explore trade-offs for managing individual stocks above B_{MSY}, we projected both recent stock assessments for SNA 7 (Langley 2024) and GUR 7 (Langley 2022) at fishing mortalities corresponding to long-term biomass of $0.55\times$ ($0.70\times$) SSB_0.

Recruitment was random but assumed to be at the long-term average level from the start of the projections (however, using recent recruitment instead led to similar outcomes). We then evaluated performance of the fisheries using the same indicators as for the simulations above. Both stocks were projected for 50 years, but snapper in particular was slow to revert from dynamics determined by recent good recruitment; we, therefore, evaluated performance from 2050 to 2074 for snapper in SNA 7, and from 2035 for gurnard in GUR 7.

2.2.2 Multispecies characterisation to inform management tradeoffs in multispecies fisheries

A multispecies characterisation was set up for trawl-caught species for Golden Bay Tasman Bay in FMA 7 (Statistical Areas 037 and 038). The characterisation dataset was defined as all trips with the primary method bottom trawl (or precision bottom trawl; PRB) in Statistical Areas 037 and 038 since 2008 (Trawl Catch Effort Return forms) to ensure that spatial data would be available for characterisation.

The characterisation concentrated on catches of species that made up at least 5% of recent (last 5 years) catch. All other catches were grouped into a group named "other" (OTH) to make patterns for species that dominate recent catches more obvious. Catches were then plotted by year across different strata, such as statistical area, target species, depth, season and spatially, with the aim of identifying areas of spatial overlap and differentiation in catch between stocks by season, depth, or other strata. It was expected that this analysis could provide the baseline methodology for multispecies characterisations more generally to identify potential consequences of management decisions in multispecies fisheries.

2.2.3 Snapper and gurnard in FMA 7: using models to evaluate tradeoffs for gurnard when setting higher targets for snapper

To extend past empirical identification of potential tradeoffs of management decisions in a multispecies fishery, we explored the consequence for gurnard fisheries of managing snapper in FMA 7 (SNA 7) at a target above SSB_{MSY}; we chose a target of 55% as an arbitrary reference in alignment with the more abstract simulations.

For gurnard, we first calculated the proportion of gurnard target catch that is associated with snapper catch. We found that nearly all gurnard catch (97%) was associated with some snapper bycatch, while 58% of total snapper catch came from gurnard target tows over the past 5 years. Assuming no change in catch rates for both species and no further possibility of avoidance, the product of these proportions (0.56) represents the impact of any reduction in snapper catch on gurnard: for a 56% overlap, a 10% reduction in snapper allowance would (approximately) equate to a 5.6% reduction in harvest rates for gurnard.

In reality, snapper catch rates may increase proportionally more than gurnard catch rates under a higher target, which would effectively lead to a further decrease in fishing effort required to catch snapper allowances (beyond that required by the reduced catch allowance at a higher target alone), leading to a larger reduction in gurnard catch compared with the 56% reduction relative to snapper (i.e., gurnard catch may need to decrease by more due to effort restrictions). We arbitrarily chose a gurnard reduction of 70% of snapper reductions to reflect such a scenario. We did not include a scenario in which gurnard catch is less affected due to potential avoidance or selectivity tweaks that may allow fishers to lower the proportion of gurnard bycatch under a higher snapper target.

3. RESULTS

3.1 Simulations

3.1.1 Examining the pros and cons of managing fish stocks above SSB_{MSY}

Although the applied harvest control rule managed to maintain the simulated stocks near the spawning stock targets (Figures 4 and 5), fishing mortality fluctuated due to the five-year timespan between assessments, and catch and status were, therefore, variable. Notably, for lower targets, the risk of the stock falling below the soft limit was higher for the stock with moderately long-lived life history—but the risk remained below 5% for the 40% target, and below 1% for higher targets (Figure 6).

For higher targets, we found a near 2:1 ratio of increase in CPUE relative to decreases in catch at higher targets (Figure 7). For example, for a 40% increase in CPUE at a target of 55% of SSB_0 relative to a target of 40% of SSB_0, catch declined by nearly 20% for both life histories.

Numbers at age and length were higher for older and larger fish (Figures 8 and 9), with up to $5\times$ $(10\times)$ the number of fish at the asymptotic size for a target of 55% (70%) of SSB_0 relative to the default target. However, as numbers at these ages and lengths are small overall, the abundance of large fish above 80% of asymptotic size increased by 25% (50%) for the long life history, and 54% (100%) for the moderate life history at a target of 55% (70%) of SSB_0, making up $\geq$10% of the population at higher targets, compared with 7% at 40% of SSB_0 (Table 1).

Economically (considering commercial target fisheries only), managing fisheries at higher targets depends strongly on cost (Figure 10). At low cost, the benefit of higher catch outweighs the improvements in CPUE and per-unit-yield profit that can be made at higher biomass (Figure 11). Nevertheless, at higher cost, a higher target allows for a higher total profit. The economic utility of higher targets (not factoring in risk) is, therefore, directly related to the cost of fishing operations.

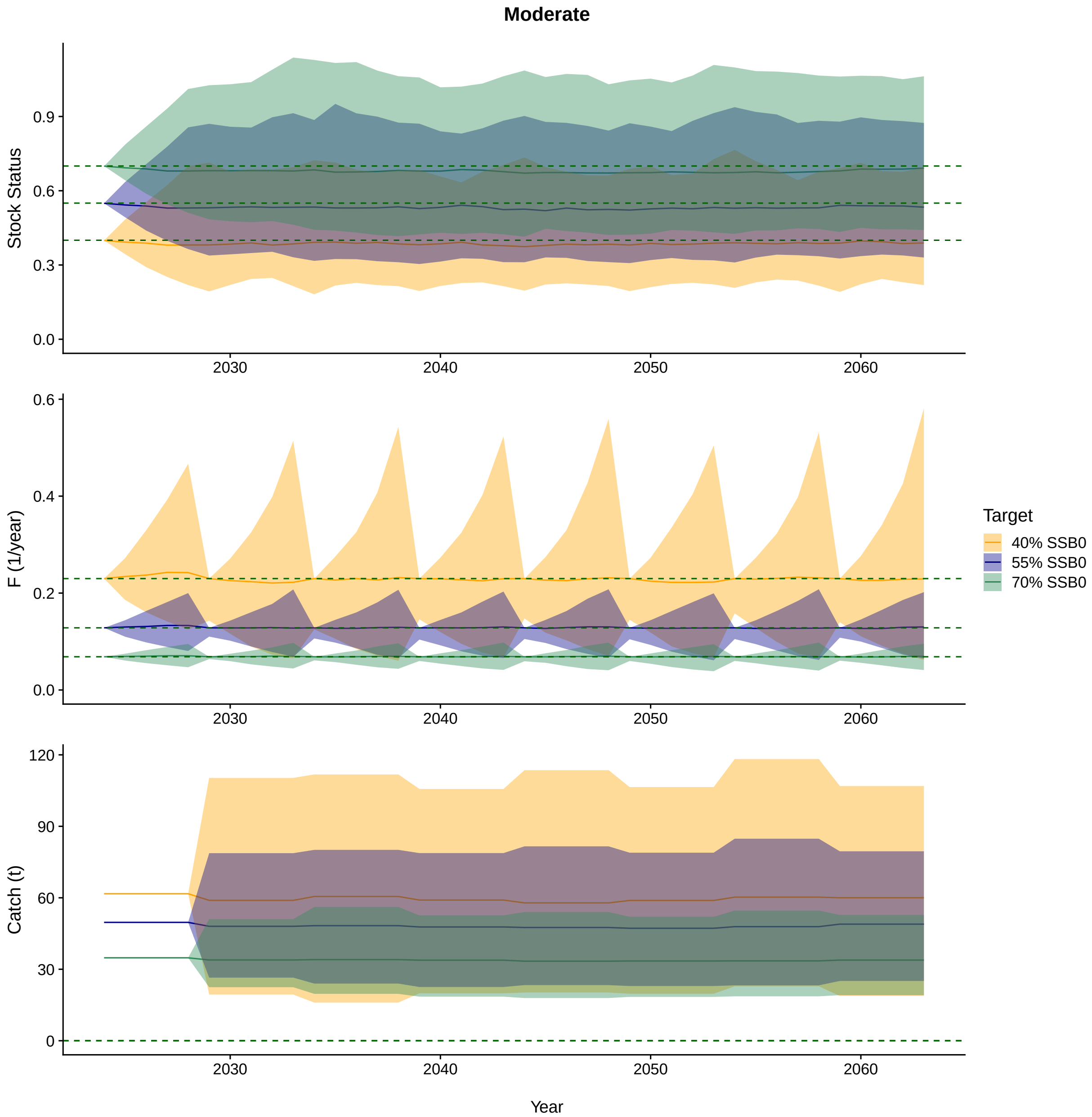


Figure 4: Stock status, fishing mortality (*F*) and catch over time for a moderately long-lived stock managed to three separate targets according to a target-20-10 control rule that aims to maintain the stock near the respective target. The harvest control rule was assumed to be applied every five years.

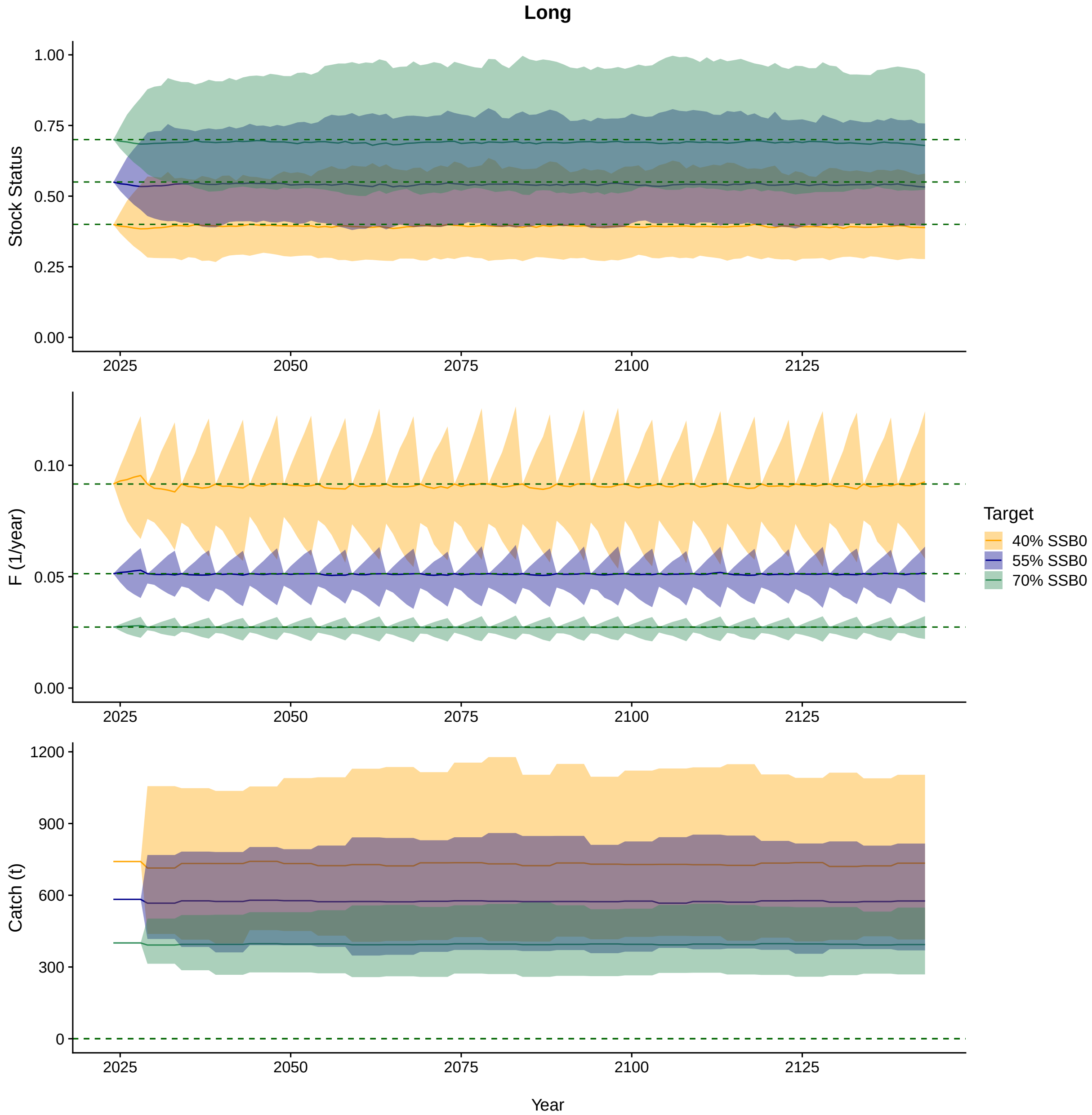


Figure 5: Stock status, fishing mortality (*F*) and catch over time for a long-lived stock managed to three separate targets according to a target-20-10 control rule that aims to maintain the stock near the respective target. The harvest control rule was assumed to be applied every five years.

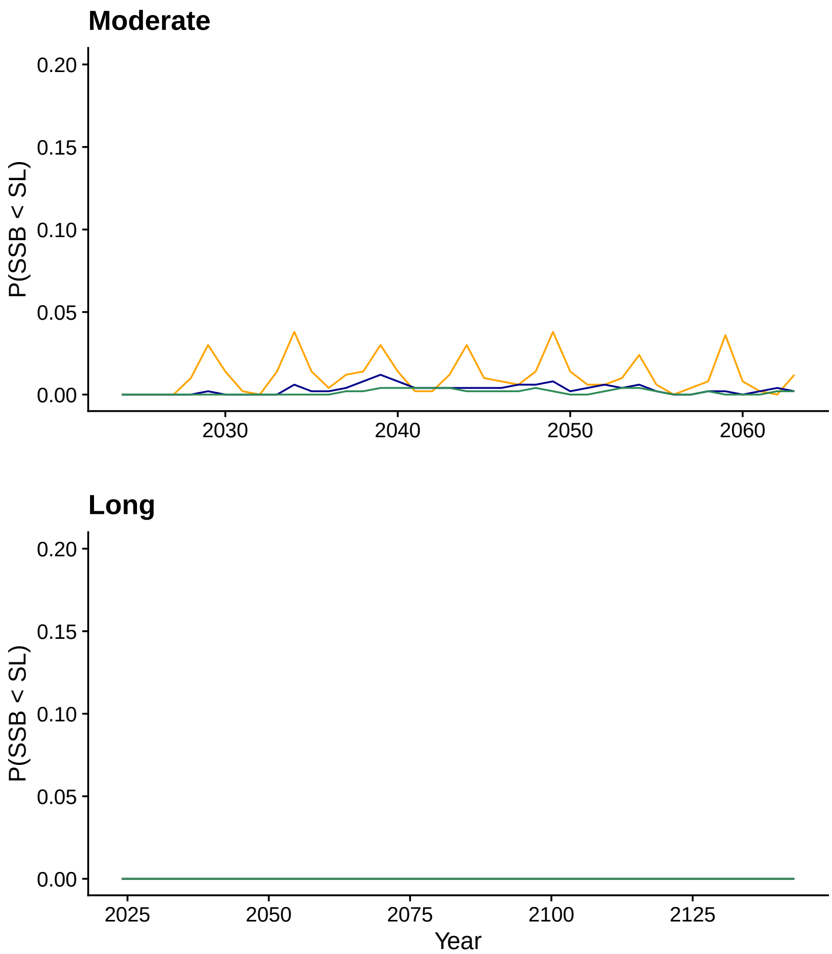


Figure 6: Probability of stocks of moderate (top) and long-lived (bottom) life histories falling below the soft limit (SL; defined as 20% of spawning stock biomass SSB_0).

Table 1: Numbers (N) for small and large fish (defined as $\geq 0.8L_\infty$) at alternative management targets (spawning stock biomass SSB_0) for alternative simulated life histories (Species).

Species	Size	Target	Mean N	Ratio
Long	Large	40% SSB_0	33 253.40	
Long	Large	55% SSB_0	41 576.66	1.250298
Long	Large	70% SSB_0	49 597.96	1.491516
Long	Small	40% SSB_0	440 669.81	
Long	Small	55% SSB_0	453 602.87	1.029349
Long	Small	70% SSB_0	461 440.72	1.047135
Moderate	Large	40% SSB_0	39 523.87	
Moderate	Large	55% SSB_0	61 147.50	1.547103
Moderate	Large	70% SSB_0	82 875.31	2.096842
Moderate	Small	40% SSB_0	598 188.77	
Moderate	Small	55% SSB_0	616 965.66	1.031390
Moderate	Small	70% SSB_0	628 411.76	1.050524

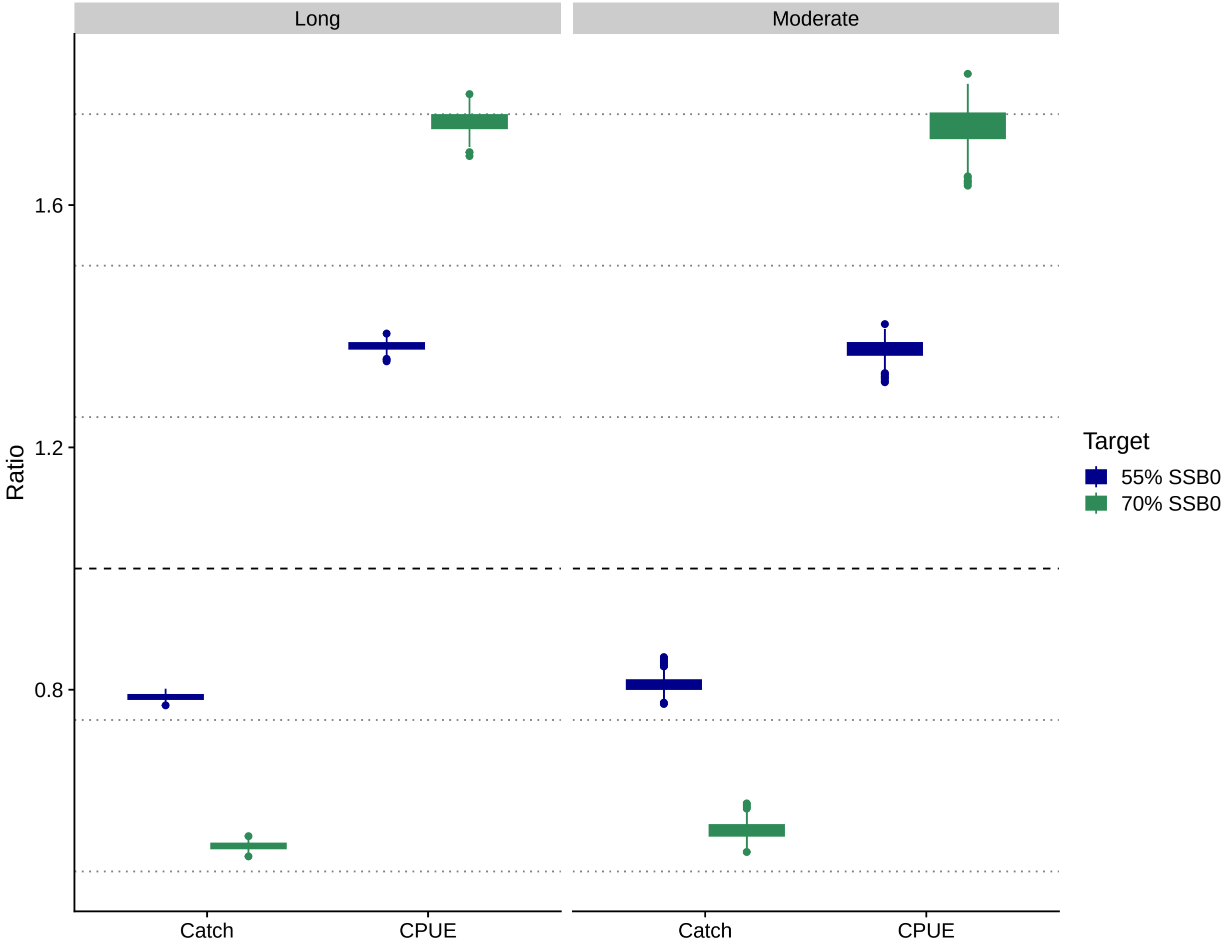


Figure 7: Ratio of catch-per-unit-effort (CPUE) and catch for management targets above B_{MSY} (achieved by applying a target-20-10 control rule) relative to fishing at the B_{MSY} proxy according to a 40-20-10 control rule. Horizontal dotted lines show 25% increments.

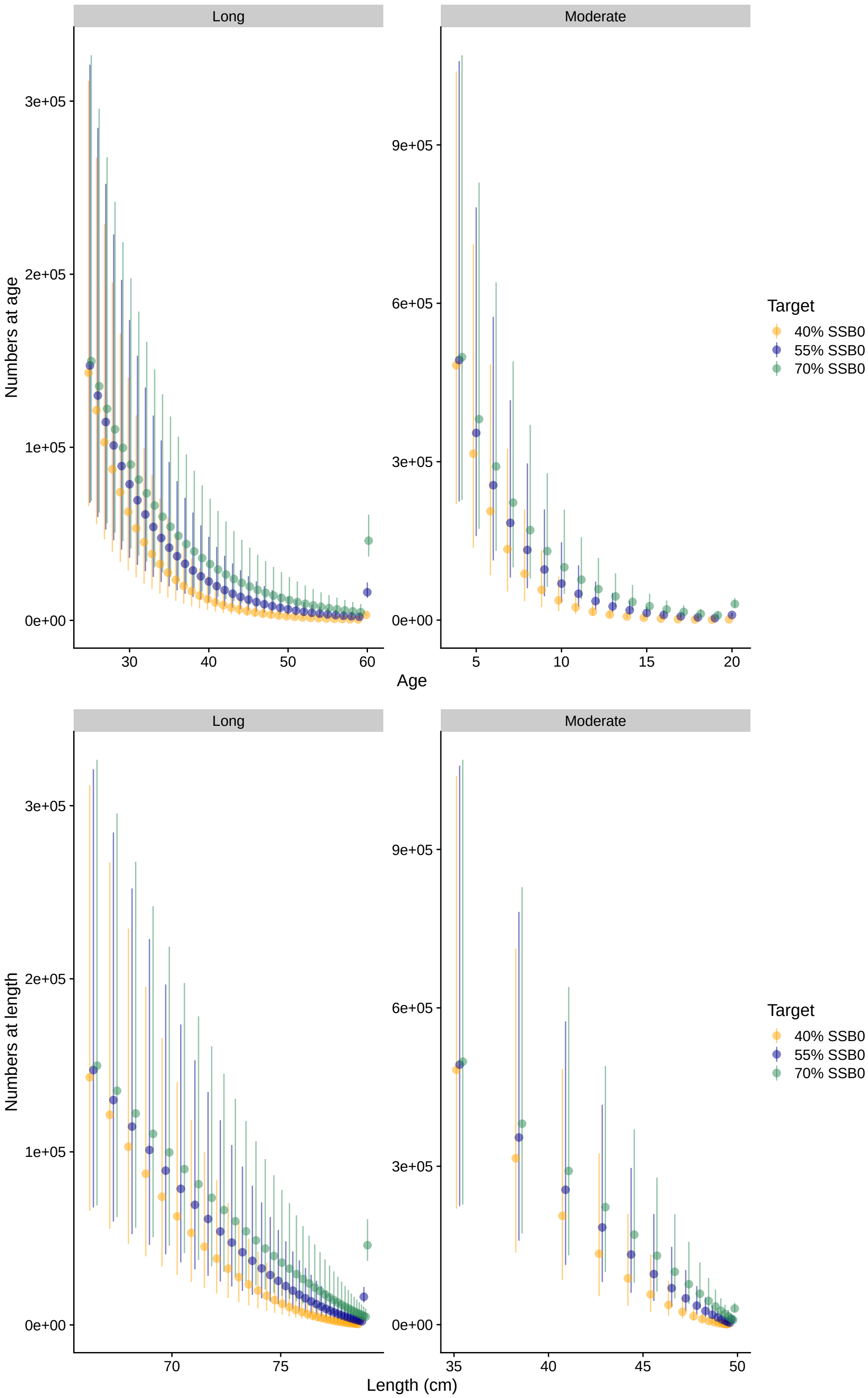


Figure 8: Average numbers at age (top row) and length (bottom row), for moderate (left column) and long-lived (right column) stocks managed to three separate targets according to a target-20-10 control rule that aims to maintain the stock near the respective target. The harvest control rule was assumed to be applied every five years.

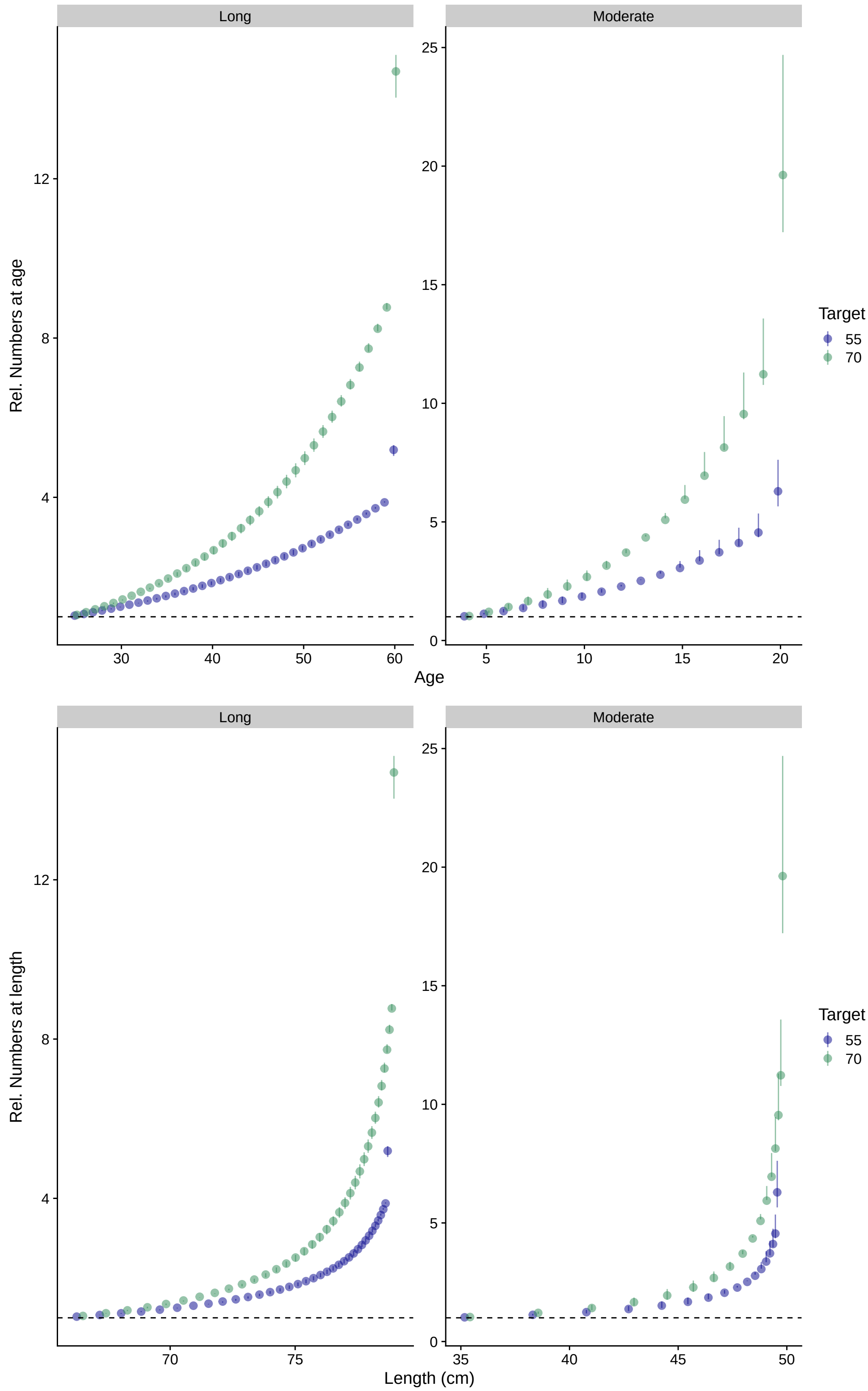


Figure 9: Relative numbers at age (top row) and length (bottom row), for moderate (left column) and long-lived (right column) stocks managed to targets above B_{MSY} (achieved by applying a target-20-10 control rule) relative to fishing at the B_{MSY} proxy according to a 40-20-10 control rule. The harvest control rule was assumed to be applied every five years.

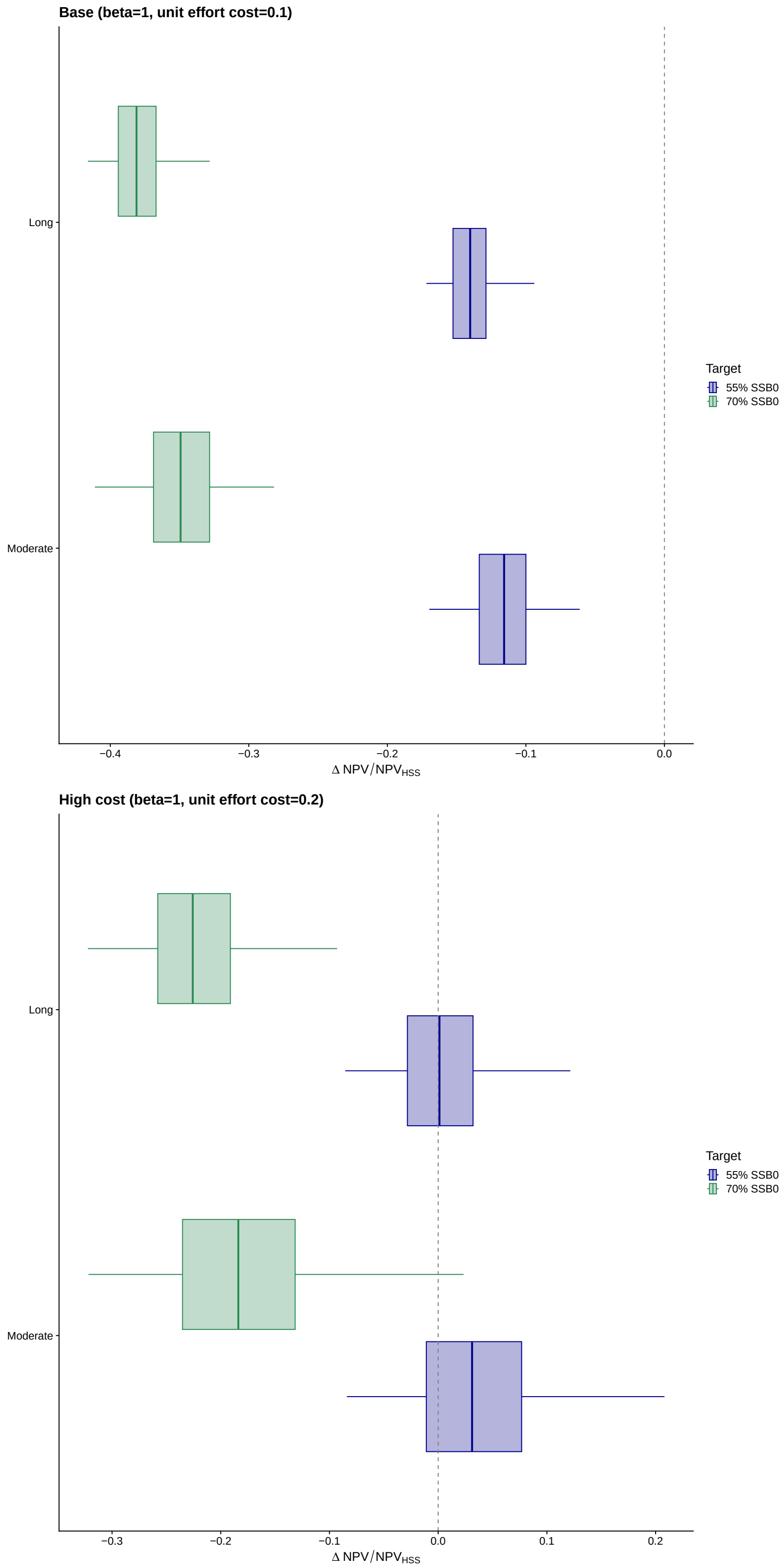


Figure 10: Relative difference in net present value (NPV) at base per-unit-effort cost (0.1; top) and high per-unit-effort cost (0.2; bottom) for moderate and long-lived stocks managed to targets above SSB_{MSY} (achieved by applying a target-20-10 control rule) relative to fishing at the SSB_{MSY} proxy according to a 40-20-10 control rule. The harvest control rule was assumed to be applied every five years.

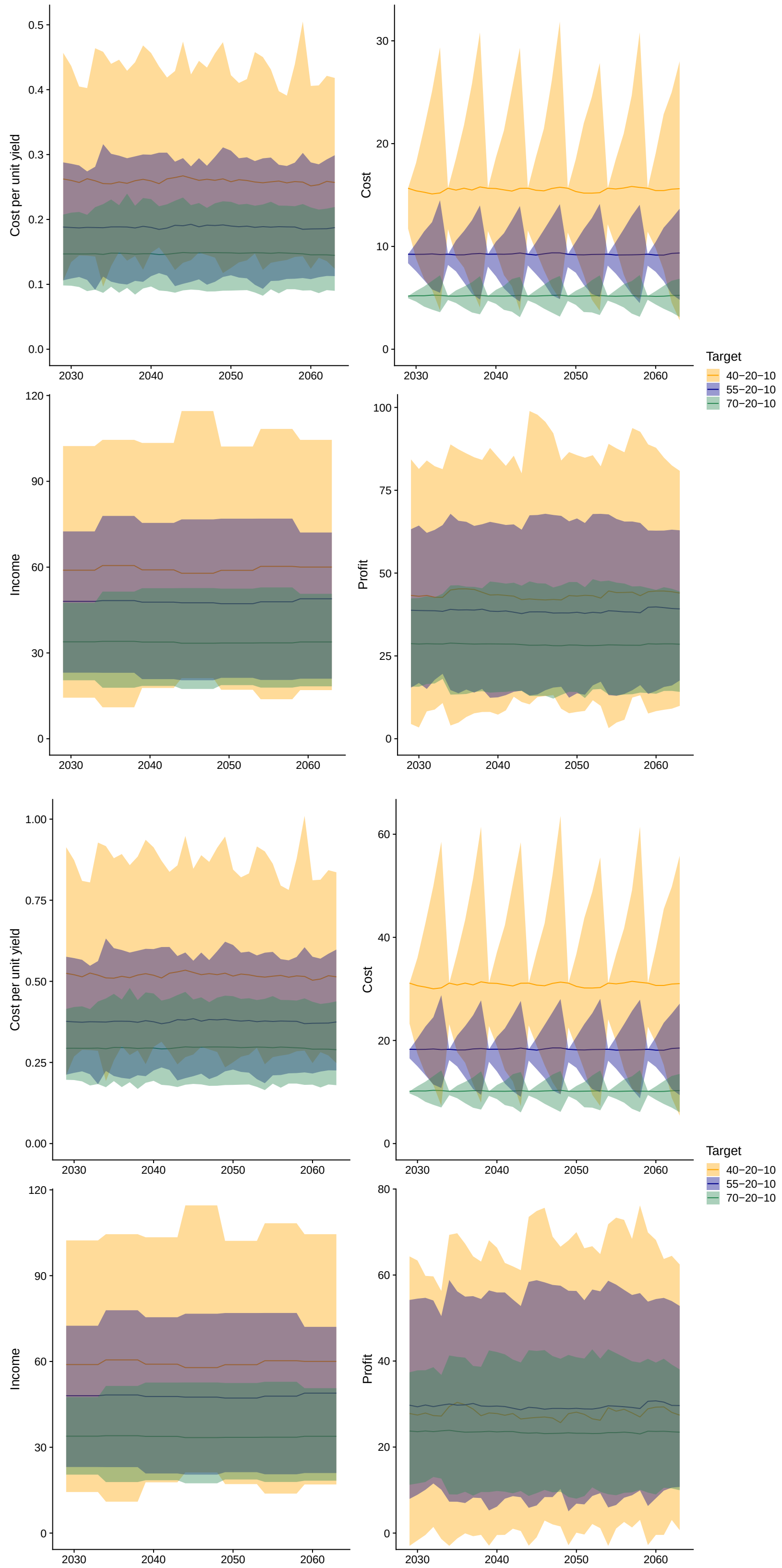


Figure 11: Cost per unit yield, total cost, income and profit over time at base per-unit-effort cost (0.1; top) and high per-unit-effort cost (0.2; bottom) for moderately long-lived stocks managed to three alternative targets (achieved by applying a target-20-10 control rule). The harvest control rule was assumed to be applied every five years.

3.1.2 Implications of using dynamic SSB_0 reference points

Allowing target reference points to vary led to transient changes in assigned stock status for population regime shifts (Figure 12, and Appendix B). After a transition period where the stock would be declared over- (under-) fished with respect to the target, stocks with negative (positive) regime shifts approached the new target under the application of the simulated harvest control rule. However, these differences in status were largely linked to the development of the underlying reference point (see Figure 2), and not of the spawning biomass itself (Figure 13).

The main difference between stocks managed using a dynamic target reference point and stocks managed with a fixed target reference point using an F-based control rule could be found with a declining productivity: the control rule will allow for a higher fishing mortality than under fixed reference points; however, given that the limit reference points were not dynamic, the stock often breached limit reference points, and the control rule reduced fishing mortality accordingly (Figure 14). Consequently, catch under this scenario was more variable, allowing at once for higher catch (Figures 15 and 16), but also periodic reductions in catch to rebuild the biomass above limit reference points. With fixed reference points, the stock cannot be rebuilt to the target despite lower F (the previous target becomes unattainable), and the stock remains over-fished despite low fishing mortality.

With increasing productivity, there was little difference between the different definitions of the target reference point in catch, CPUE, and age/size composition (Figure 17): under the simulated control rule, the same F is applied when the stock is at or above the target biomass. As the F directly references the available biomass, there is little benefit of a dynamic target over using fishing-mortality based management, as a control rule based on F already addresses changing productivity, and the potential economic benefits of dynamic reference points (allowing higher catch) with declining stocks are cancelled by a slightly lower economic value for stocks with increasing productivity (Figure 18).

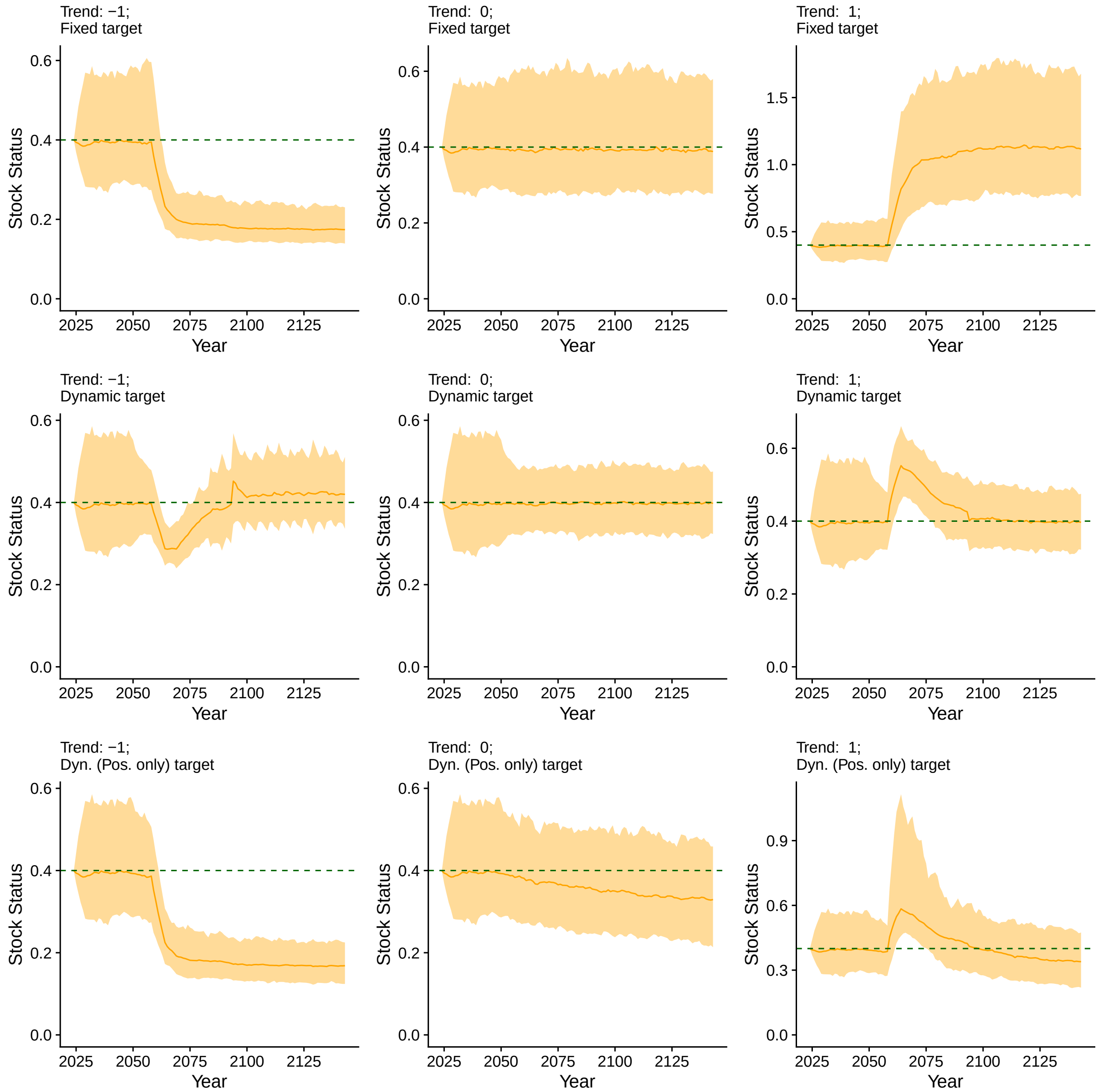


Figure 12: Stock status (median and 95% of simulated outcomes) for the long-lived simulated life history over time for stocks referenced against fixed, dynamic and positive only dynamic reference points (rows), for declining (-1), stable (0), and increasing (1) recruitment trends (columns).

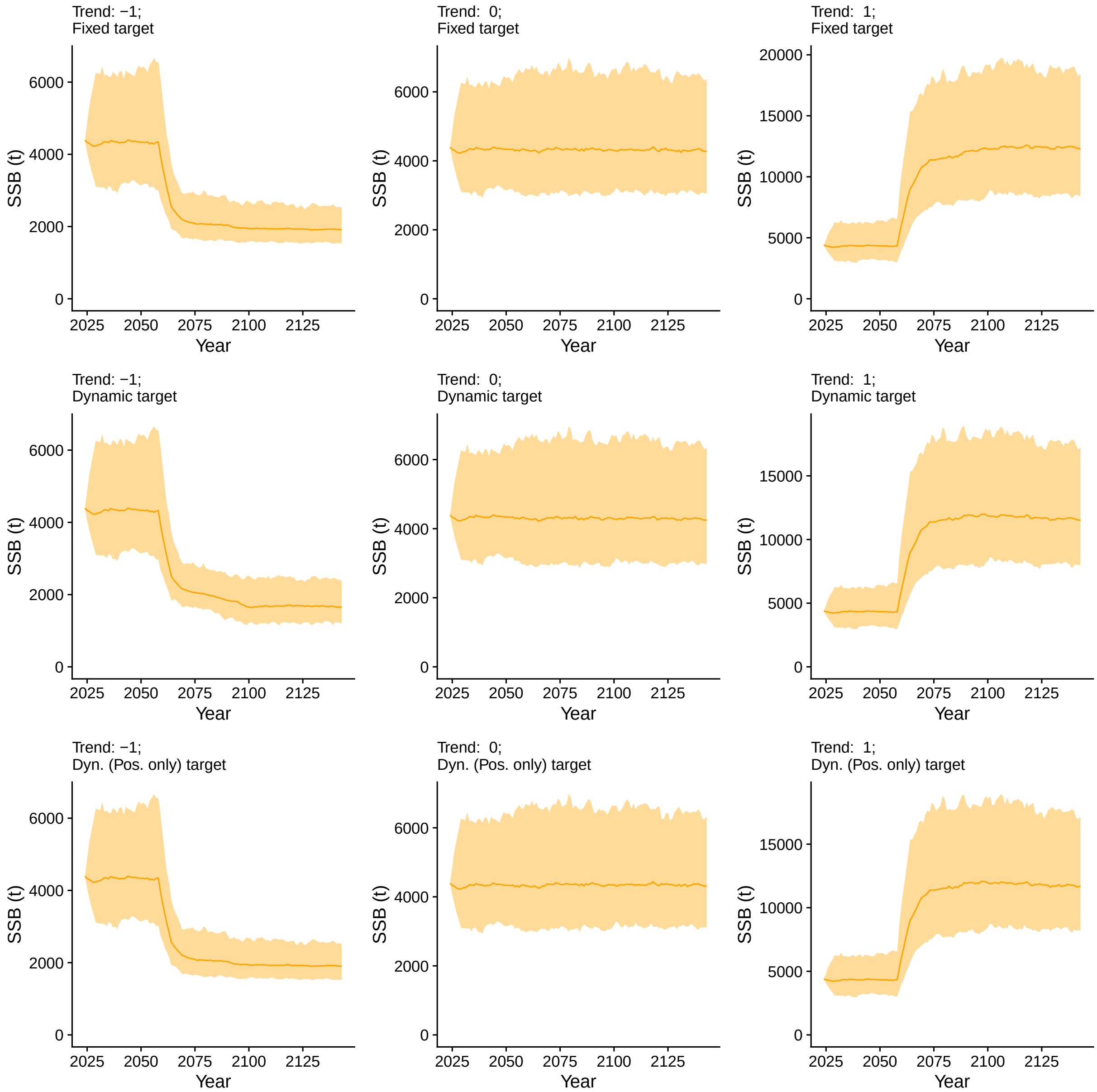


Figure 13: Spawning stock biomass (*SSB*; median and 95% of simulated outcomes) for the long-lived simulated life history over time for stocks referenced against fixed, dynamic and positive only dynamic reference points (rows), for declining (-1), stable (0), and increasing (1) recruitment trends (columns).

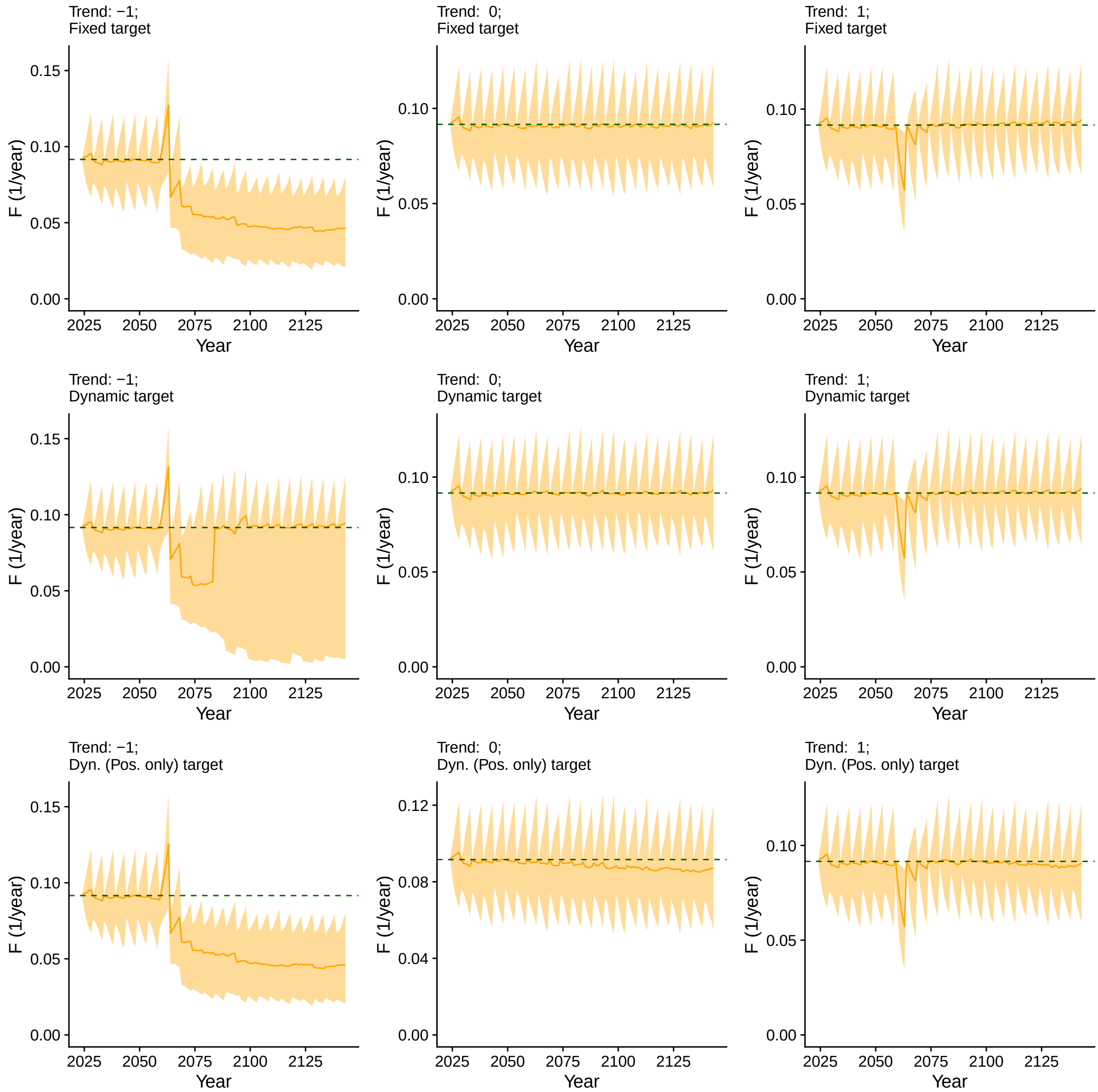


Figure 14: Fishing mortality (median and 95% of simulated outcomes) for the long-lived simulated life history over time for stocks referenced against fixed, dynamic and positive only dynamic reference points (rows), for declining (-1), stable (0), and increasing (1) recruitment trends (columns).

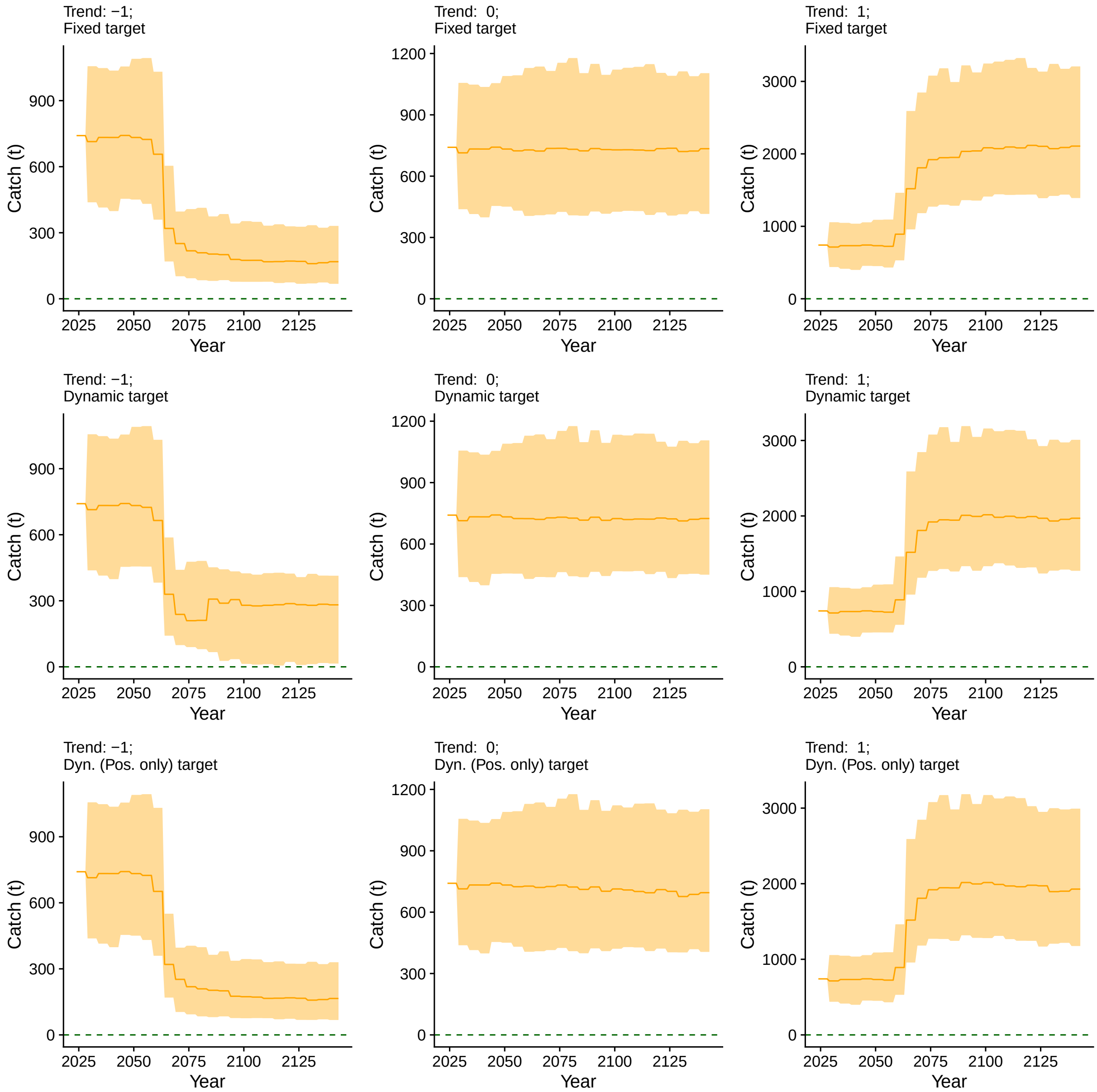


Figure 15: Catch (median and 95% of simulated outcomes) for the long-lived simulated life history over time for stocks referenced against fixed, dynamic and positive only dynamic reference points (rows), for declining (-1), stable (0), and increasing (1) recruitment trends (columns).

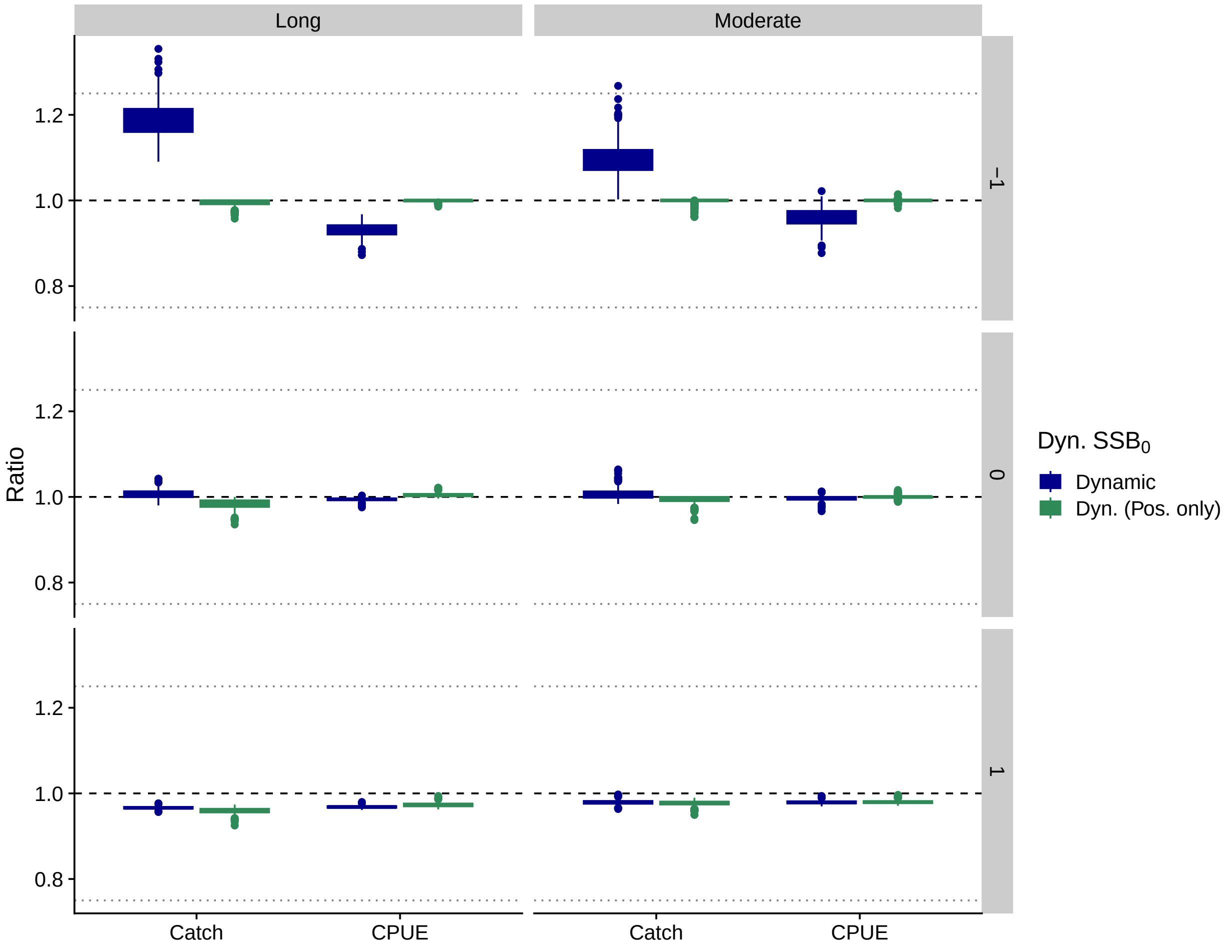


Figure 16: Catch and catch-per-unit-effort (CPUE) for simulated life-histories for stocks referenced against dynamic and positive only dynamic reference points, relative to management using fixed target reference points for declining (-1), stable (0), and increasing (1) recruitment trends (rows).

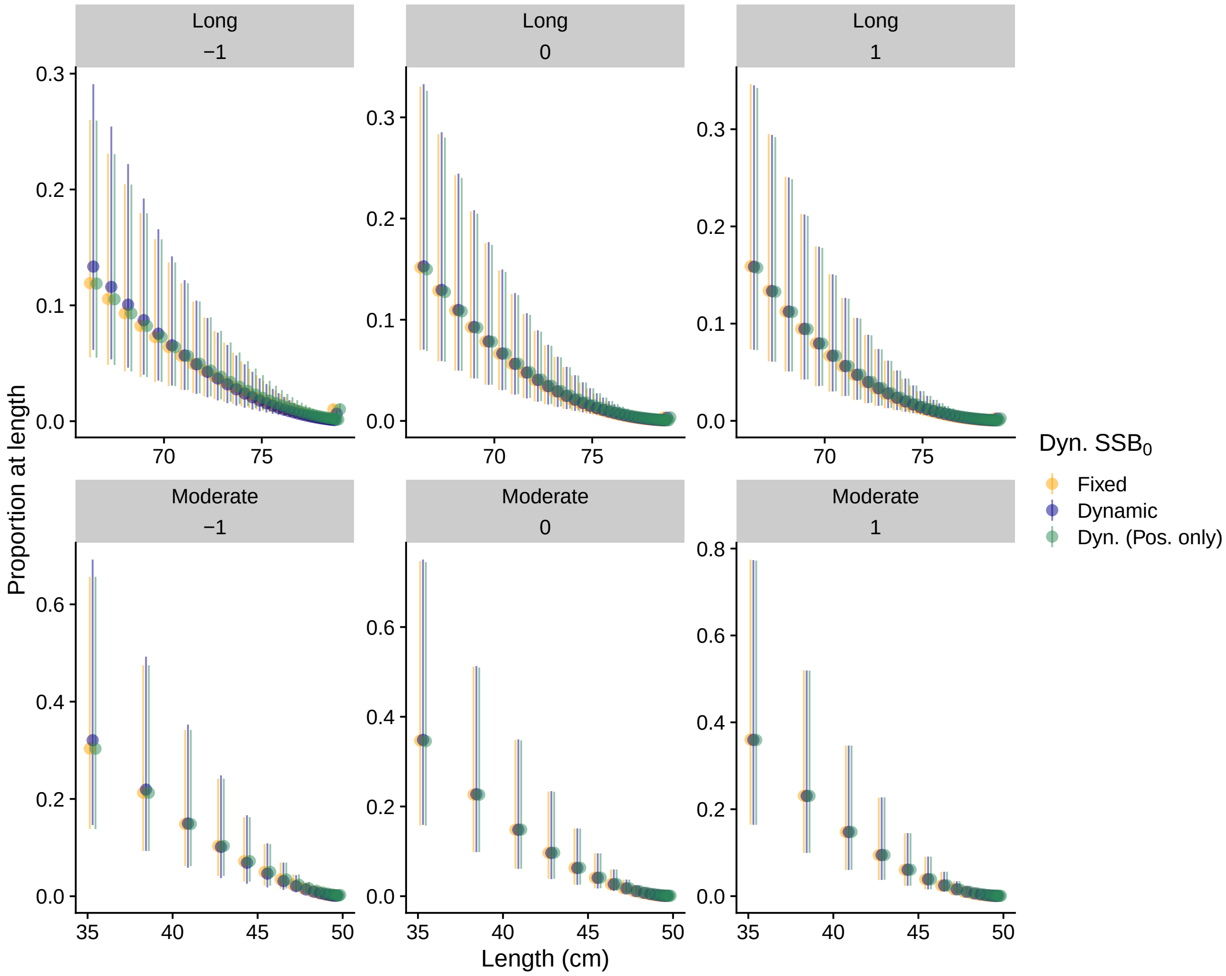
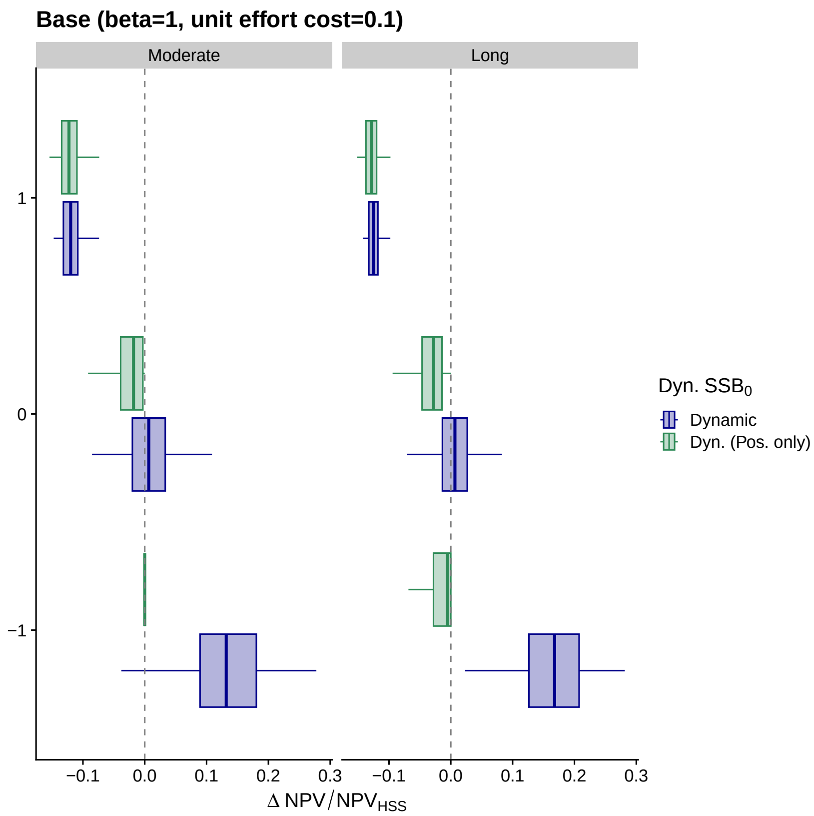


Figure 17: Relative numbers at length, for moderate and long-lived stocks for stocks referenced against dynamic and positive only dynamic reference points, relative to management using fixed target reference points for declining (-1), stable (0), and increasing (1) recruitment trends (rows).



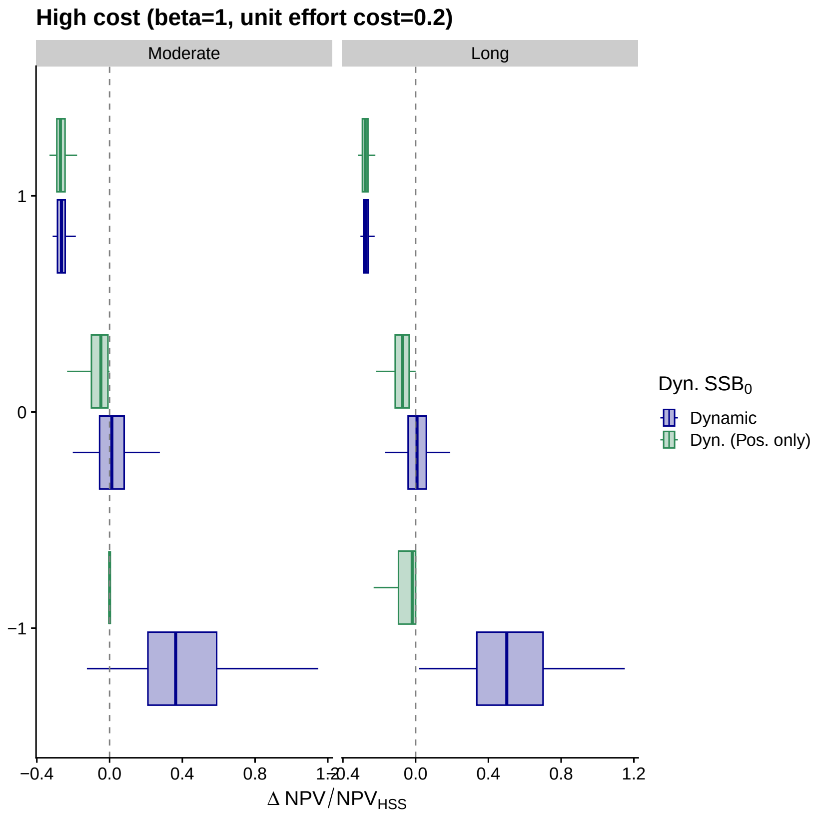


Figure 18: Relative numbers at length, for moderate and long-lived stocks for stocks referenced against dynamic and positive only dynamic reference points, relative to management using fixed target reference points for declining (-1), stable (0), and increasing (1) recruitment trends (rows).

3.2 FMA 7 case study

3.2.1 Single species considerations: managing SNA 7 and/or GUR 7 above SSB_{MSY}

Both the GUR 7 and SNA 7 stock projections were initially dominated by recent recruitment (Figure 19). For snapper, the transient dynamics persisted for about 25 years, the time that recent recruits become sufficiently low in abundance as to not contribute substantially to the spawning biomass.

Catch for snapper and gurnard was about 20% (45%) lower at a higher 55% (70%) SSB_0 target, while CPUE reflected the increased spawning biomass in both fisheries, albeit with a more substantial increase for gurnard (Figure 20). Although numbers at age and length appeared more responsive to changes in targets for snapper (Figure 21), the relative numbers at age (compared with a 40% target) showed a stronger response at large sizes and old ages for gurnard (Figure 22): the snapper length composition is more right-skewed even at a lower target, meaning more larger fish are present, whereas the gurnard distribution shows distinct modes at intermediate sizes. For gurnard, the largest differences are, therefore, in a part of the length distribution that represents few fish, whereas for snapper, the change affects a considerably larger number of fish, with up to 2× (3×) the number of large fish at a target of 55% (70%). As shown for simulations, the economic value of each target is closely linked to the cost structure of the fishery, with lower cost (or more hyper-stable CPUE) leading to better economic outcomes under the default target of 40% and vice versa (Figure 23).

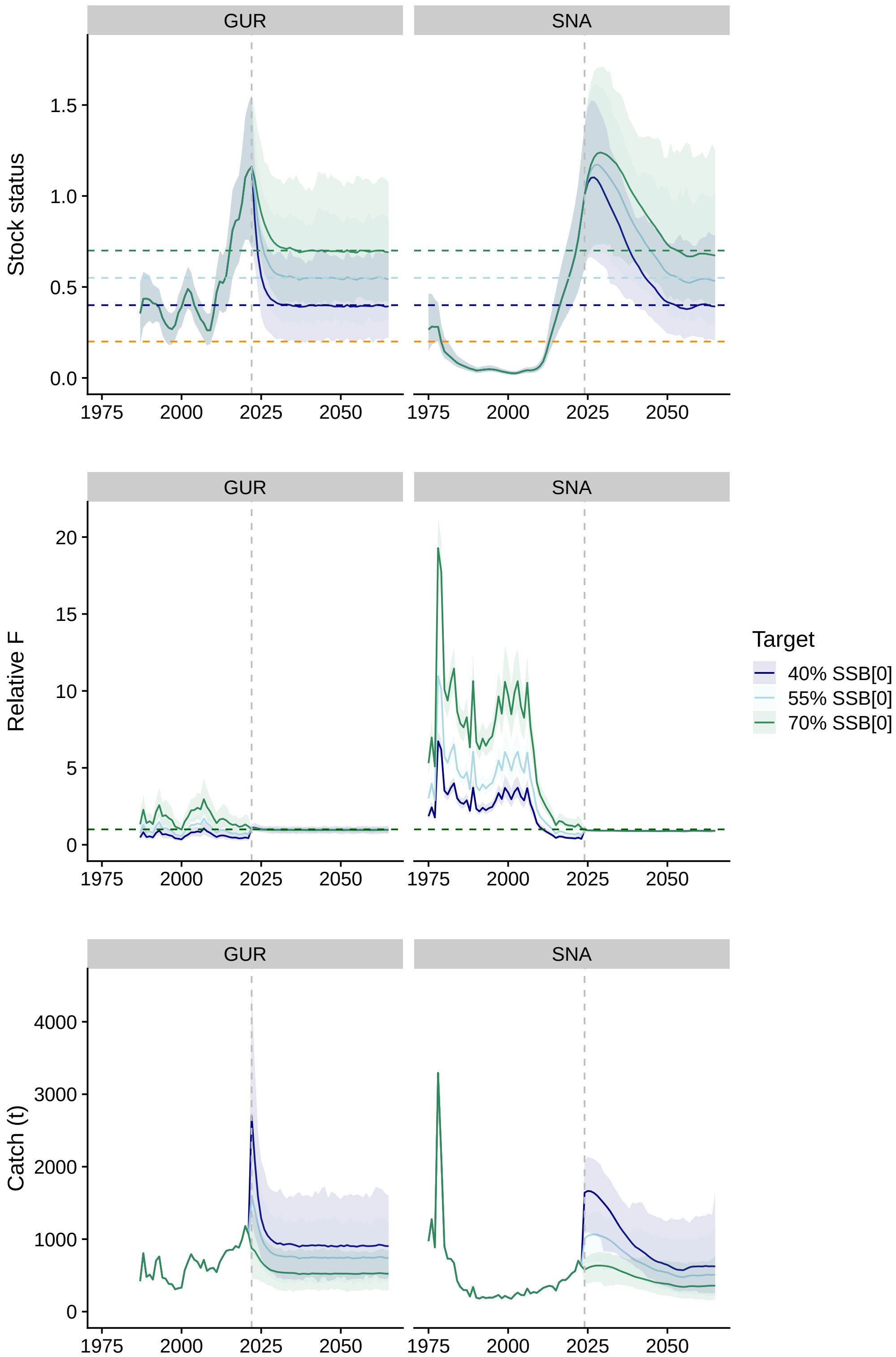


Figure 19: Trajectories (posterior median and 95% credible interval) for gurnard (GUR) and snapper (SNA) stock status, relative fishing mortality, and catch in FMA 7 under alternative target biomass levels, achieved by applying annual target fishing mortality levels corresponding to each biomass target.

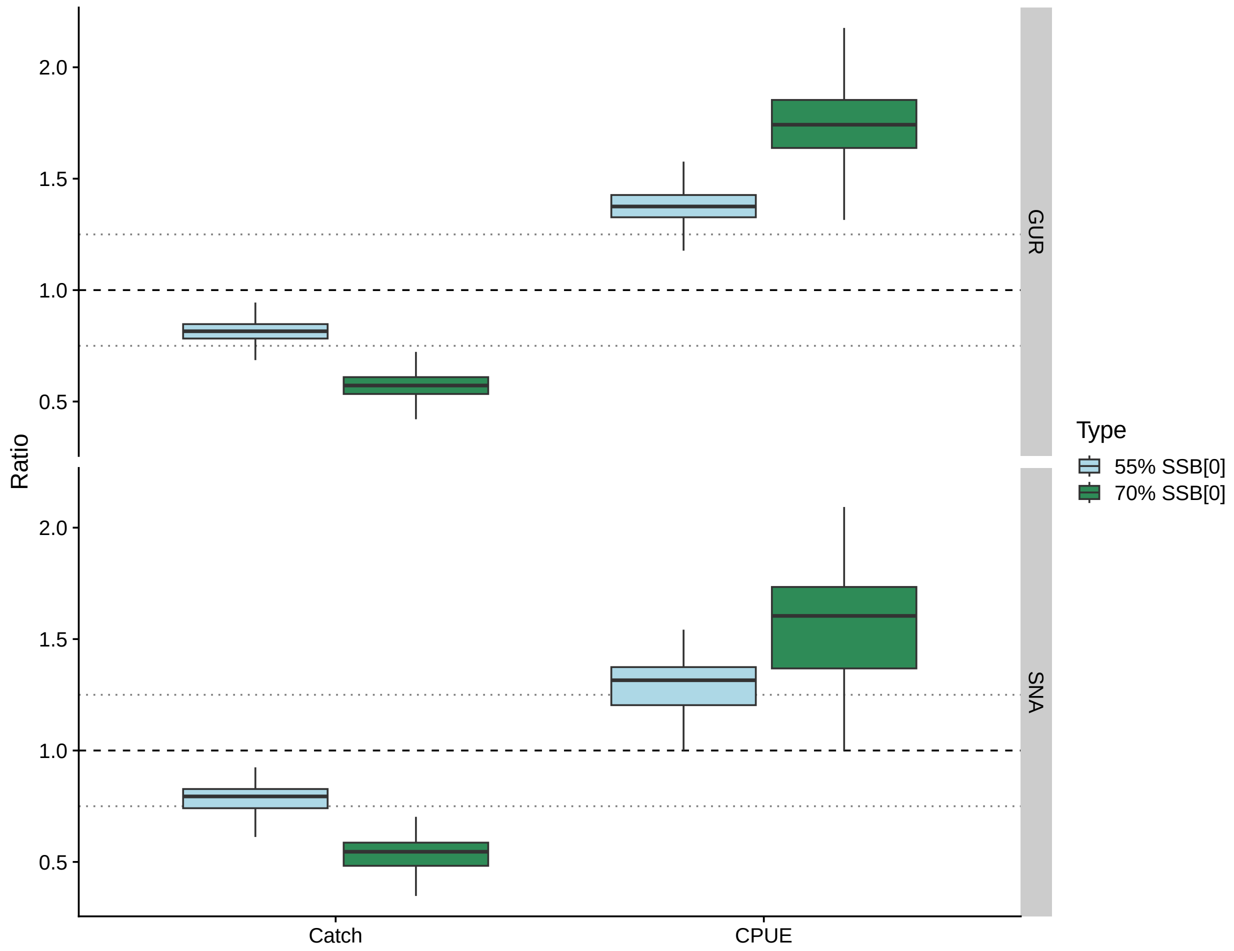


Figure 20: Ratio of catch-per-unit-effort (CPUE) and catch for management targets for GUR 7 and SNA 7 above SSB_{MSY}, achieved by applying annual target fishing mortality levels corresponding to each biomass target.

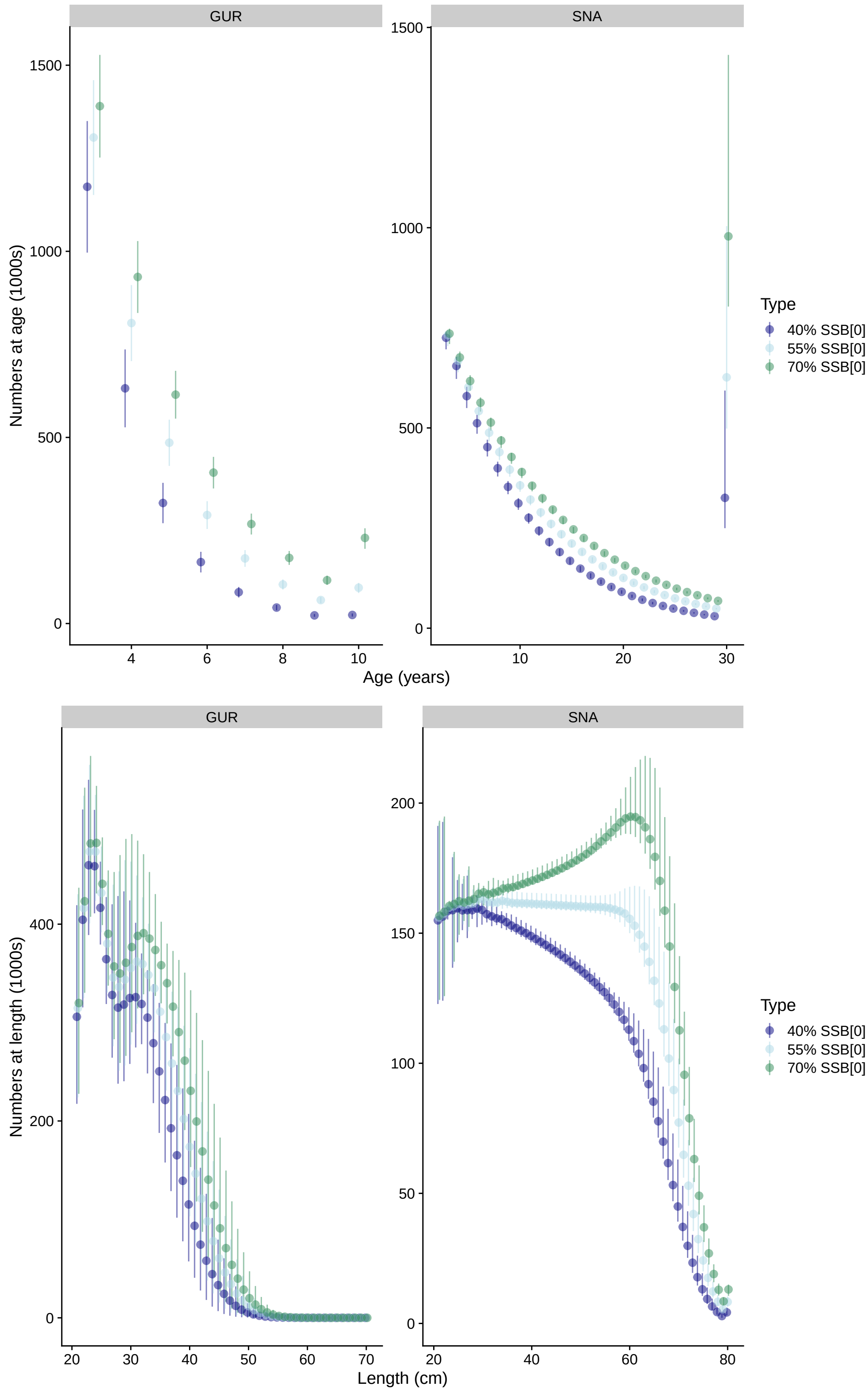


Figure 21: Average numbers at age (top row) and length (bottom row) for GUR 7 and SNA 7 stocks managed to targets at or above SSB_{MSY}, achieved by applying annual target fishing mortality levels corresponding to each biomass target.

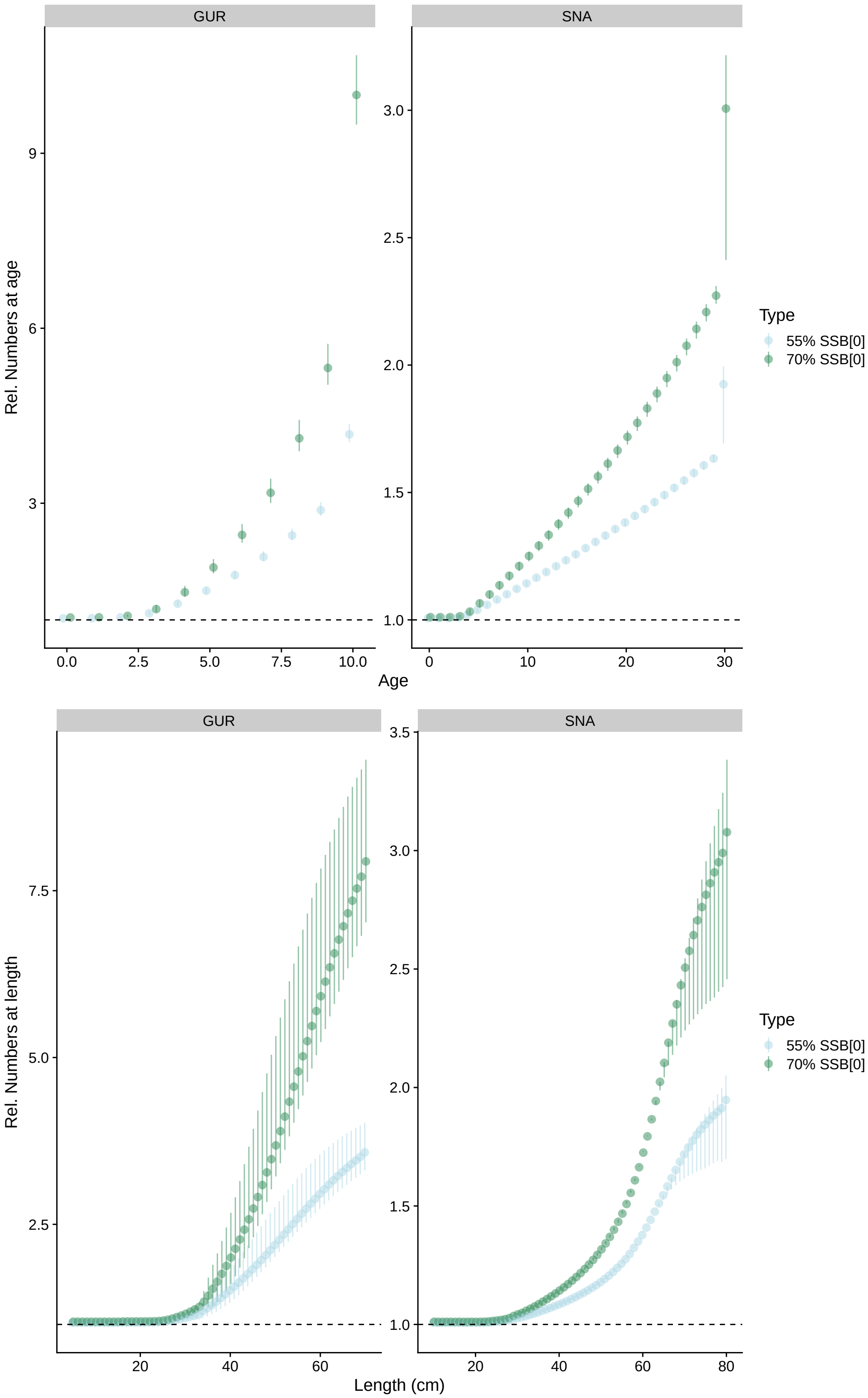


Figure 22: Relative numbers at age (top row) and length (bottom row), for for GUR 7 and SNA 7 stocks managed to targets above SSB_{MSY}, achieved by applying annual target fishing mortality levels corresponding to each biomass target.

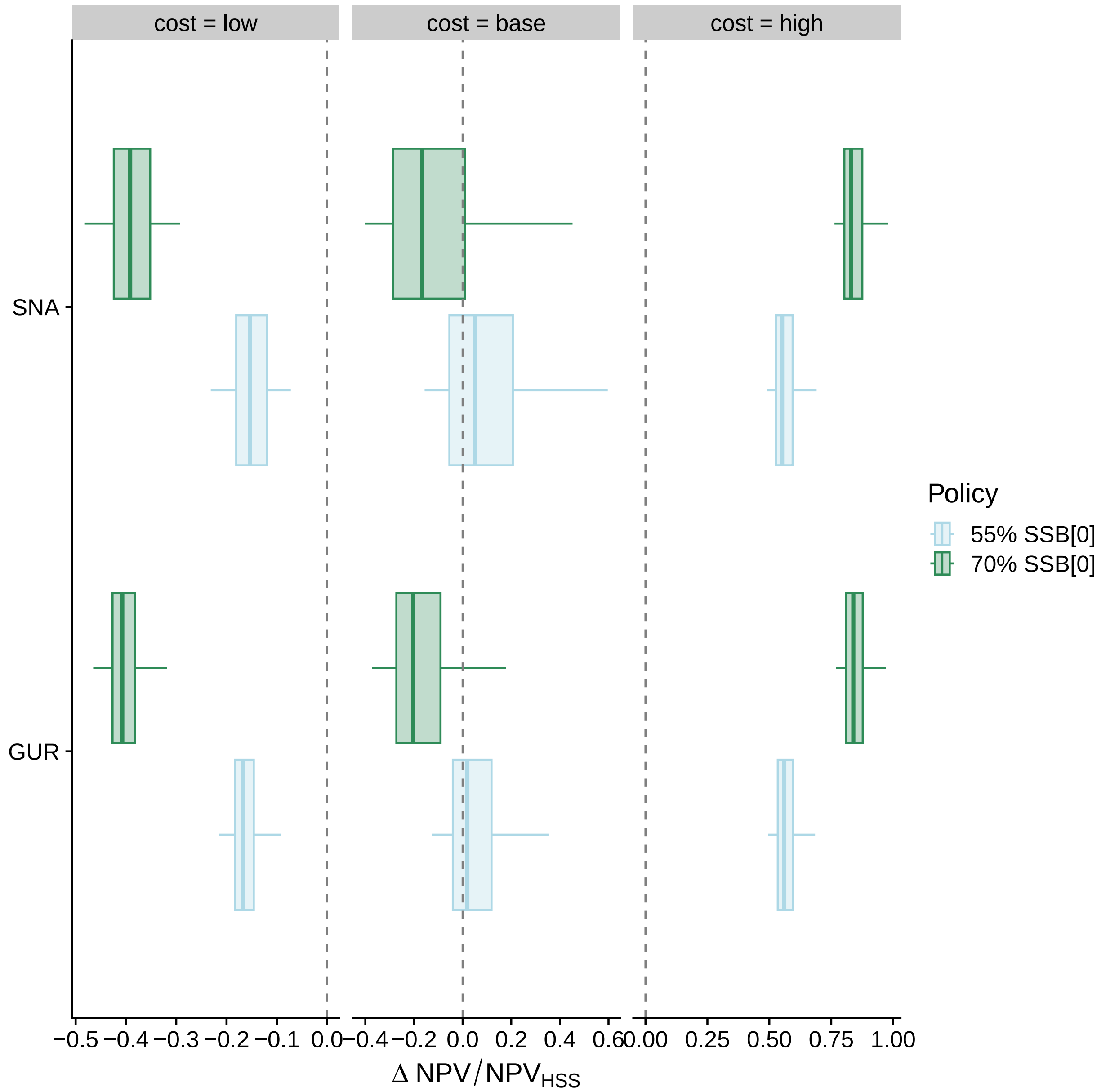


Figure 23: Relative difference in net present value (*NPV*) at base per-unit-effort cost, low and high per-unit-effort costs (columns) for GUR 7 and SNA 7 stocks managed to targets above SSB_{MSY}, relative to fishing at the SSB_{MSY} proxy (vertical dashed line).

3.2.2 Multispecies characterisation in FMA 7

The species composition in the Tasman Bay Golden Bay trawl fisheries has changed substantially over time, with recent catch and targeting dominated by gurnard (Figures 24 and 25, and see Appendix C, Figure C-1), and increasing snapper catch, but with markedly lower catch proportions and targeting of flatfish. While most of the catch and temporal patterns were determined by trends in Statistical Area 038, with about 7× the amount of bottom trawl effort in Statistical Area 037, patterns evident in Statistical Area 038 are also evident in Statistical Area 037 (Figure 26).

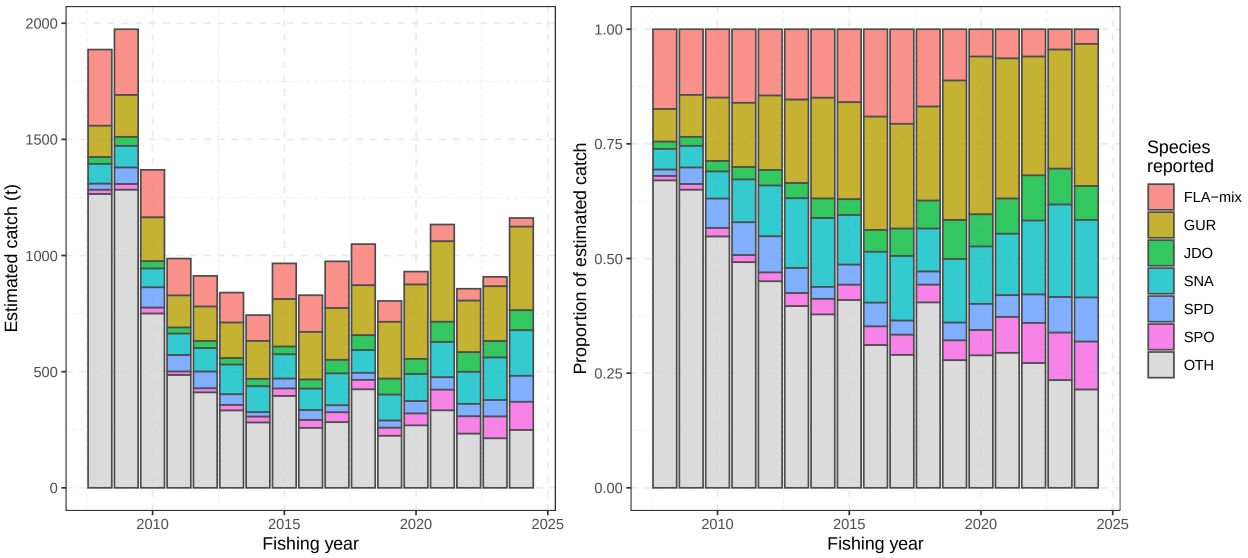


Figure 24: Catch and proportion of catch for species representing at least 5% of total catch in the last five years, plus flatfish-species mixture group (FLA-mix); gurnard (GUR), john dory (JDO), snapper (SNA), spiny dogfish (SPD), rig (SPO).

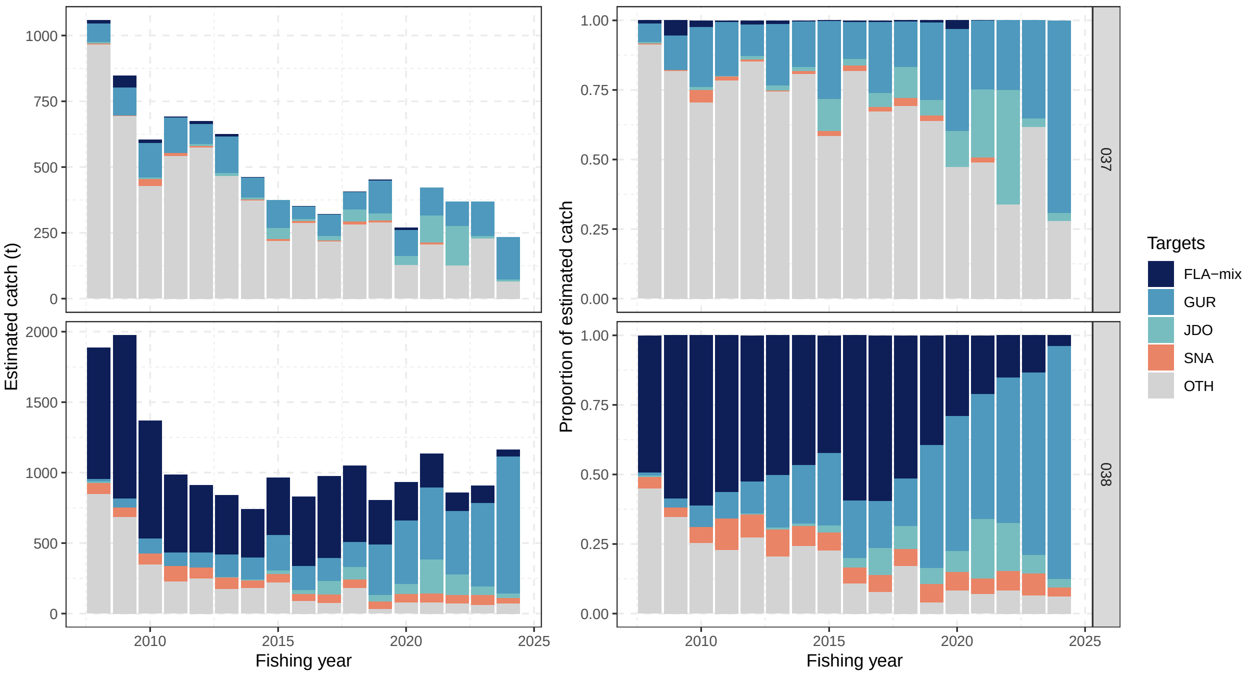


Figure 25: Annual total (left) and proportion (right) of estimated catch by the four main target fisheries of interest in FMA 7; gurnard (GUR), john dory (JDO), snapper (SNA), and flatfish-species mixture group (FLA-mix).

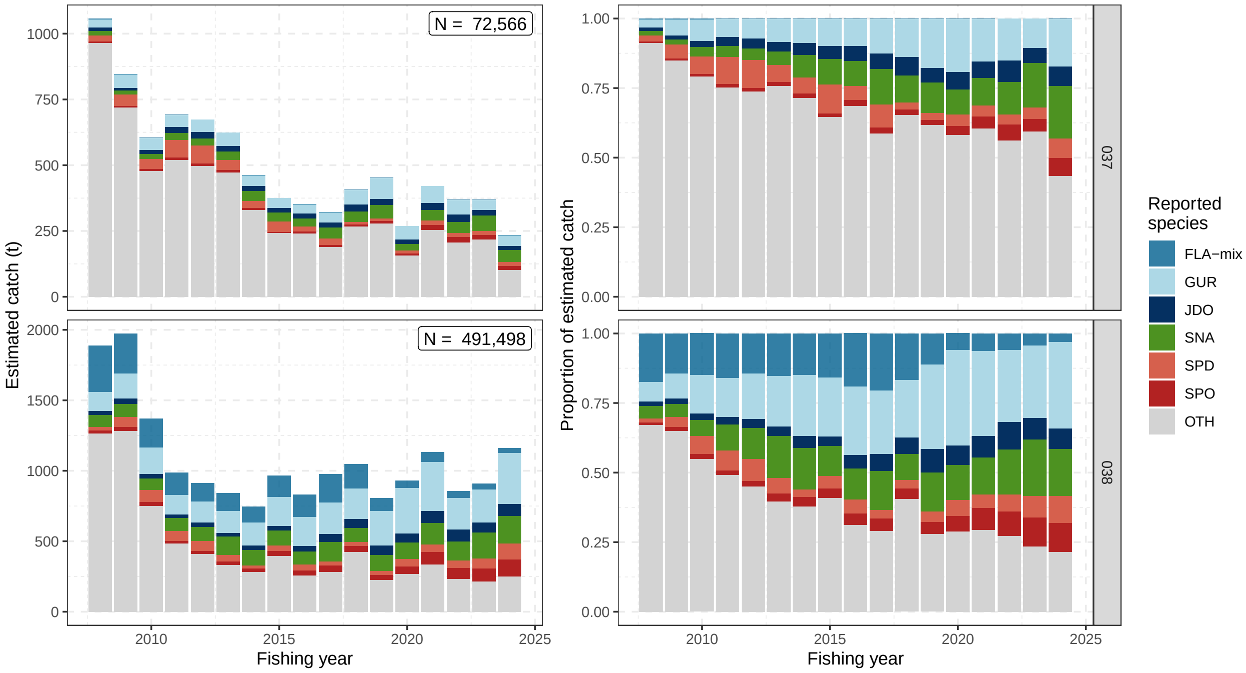


Figure 26: Annual total (left) and proportion (right) of estimated catch by the main species reported in FMA 7; gurnard (GUR), john dory (JDO), snapper (SNA), spiny dogfish (SPD), rig (SPO), and flatfish-species mixture group (FLA-mix). The total effort (number of events) is shown in the top right corner in the annual total catch plots.

Although the overall proportion and catch of flatfish has declined markedly, flatfish target trawls now land a high proportion of snapper (Figure 27). Although snapper target effort mostly nets snapper, the majority of snapper catch comes from gurnard target fishing, although gurnard and snapper appear in reasonable proportions in all target fisheries (Figure 27).

The main separation between species compositions in the trawl fishery is seasonally and by depth (Figures 28 to 30, and Appendix C, Figures C-2 to C-8), with snapper occurring in shallow water in the summer months, but being mostly absent from the fishery in winter. Other species, such as gurnard, are found year around, with gurnard catch occurring between zero and 75 metres depth, although gurnard targeting has been deeper, with a peak at 50 metres (Figure 30).

Spatially, the target effort and catch distribution mirrors the depth range of each species, with flatfish and snapper target effort and catch occurring in shallower water in Tasman Bay Golden Bay (Figure 31), and gurnard, john dory, and other targets occurring deeper along the south-east of Tasman Bay and north of Abel Tasman National Park. The species composition spatially matches the target effort for most species, reflecting a wider distribution of the overall species mix (Figure 32). Nevertheless, catch distributions varied over time with changes in abundance (Figures 33 and 34), with more variation and less clear areas for gurnard in years prior to 2020, and a more clearly-delineated distribution in recent years reflecting increased catches.

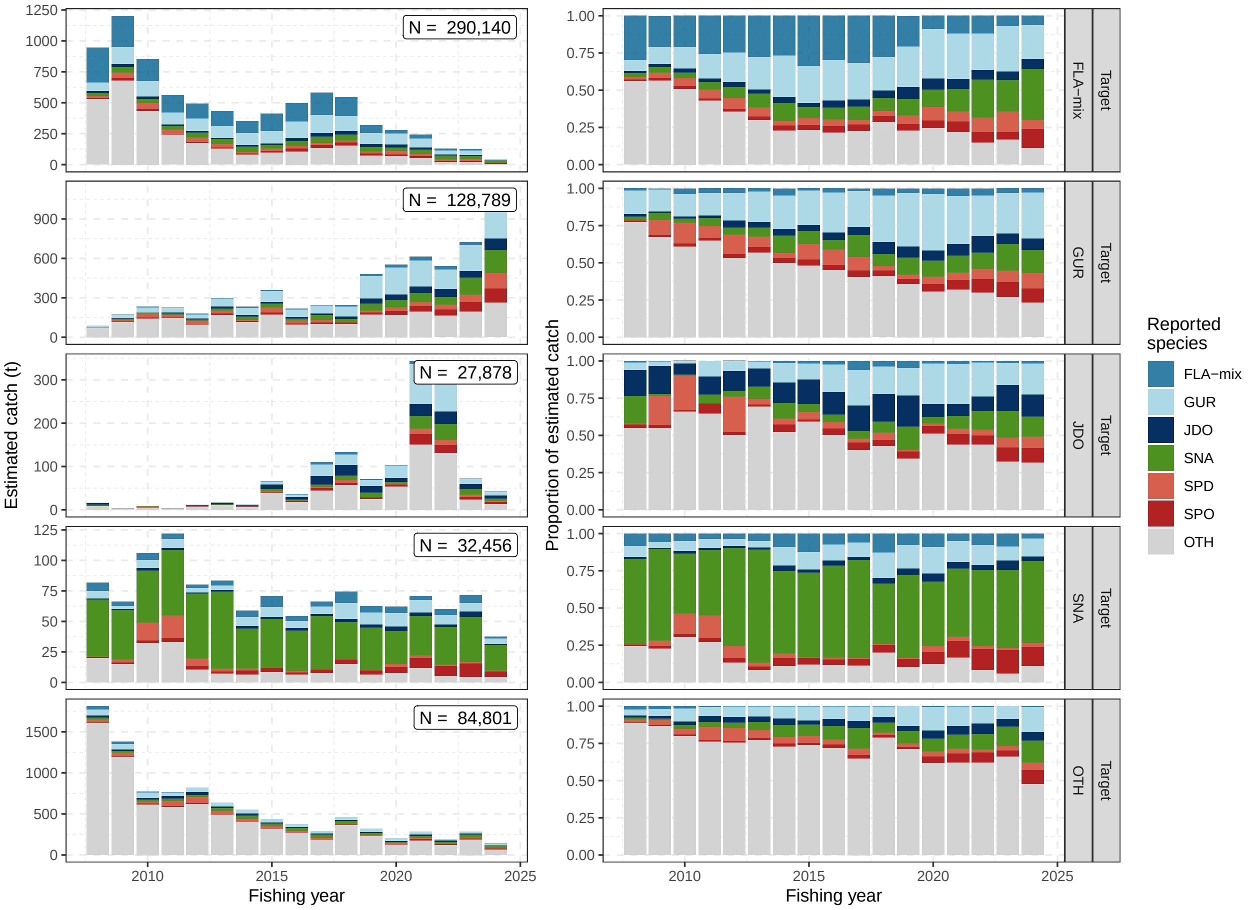


Figure 27: Annual total (left) and proportion (right) of estimated catch by the main target fisheries with species-level distinction in catches; gurnard (GUR), john dory (JDO), snapper (SNA), spiny dogfish (SPD), rig (SPO), and flatfish-species mixture group (FLA-mix). The total effort (number of events) is shown in the top right corner in the annual total catch plots.

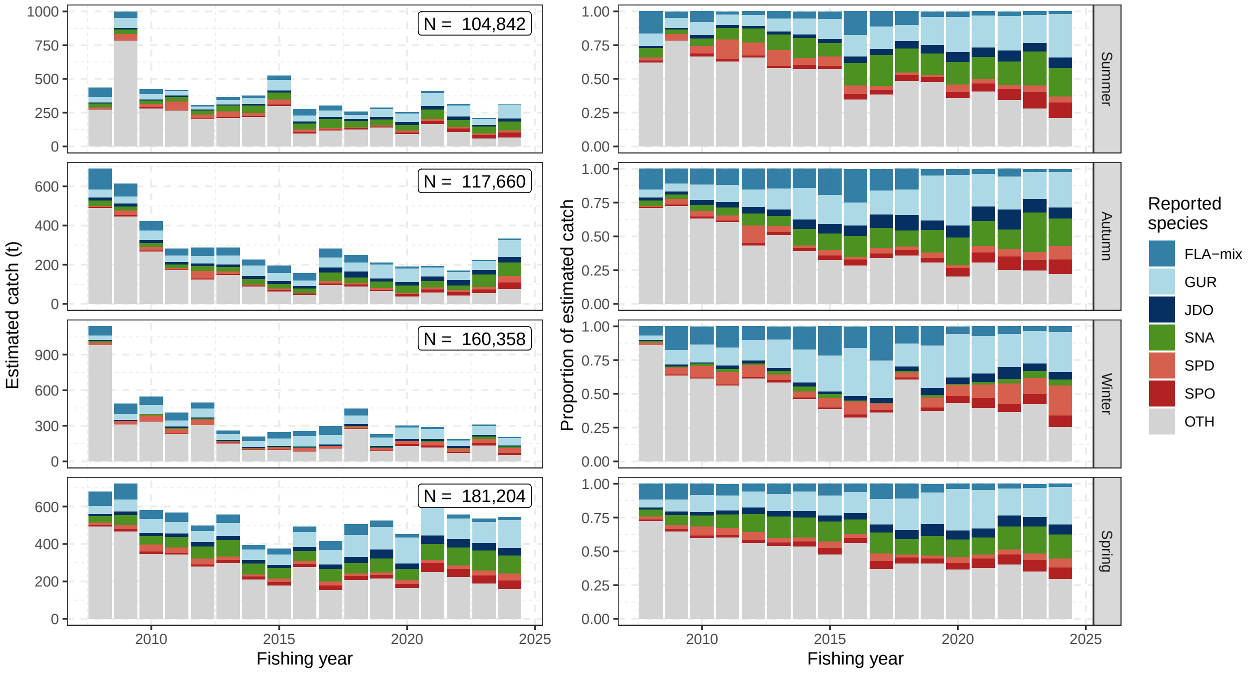


Figure 28: Seasonal patterns in the annual total (left) and proportion (right) of estimated catch with species-level distinction in catches; gurnard (GUR), john dory (JDO), snapper (SNA), spiny dogfish (SPD), rig (SPO), and flatfish-species mixture group (FLA-mix). The total effort (number of events) is shown in the top right corner in the annual total catch plots.

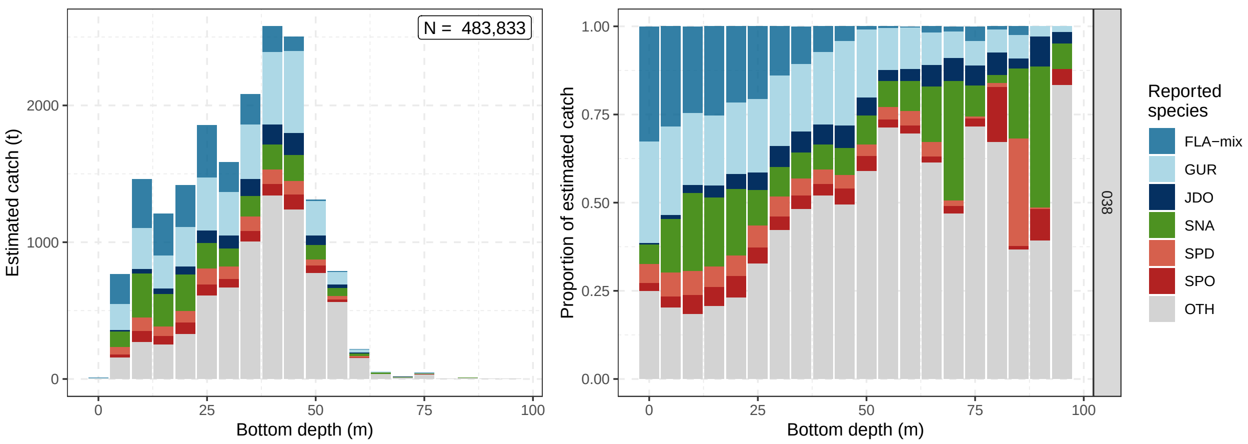


Figure 29: Operational (bottom fishing depth) patterns in the annual total (left) and proportion (right) of estimated catch from Statistical Area 038; with species-level distinction in catches; gurnard (GUR), john dory (JDO), snapper (SNA), spiny dogfish (SPD), rig (SPO), and flatfish-species mixture group (FLA-mix). The total effort (number of events) is shown in the top right corner in the annual total catch plots.

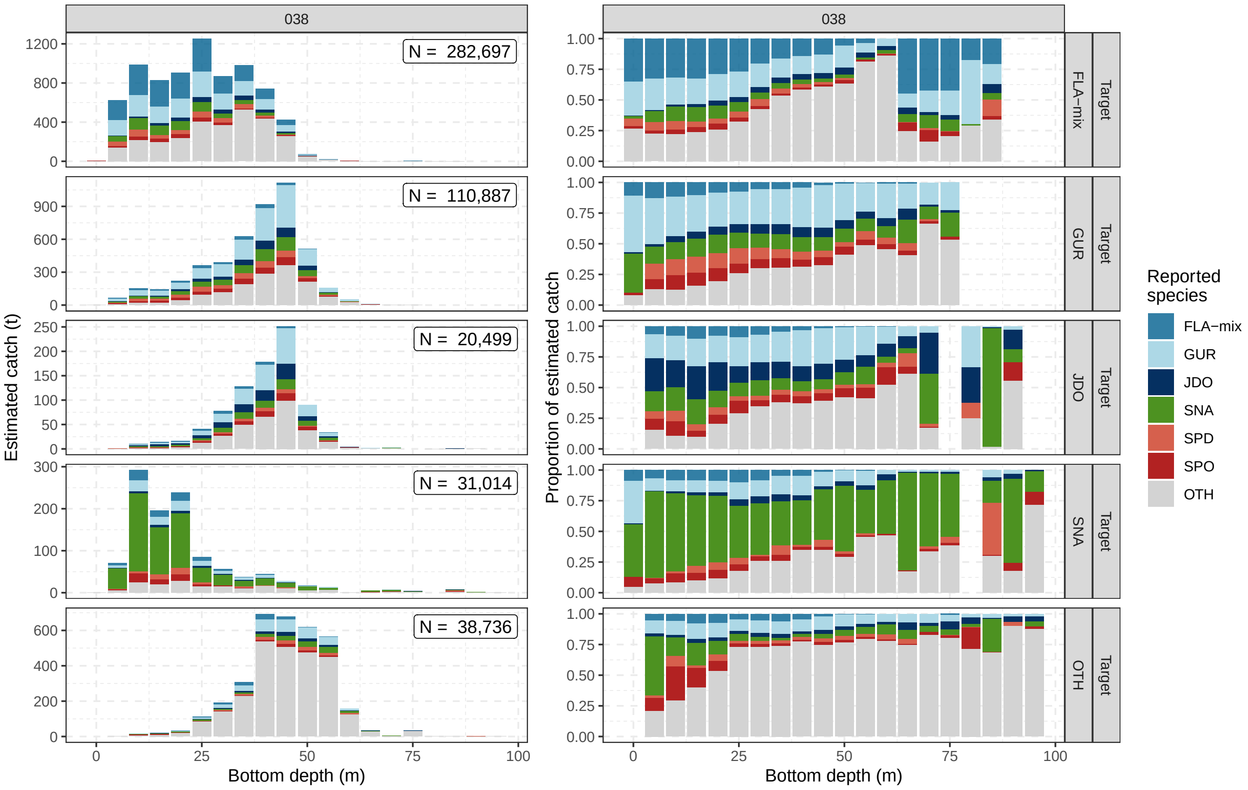


Figure 30: Operational (bottom fishing depth) patterns in the annual total (left) and proportion (right) of estimated catch from Statistical Area 038 by the main target fisheries; with species-level distinction in catches; gurnard (GUR), john dory (JDO), snapper (SNA), spiny dogfish (SPD), rig (SPO), and flatfish-species mixture group (FLA-mix). The total effort (number of events) is shown in the top right corner in the annual total catch plots.

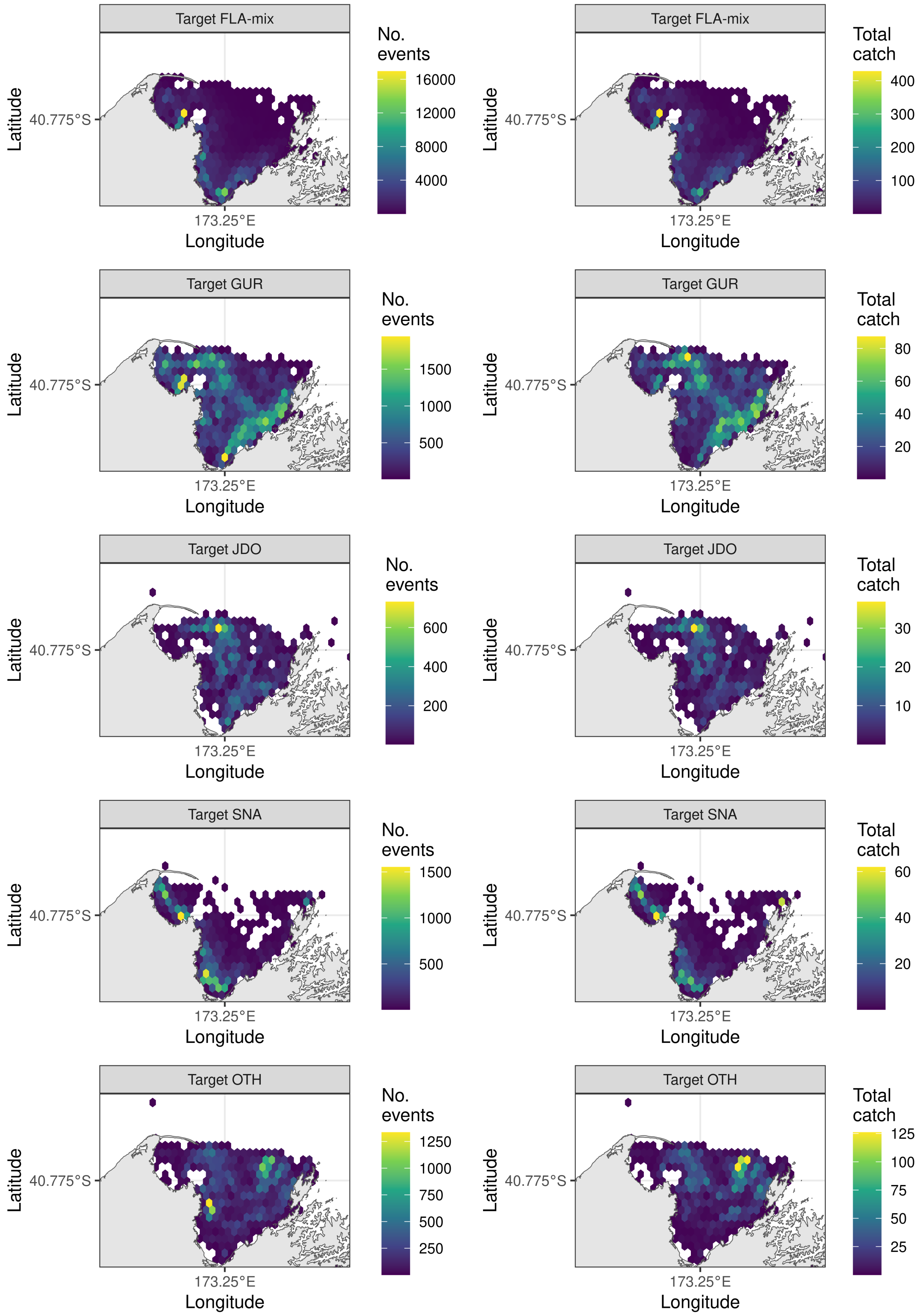


Figure 31: Spatial distribution of catch and effort by the main target fisheries for trawl fisheries in Tasman Bay Golden Bay. Targets: flatfish-species mixture group (FLA-mix), gurnard (GUR), john dory (JDO), snapper (SNA), other (OTH).

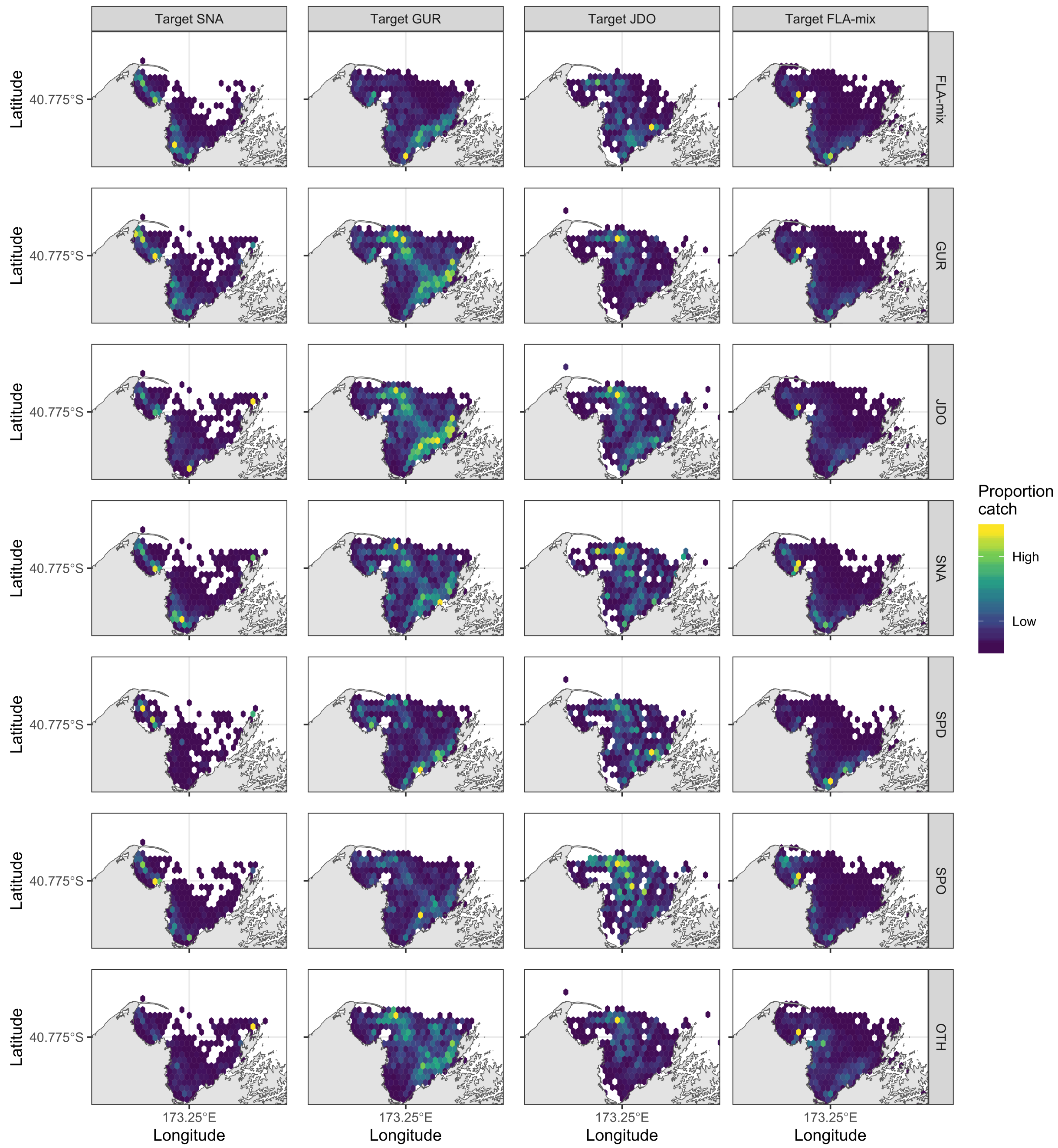


Figure 32: Spatial distribution of species catch (rows) against target effort (columns) by target fisheries for trawl fisheries in Tasman Bay Golden Bay. Targets: flatfish-species mixture group (FLA-mix), gurnard (GUR), john dory (JDO), snapper (SNA), spiny dogfish (SPD), rig (SPO), other (OTH).

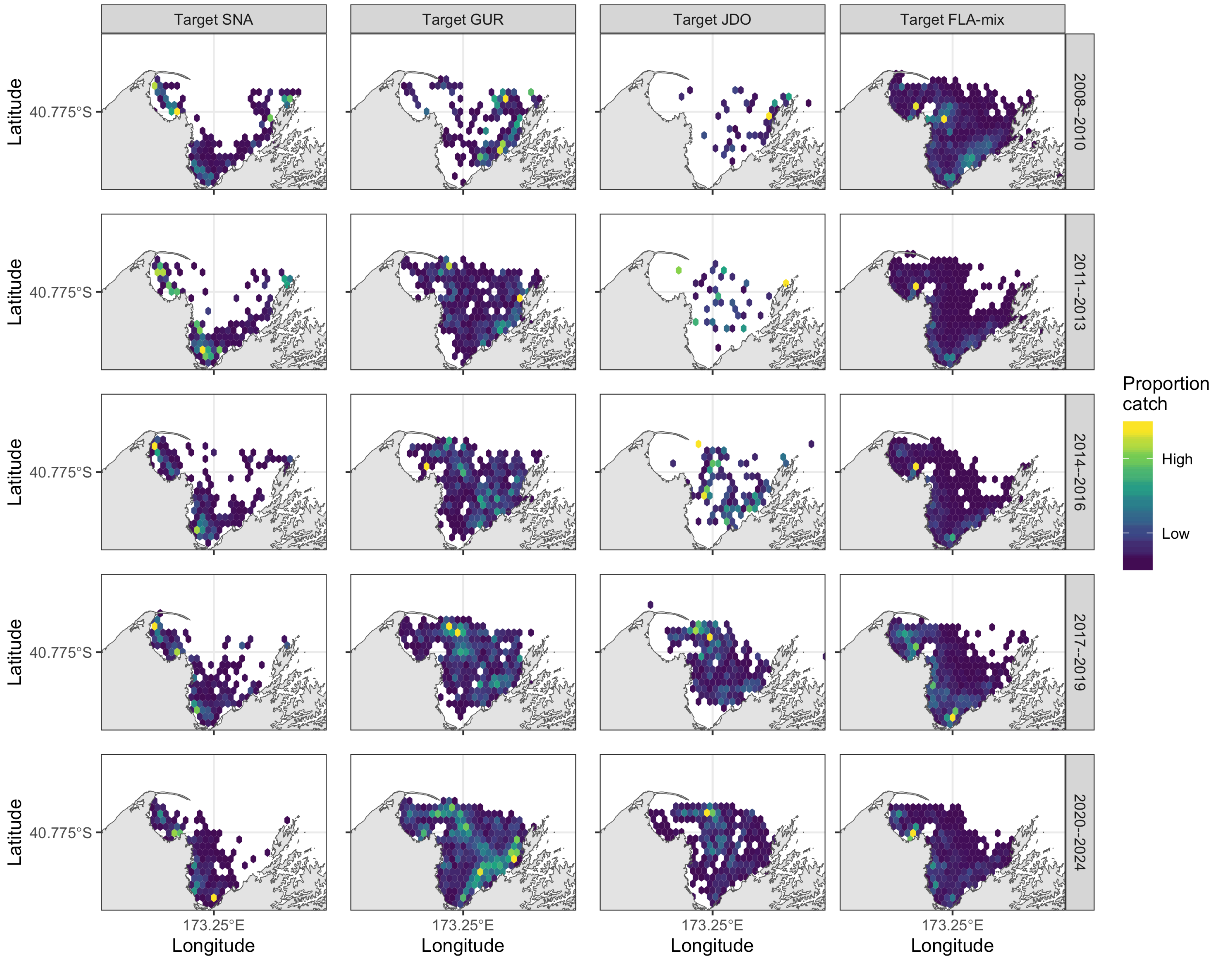


Figure 33: Spatial distribution of catch and effort over time periods by target fisheries for trawl fisheries in Tasman Bay Golden Bay. Targets: snapper (SNA), gurnard (GUR), john dory (JDO), flatfish-species mixture group (FLA-mix).

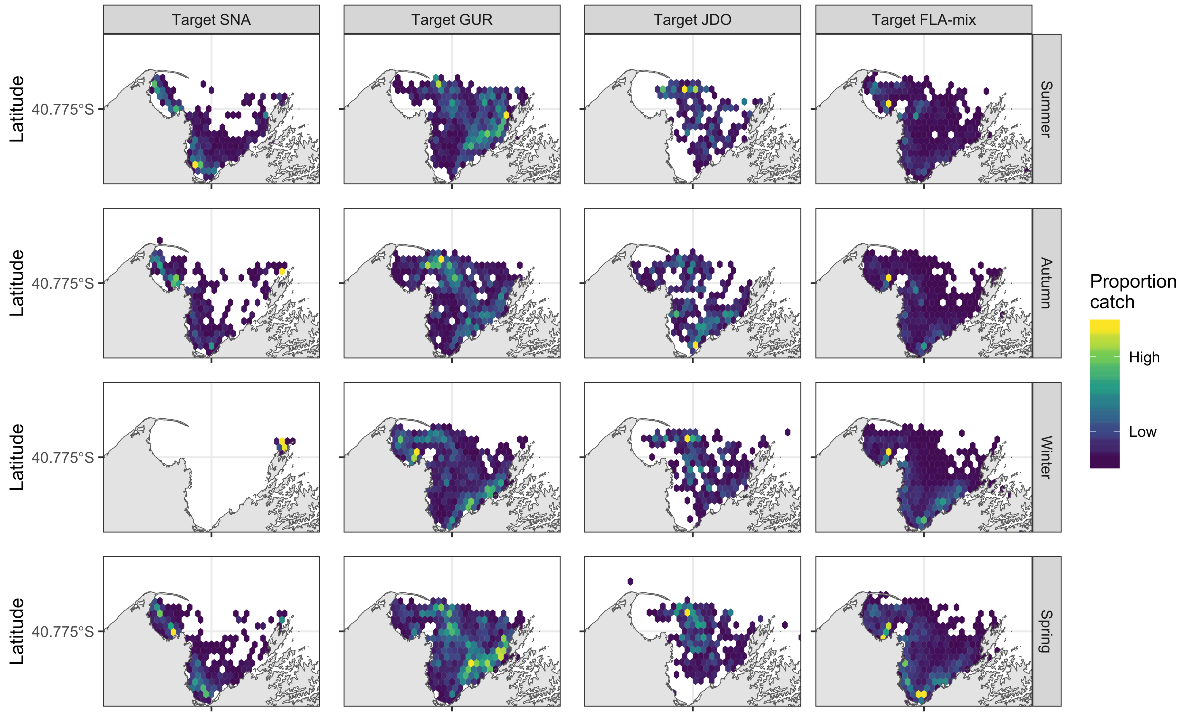


Figure 34: Spatial distribution of catch and effort by season and target fisheries for trawl fisheries in Tasman Bay Golden Bay. Targets: snapper (SNA), gurnard (GUR), john dory (JDO), flatfish-species mixture group (FLA-mix).

3.2.3 Impacts on GUR 7 fisheries when managing SNA 7 above SSB_{MSY}

Reducing gurnard fishing mortality in GUR 7 by an equivalent of 0.56 times the reduction required to achieve a 55% target for snapper led to a higher stock status of ~0.48%; assuming a 70% reduction relative to the reduction in snapper catch led to an increase in gurnard status to ~0.50% (Figure 35). This increase in biomass led to an increase in CPUE of 20% (25%) at the expense of a 10% (14%) reduction in catch for gurnard (Figure 36).

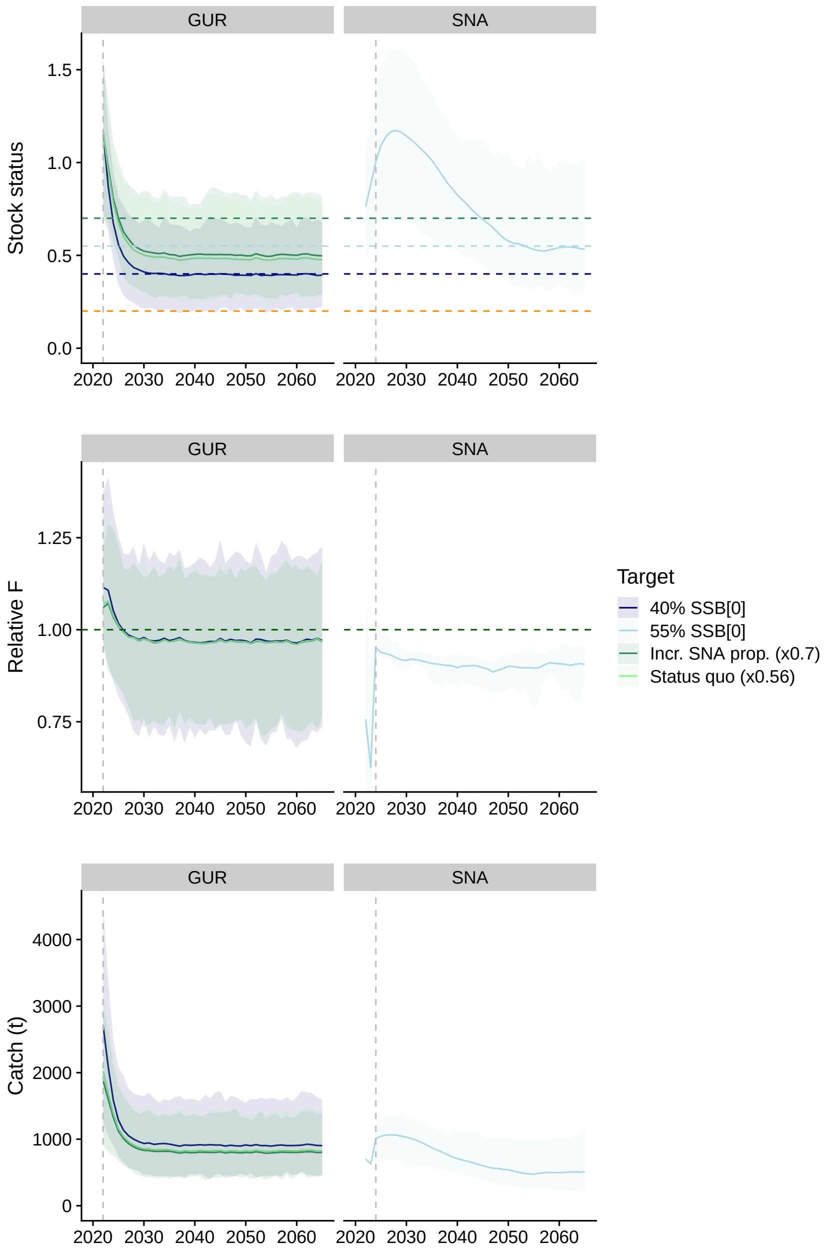


Figure 35: Trajectories (posterior median and 95% credible interval) for gurnard (GUR) and snapper (SNA) stock status, relative fishing mortality, and catch in FMA 7 under alternative scenarios for gurnard: the default 40% SSB_0 target, the impact of reducing gurnard effort by 56% of snapper catch reductions under a 55% SSB_0 SNA 7 target, and a reduction of gurnard effort by 70% of snapper catch reductions, reflecting a scenario of higher snapper biomass under a higher snapper target, leading to reduced opportunities to fish for GUR 7 relative to the current 56% overlap.

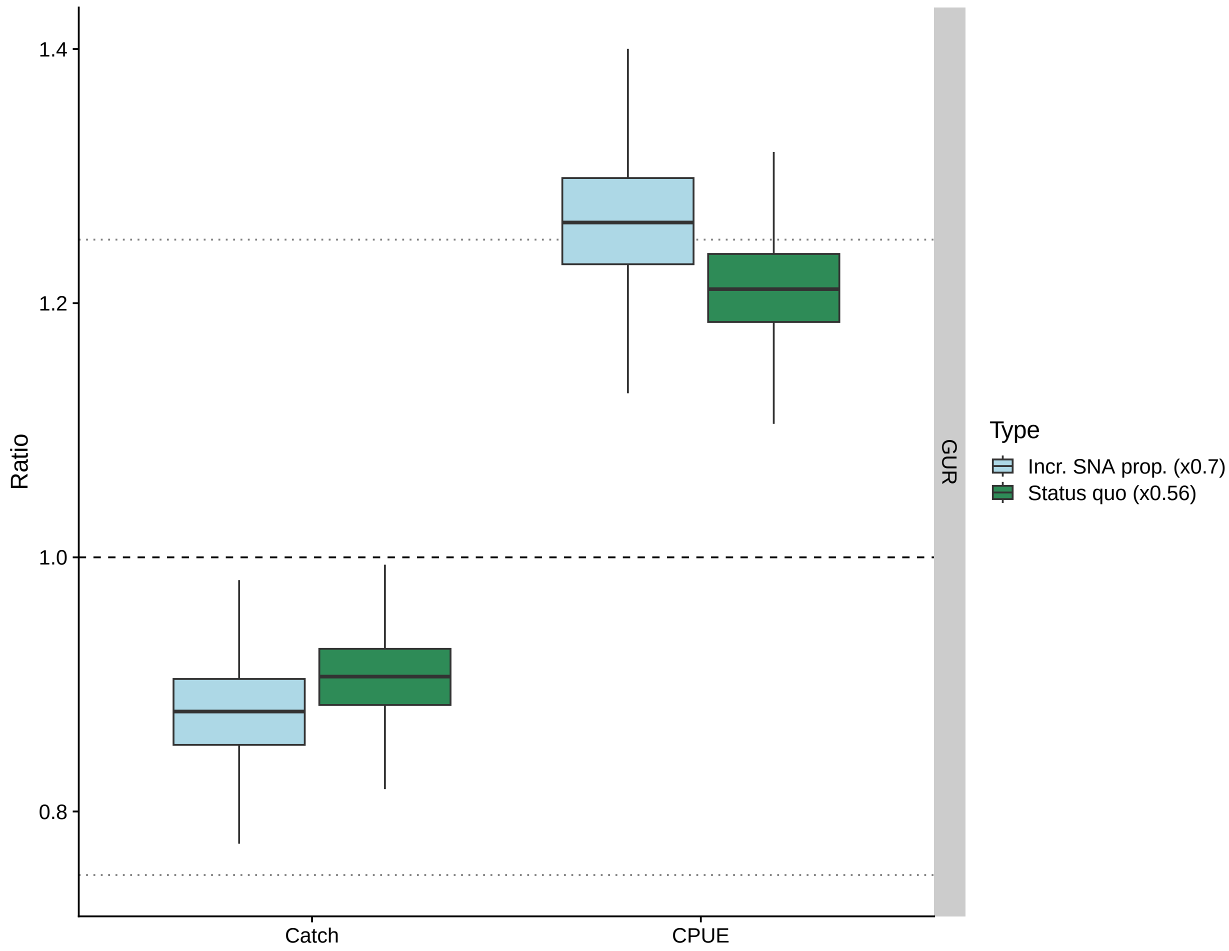


Figure 36: Ratio of catch-per-unit-effort (CPUE) and catch for management targets for GUR 7 and SNA 7 above SSB_{MSY} (achieved by applying a target-20-10 control rule) relative to fishing at the SSB_{MSY} proxy according to a 40-20-10 control rule. Horizontal dotted lines show 25% increments.

4. DISCUSSION

The findings of this study illustrate some of the complexities of incorporating ecosystem considerations into fisheries management, particularly through exploring alternative management targets and dynamic reference points. By using both idealised simulations and an empirical case study in New Zealand's FMA 7, the research illustrates trade-offs in single and multispecies fisheries management.

Higher targets led to predictable outcomes of lower catch and higher CPUE. While the proportional increase of CPUE was usually higher than the corresponding decline in catch, the overall economic performance of higher targets was greatly dependent on the cost structure of fishing operations. At low operational costs relative to the price per unit yield, the benefits of higher catch volumes outweighed potential improvements in CPUE and per-unit-yield profits. Conversely, at higher operational costs, managing fisheries at elevated targets could generate higher total profits by saving on operating costs such as fuel. Fisheries managed at a higher target are also potentially less prone to reductions in catch when managed according to a harvest control rule, as the risk of declining below limit reference points in years of poor recruitment is lower. Stable catch is often an objective in fisheries management (Punt 2017), and provides the necessary confidence for investments. In addition, multispecies simulations often show that in mixed fisheries, exploiting individual species at their MSY leads to the inevitable collapse of less productive stocks, but that overall reductions of harvest rates greatly reduce the likelihood of collapse of secondary species (Walters et al. 2005, Worm et al. 2009).

Simulations also illustrated that dynamic target reference points do not produce substantial benefits over static targets when harvest control rules based on fishing mortality are applied. As our simulations used static limit reference points, the main difference was in the amount of yield that could be obtained during an environmentally-driven decline of a stock: moving the target reference point allows for higher maximum yield during this period, but also increases the risk of breaching the static limit reference points, with ensuing substantial declines in catch. In contrast, with an increase in productivity, an F-based strategy leads to comparable catch. In all cases, the main difference was in the declared stock status, rather than in the actual biomass or catch between scenarios of static and dynamic target reference points. These results align with other simulations that found limited (and largely declarative) benefits to using dynamic reference points with F-based harvest control rules (Berger 2019).

The reason for similarities between static and dynamic targets is that under the assumption of un-biased stock assessment results, the fishing mortality applied for a stock at or above the target reference point is the same (at least under default harvest strategies in place in the New Zealand Harvest Strategy Standard (Ministry of Fisheries 2008), and also in the 40-10 harvest control rules employed for United States West Coast groundfish (Wetzel & Punt 2016), for example). As abundance increases in a scenario of strong recruitment, this fishing mortality will track increasing abundance, leading to increased catch regardless of the declared stock status. When productivity declines, a lower fishing mortality is continuously applied to rebuild the stock under a static target; however, this target becomes unachievable, and the stock remains "overfished" despite lower fishing mortality rates. While this state is clearly undesirable, the practice of maintaining static limit reference points with dynamic target reference points may introduce unacceptable levels of risk of large catch reductions; at the same time, moving these reference points may lead to increased risk of population collapse. A compromise in that case may be to use dynamic target reference points, but to manage to a higher dynamic target status (i.e., a lower target F) that reduces risk of breaching static limit reference points even under reduced productivity. This trade-off between risk, fishing opportunity and adequate control rules could be further investigated using the simulation tools used in the present study.

Reference points, static or dynamic, are difficult to accurately estimate with limited time-series data (e.g., less than 50 years; Haltuch et al. 2009, Neubauer et al. 2023), and may be more biased than absolute biomass estimates (Marsh et al. 2024). Our simulations did not include any error or systematic bias in the estimation of recent recruitment and, therefore, biased dynamic reference points that would lead to an inappropriate management response. For example, there is potential for assessment models to estimate recent markedly strong or weak year classes that will overly influence the dynamic target; however, it is only after those year classes have been in the fishery for an extended period of time that they are well estimated. Complexities around the designation of environmental factors of stock productivity, and the case dependence of the performance of dynamic reference points have been suggested to be partly responsible for a lack of general adoption of dynamic reference points (Eddy et al. 2023). A key requirement for dynamic management is a dynamic science and management system that can respond to climate-driven changes in stocks in a timely manner (Link et al. 2021). Such a process, coupled with control rules such as the F-based control rules tested here, may be sufficient to account for bottom-up influences of the ecosystem on fisheries productivity.

Although single-species considerations of environmental influences represent one aspect of an ecosystem approach to fisheries, many fisheries are part of complex foodwebs with a range of species that are either targeted or caught as bycatch. Our FMA 7 case study illustrates the complexity of translating single-species considerations into a multispecies context. In Tasman Bay Golden Bay, species are generally caught together in trawl fisheries, and only snapper are absent from the fishery during winter. Avoiding a particular species and lowering catch while maintaining catch of other species is, therefore, a difficult undertaking. The considerable overlap of snapper and gurnard catch in the area, for example, meant that a catch reduction in snapper may restrict gurnard effort by at least 50% of the snapper reduction unless gear changes or other fishing practices can substantially alter the catch composition (limitations imposed by snapper quotas in the area have already led to increasingly strong effort for gurnard; Langley 2024). Managing snapper at a higher target may, therefore, translate to a higher target for other species also by restricting overall effort. In contrast, target switching may occur in favour of other species that have lower overlap with snapper, or for areas with low snapper bycatch, and lead to higher exploitation of species that are less associated with snapper. The overall extent of these changes in targeting and selectivity is difficult to predict, and is confounded by the abundance and available annual catch entitlement of alternative target species. Despite this difficulty in predicting, quantitatively, the outcome of these single-species management decisions in a multispecies context, multispecies characterisations such as provided here can help establish scenarios based on current fishing practice that can be discussed with stakeholders and used to guide management decisions.

ACKNOWLEDGMENTS

We would like to thank Fisheries New Zealand for funding this project (SEA2023-08), and Pamela Mace and the members of the Statistics, Assessments and Methods Working Group for helpful feedback in developing the work outlined in the present report.

5. REFERENCES

Abelson, P.; Dalton, T. (2024). Declining discount rates in cost benefit analysis. Commissioned report for The Treasury, New Zealand. 28 p.

Arrow, K.; Cropper, M.; Gollier, C.; Groom, B.; Heal, G.; Newell, R.; Nordhaus, W.; Pindyck, R.; Pizer, W.; Portney, P.; Sterner, T.; Tol, R.S.J.; Weitzman, M. (2013). Determining benefits and costs for future generations. *Science 341 (6144)*: 349–350. https://doi.org/10.1126/science.1235665

Berger, A.M. (2019). Character of temporal variability in stock productivity influences the utility of dynamic reference points. *Fisheries Research 217*: 185–197. https://doi.org/10.1016/j.fishres.2018.11.028

Bessell-Browne, P.; Punt, A.E.; Tuck, G.N.; Day, J.; Klaer, N.; Penney, A. (2022). The effects of implementing a 'dynamic B0' harvest control rule in Australia's Southern and Eastern Scalefish and Shark Fishery. *Fisheries Research 252*: 106306. https://doi.org/10.1016/j.fishres.2022.106306

Carpenter, B.; Gelman, A.; Hoffman, M.; Lee, D.; Goodrich, B.; Betancourt, M.; Brubaker, M.A.; Guo, J.; Li, P.; Riddell, A. (2017). Stan: A probabilistic programming language. *Journal of Statistical Software 76*: 1–32. https://doi.org/10.18637/jss.v076.i01

Clark, C. (1973). Profit maximization and the extinction of animal species. *Journal of Political Economy 81 (4)*: 950–961. https://doi.org/10.1086/260090

Craig, J.K.; Link, J.S. (2023). It is past time to use ecosystem models tactically to support ecosystem-based fisheries management: Case studies using Ecopath with Ecosim in an operational management context. *Fish and Fisheries 24 (3)*: 381–406. https://doi.org/10.1111/faf.12733

Cryer, M.; Mace, P.; Sullivan, K. (2016). New Zealand's ecosystem approach to fisheries management. *Fisheries Oceanography 25*: 57–70. https://doi.org/10.1111/fog.12088

Eddy, T.D.; Duplisea, D.; Robertson, M.D.; Ruiz-Díaz, R.; Solberg, C.A.; Zhang, F. (2023). Barriers to implementation of dynamic reference points in fisheries management (S. Cooke, Ed.). *FACETS 8*: 1–10. https://doi.org/10.1139/facets-2022-0216

Fogarty, M.J. (2014). The art of ecosystem-based fishery management. *Canadian Journal of Fisheries and Aquatic Sciences 71 (3)*: 479–490.

Fournier, D.A.; Hampton, J.; Sibert, J.R. (1998). MULTIFAN-CL: a length-based, age-structured model for fisheries stock assessment, with application to South Pacific albacore, *Thunnus alalunga*. *Canadian Journal of Fisheries and Aquatic Sciences 55*: 2105–2116.

Fournier, D.A.; Sibert, J.R.; Majkowski, J.; Hampton, J. (1990). MULTIFAN a likelihood-based method for estimating growth parameters and age composition from multiple length frequency data sets illustrated using data for southern bluefin tuna (*Thunnus maccoyii*). *Canadian Journal of Fisheries and Aquatic Sciences 47 (2)*: 301–317.

Haltuch, M.A.; Punt, A.E.; Dorn, M.W. (2009). Evaluating the estimation of fishery management reference points in a variable environment. *Fisheries Research 100 (1)*: 42–56.

Hilborn, R. (2011). Future directions in ecosystem based fisheries management: A personal perspective. *Fisheries Research 108 (2-3)*: 235–239.

Jennings, S.; Kaiser, M.J. (1998). The effects of fishing on marine ecosystems. *In*: Advances in Marine Biology (pp. 201–352). Elsevier. https://doi.org/10.1016/S0065-2881(08)60212-6

King, J.R.; McFarlane, G.A.; Punt, A.E. (2015). Shifts in fisheries management: Adapting to regime shifts. *Philosophical Transactions of the Royal Society B: Biological Sciences 370 (1659)*: 20130277. https://doi.org/10.1098/rstb.2013.0277

Langley, A.D. (2022). A stock assessment of red gurnard in GUR 7 for 2022. *New Zealand Fisheries Assessment Report 2022/22*. 36 p.

Langley, A.D. (2024). A stock assessment of snapper in SNA 7 for 2024. *New Zealand Fisheries Assessment Report 2024/48*. 86 p.

Link, J.; Karp, M.; Lynch, P.; Morrison, W.; Peterson, J. (2021). Proposed business rules to incorporate climate-induced changes in fisheries management. *ICES Journal of Marine Science 78 (10)*: 3562–3580.

Mace, P.M.; Doonan, I. (1988). A generalised bioeconomic simulation model for fish population dynamics. *New Zealand Fisheries Assessment Research Document 88/4*. MAFFish, New Zealand Ministry of Agriculture and Fisheries. 53 p.

Marsh, C.; McKenzie, J.; Langley, A. (2024). Simulation testing recruitment productivity shifts based on the 2021 SNA 8 stock assessment. *New Zealand Fisheries Assessment Report 2024/24*. 27 p.

Ministry of Fisheries (2008). *Harvest Strategy Standard for New Zealand fisheries*. Ministry for Primary Industries, Wellington. https://fs.fish.govt.nz/Doc/16543/harveststrategyfinal.pdf. Ministry of Fisheries (now MPI)

Moffitt, E.A.; Punt, A.E.; Holsman, K.; Aydin, K.Y.; Ianelli, J.N.; Ortiz, I. (2016). Moving towards ecosystem-based fisheries management: Options for parameterizing multi-species biological reference points. *Deep Sea Research Part II: Topical Studies in Oceanography 134*: 350–359. https://doi.org/10.1016/j.dsr2.2015.08.002

Neubauer, P.; A'mar, T.; Dunn, M. (2023). Climate impacts on fished populations. Part 2: Effects of climate and environmental variability on fishery stock assessment accuracy. *New Zealand Fisheries Assessment Report 2023/57*. 40 p.

Plagányi, É.E.; Punt, A.E.; Hillary, R.; Morello, E.B.; Thébaud, O.; Hutton, T.; Pillans, R.D.; Thorson, J.T.; Fulton, E.A.; Smith, A.D.; et al. (2014). Multispecies fisheries management and conservation: Tactical applications using models of intermediate complexity. *Fish and Fisheries 15 (1)*: 1–22.

Punt, A. (2017). Strategic management decision-making in a complex world: Quantifying, understanding, and using trade-offs. *ICES Journal of Marine Science 74 (2)*: 499–510.

Punt, A.; Butterworth, D.; Penney, A. (1995). Stock assessment and risk analysis for the South Atlantic population of albacore *Thunnus alalunga* using an age-structured production model. *South African Journal of Marine Science 16 (1)*: 287–310.

R Core Team (2021). *R: A language and environment for statistical computing*. R Foundation for Statistical Computing. Vienna, Austria. https://www.R-project.org/

Townsend, H.; Harvey, C.J.; DeReynier, Y.; Davis, D.; Zador, S.G.; Gaichas, S.; Weijerman, M.; Hazen, E.L.; Kaplan, I.C. (2019). Progress on implementing ecosystem-based fisheries management in the United States through the use of ecosystem models and analysis. *Frontiers in Marine Science 6*: 641.

Walters, C.J.; Christensen, V.; Martell, S.J.; Kitchell, J.F. (2005). Possible ecosystem impacts of applying MSY policies from single-species assessment. *ICES Journal of Marine Science 62 (3)*: 558–568.

Wetzel, C.R.; Punt, A. (2016). The impact of alternative rebuilding strategies to rebuild overfished stocks. *ICES Journal of Marine Science 73 (9)*: 2190–2207. https://doi.org/10.1093/icesjms/fsw073

Worm, B.; Hilborn, R.; Baum, J.K.; Branch, T.A.; Collie, J.S.; Costello, C.; Fogarty, M.J.; Fulton, E.A.; Hutchings, J.A.; Jennings, S.; et al. (2009). Rebuilding global fisheries. *Science 325 (5940)*: 578–585.

APPENDIX A: SIMULATION MODEL

For the simulation-estimation experiments, we developed a simple age-structured population model. The operating model to simulate data was developed in *R* (R Core Team 2021) and *Stan* (Carpenter et al. 2017) to allow efficient simulation.

A.1 Parameter definitions

Table A-1: Definitions for the terms used in the age-structured model.

Notation	Description
a	Index for ages.
A	Maximum age.
t	Index for years.
T	Index for the last year.
$N_{a,t}$	Abundance of fish of age a in year t.
H_t	Exploitation rate for year t.
Y_t	Yield (i.e., catch in weight) in year t.
$\tilde{N}_a$	Abundance of fish of age a at unexploited equilibrium.
R_0	Recruitment at unexploited equilibrium.
R_t	Recruitment in year t.
σ_R^2	Variance of recruitment deviations.
M	Instantaneous rate of natural mortality.
h	Steepness parameter.
l_a	Mean length at age a .
L_∞, κ, a_0	von Bertalanffy parameters.
ζ	Brody coefficient (i.e., $\zeta = e^{-\kappa}$).
SSB_t	Spawning stock biomass in year t.
SSB_0	Spawning stock biomass at unexploited equilibrium.
W_a	Mean weight at age a.
ω_1, ω_2	Length-weight relationship parameters.
S_a	Selectivity at age a.
a_{50}, v	Selectivity parameters.
Mat_a	Maturity at age a.
a_{Mat}	Age at 100% maturity.
VB_t	Vulnerable biomass in year t.
VB_0	Vulnerable biomass at unexploited equilibrium.
φ	Proportion of females.
I_t	Abundance index in year t.
q	Catchability coefficient.
$\hat{P}_{a\|t}$	Model-estimated age-composition proportion of age a in year t.

A.2 Age-structured dynamics

The age-structured dynamics of the population are defined as:

$$N_{a,t} = \begin{cases} R_t, & \text{for } a = 1 \\ N_{a-1,t-1} \cdot (1 - S_{a-1} \cdot H_{t-1}) \cdot e^{-M}, & \text{for } 1 < a < A \\ N_{a-1,t-1} \cdot (1 - S_{a-1} \cdot H_{t-1}) \cdot e^{-M} + N_{a,t-1} \cdot (1 - S_a \cdot H_{t-1}) \cdot e^{-M}, & \text{for } a = A \end{cases} \quad \text{(A-1)}$$

,

where $N_{a,t}$ is the abundance of fish of age a at the beginning of year t, R_t is the recruitment at age 1 in year t, S_a is the time-invariant age-dependent selectivity, H_t is the exploitation rate ($0 \leq H_t \leq 1$) in year t, A is the maximum age which is the plus group, and M is the instantaneous rate of natural mortality.

The initial population (i.e., $N_{a,1}$) was assumed to be at unexploited equilibrium:

$$\tilde{N}_a = \begin{cases} R_0, & \text{for } a = 1 \\ \tilde{N}_{a-1} \cdot e^{-M}, & \text{for } 1 < a < A \\ \dfrac{\tilde{N}_{a-1} \cdot e^{-M}}{1 - e^{-M}}, & \text{for } a = A \end{cases} \tag{A-2}$$

,

where $\tilde{N}_a$ is the abundance of fish of age a at unexploited equilibrium, R_0 is the recruitment at age 1 at unexploited equilibrium, M is the instantaneous rate of natural mortality, and A is the maximum age which is the plus group.

A.3 Stock-recruitment relationship

The Beverton-Holt stock-recruitment function, reparameterised in terms of the steepness parameter h (Mace & Doonan 1988), was used to model the annual recruitment at age 1 R_t:

$$R_{t+1} = \frac{4 \cdot h \cdot R_0 \cdot SSB_t}{(1-h) \cdot SSB_0 + (5 \cdot h - 1) \cdot SSB_t} \cdot e^{\varepsilon_{t+1} - 0.5 \cdot \sigma_R^2} \tag{A-3}$$

,

where SSB_t is the spawning stock biomass in year t, SSB_0 is the spawning stock biomass at unexploited equilibrium, ε_t are the annual recruitment deviations, which are normally distributed with mean 0 and variance σ_R^2, R_0 is the recruitment at age 1 at unexploited equilibrium, and the subtracted term $-0.5 \cdot \sigma_R^2$ is the bias correction term.

A.4 Length-at-age distribution of the catch

For simplicity, the length-at-age distribution of the catch $G_{j|a}$ was assumed to be the same as the length-at-age distribution of the population (i.e., there is no length-dependent selectivity):

$$G_{j|a} = \begin{cases} \int_0^{\bar{L}_j + r/2} f(L|l_a, \sigma_a^2) dL, & \text{for } j = 1 \\ \int_{\bar{L}_i - r/2}^{\bar{L}_j + r/2} f(L|l_a, \sigma_a^2) dL, & \text{for } 1 < j < J \\ 1 - \int_0^{\bar{L}_j - r/2} f(L|l_a, \sigma_a^2) dL, & \text{for } j = J \end{cases} \tag{A-4}$$

where r is the length bin width, $\bar{L}_j$ is the midpoint of the length bin j, l_a is the mean length-at-age, σ_a is the standard deviation of the length-at-age distribution, $f(L|l_a, \sigma_a^2)$ is the normal density of the random variable L with mean l_a and variance σ_a^2, and J is the last length bin.

The mean length-at-age, l_a, was modelled with the von Bertalanffy function:

$$l_a = L_\infty \cdot [1 - e^{-\kappa \cdot (a - a0)}], \tag{A-5}$$

where L_∞ is the asymptotic length, κ is the growth rate, and a_0 is the theoretical age at length 0.

The standard deviation of the length-at-age distribution σ_a was modelled with the function, which was adopted from the MULTIFAN-CL model (Fournier et al. 1990, Fournier et al. 1998):

$$\sigma_a = \lambda_1 \cdot e^{\lambda_2 \cdot \left[-1+2\cdot\left(\frac{1-\zeta^{a-1}}{1-\zeta^{A-1}}\right)\right]}, \tag{A-6}$$

where λ_1 determines the scale of the standard deviations, λ_2 determines the length-dependent increase in the standard deviations, and ζ is the Brody growth coefficient (i.e., $\zeta = e^{-\kappa}$).

A.5 Length-weight relationship

The mean weight-at-age, W_a, was modelled with the length-weight relationship function:

$$W_a = \omega_1 \cdot \mu_a^{\omega_2}, \tag{A-7}$$

where ω_1 and ω_2 are the two parameters which determine the allometric curve.

A.6 Maturity

The sexual maturity-at-age Mat_a was assumed to follow a knife-edged function (Punt et al. 1995):

$$Mat_a = \begin{cases} 0 & \text{if } a < a_{Mat} \\ 1 & \text{if } a \geq a_{Mat} \end{cases} \tag{A-8}$$

,

where a_{Mat} is the age at 100% maturity.

A.7 Selectivity

Selectivity was assumed to be knife-edge at the age of maturity.

A.8 Biomass quantities

The spawning stock biomass SSB_t and its unexploited value at equilibrium SSB_0 are:

$$SSB_t = \varphi \cdot \sum_{a=1}^{A} N_{a,t} \cdot W_a \cdot Mat_a; \quad SSB_0 = \varphi \cdot \sum_{a=1}^{A} \tilde{N}_a \cdot W_a \cdot Mat_a, \tag{A-9}$$

where φ is the proportion of females in the stock.

Similarly, the vulnerable (or exploitable) biomass VB_t and its unexploited equilibrium value VB_0 are:

$$VB_t = \sum_{a=1}^{A} N_{a,t} \cdot W_a \cdot S_a; \quad VB_0 = \sum_{a=1}^{A} \tilde{N}_a \cdot W_a \cdot S_a. \tag{A-10}$$

A.9 Exploitation rate

We assumed the catch data Y_t had no error, thus treating the exploitation rates H_t as derived quantities:

$$H_t = Y_t / VB_t. \tag{A-11}$$

A.10 Catch-at-age

Based on the exploitation rate H_t, population abundance $N_{a,t}$, and age-dependent selectivity S_a, the model estimated catch-at-age $\hat{C}_{a,t}$ as:

$$\hat{C}_{a,t} = N_{a,t} \cdot S_a \cdot H_t.$$

APPENDIX B: SIMULATIONS

B.1 Implications of using dynamic reference points

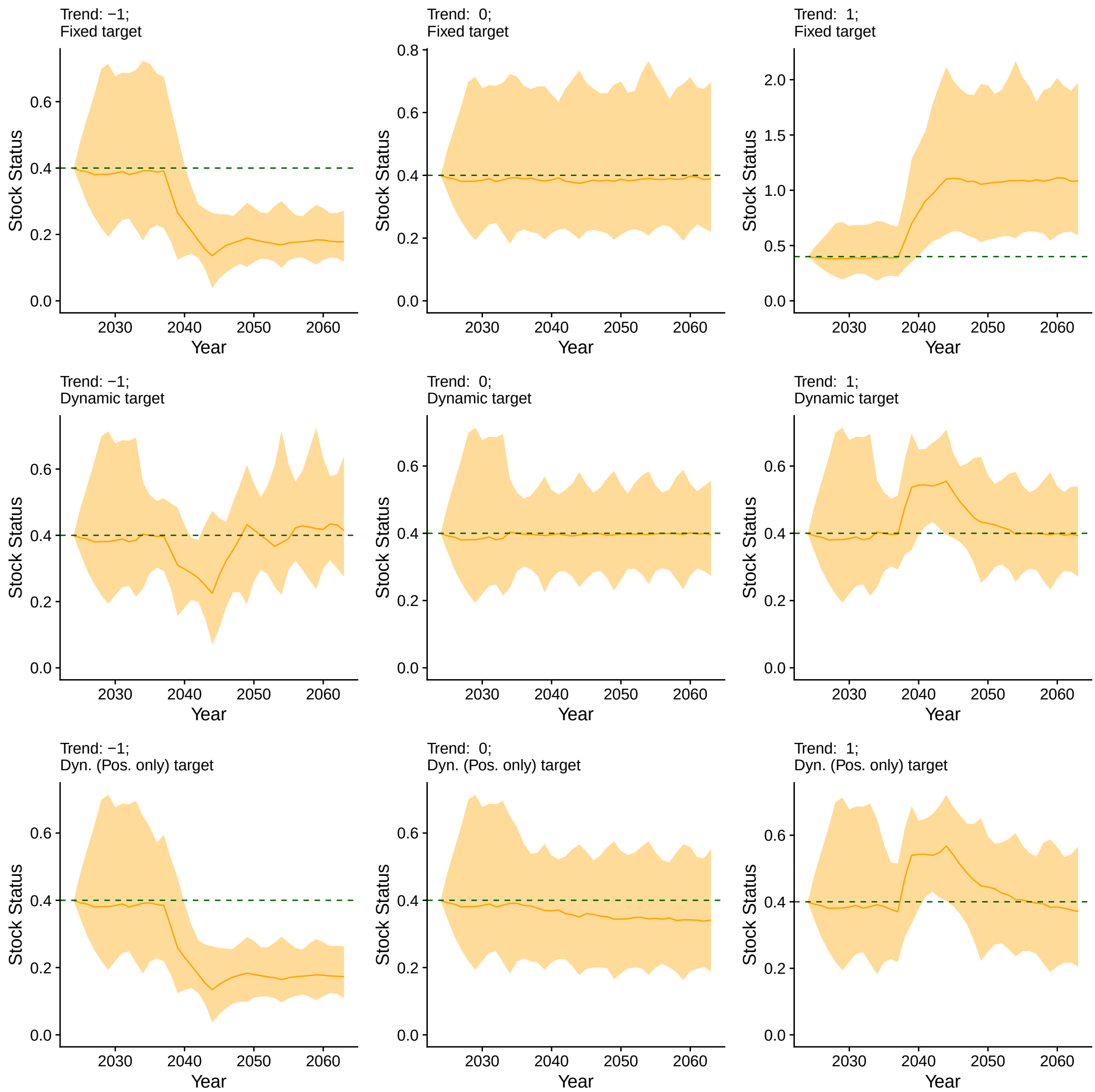


Figure B-1: Stock status (median and 95% of simulated outcomes) for the intermediate simulated life history over time for stocks referenced against fixed, dynamic and positive only dynamic reference points (rows), for declining (-1), stable (0), and increasing (1) recruitment trends (columns).

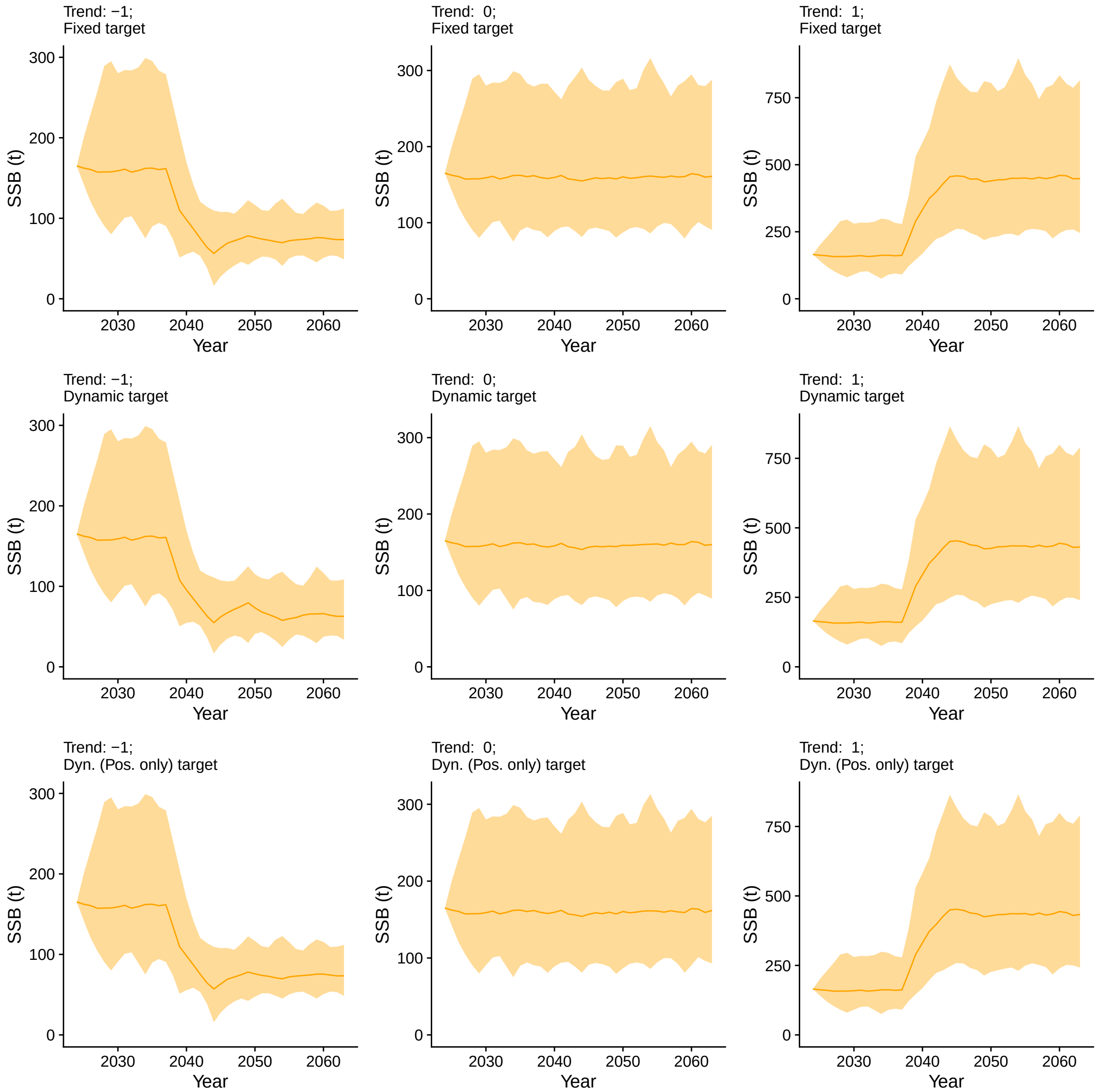


Figure B-2: Spawning stock biomass (*SSB*; median and 95% of simulated outcomes) for the intermediate simulated life history over time for stocks referenced against fixed, dynamic and positive only dynamic reference points (rows), for declining (-1), stable (0), and increasing (1) recruitment trends (columns).

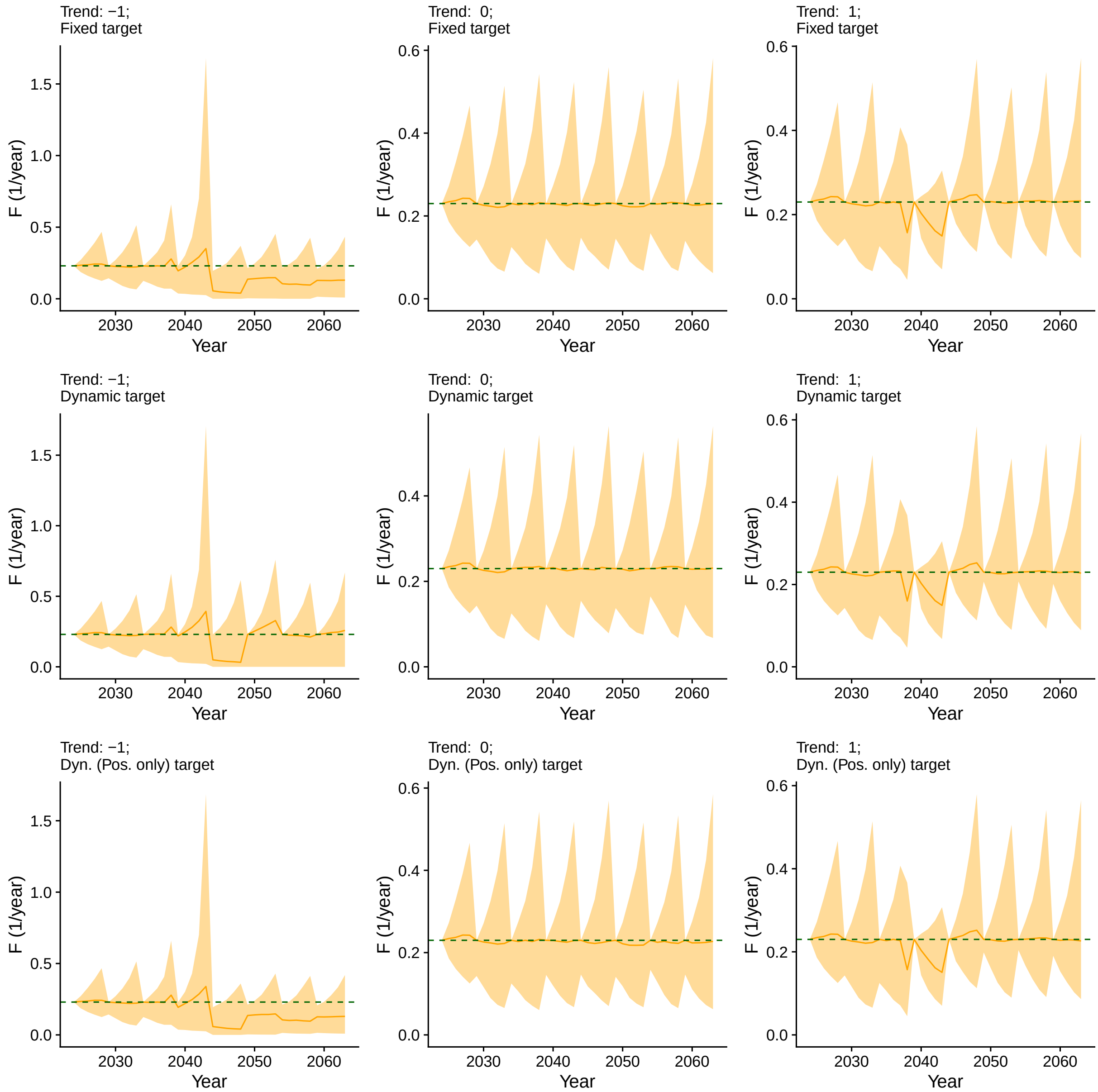


Figure B-3: Fishing mortality (*F*; median and 95% of simulated outcomes) for the intermediate simulated life history over time for stocks referenced against fixed, dynamic and positive only dynamic reference points (rows), for declining (-1), stable (0), and increasing (1) recruitment trends (columns).

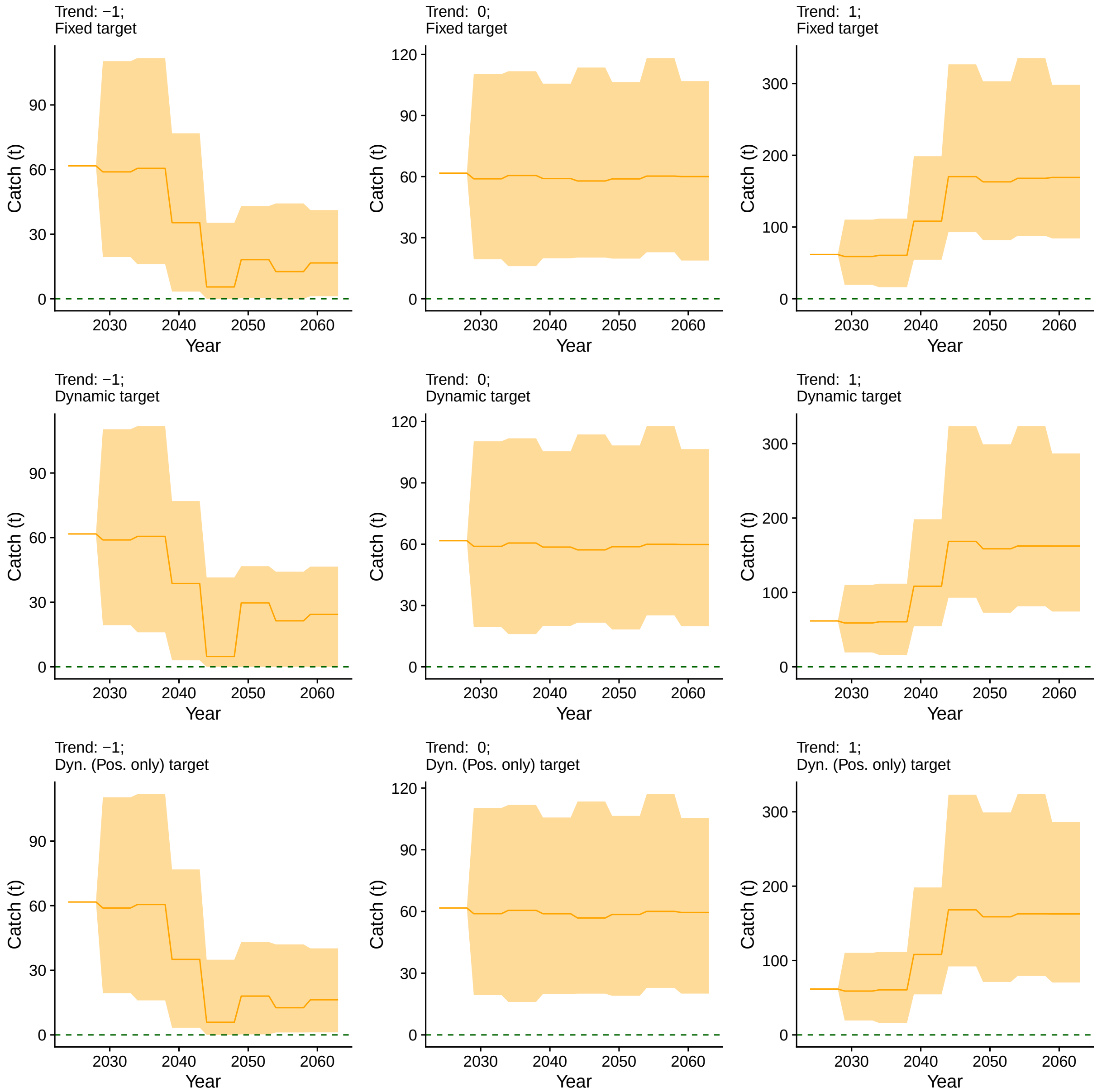


Figure B-4: Catch (median and 95% of simulated outcomes) for the intermediate simulated life history over time for stocks referenced against fixed, dynamic and positive only dynamic reference points (rows), for declining (-1), stable (0), and increasing (1) recruitment trends (columns).

APPENDIX C: FMA 7 CASE STUDY

C.1 Multispecies characterisation in FMA 7

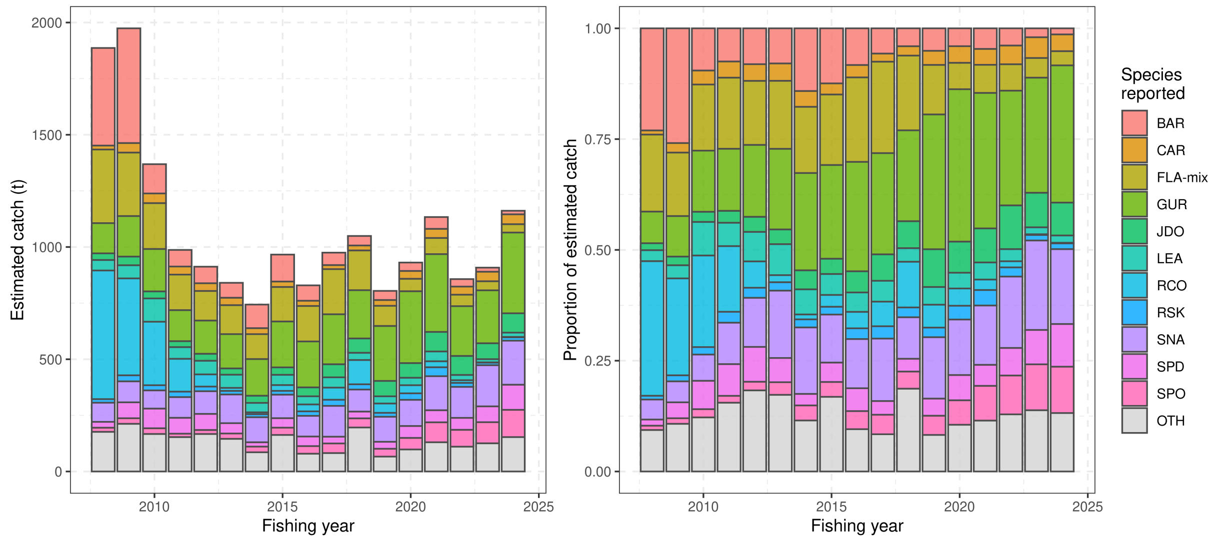


Figure C-1: Catch and proportion of catch for species representing at least 5% of total catch in any one year, plus flatfish-species mixture group (FLA-mix); barracouta (BAR), carpet shark (CAR), (GUR), john dory (JDO), leatherjacket (LEA), red cod (RCO), rough skate (RSK), snapper (SNA), spiny dogfish (SPD), rig (SPO).

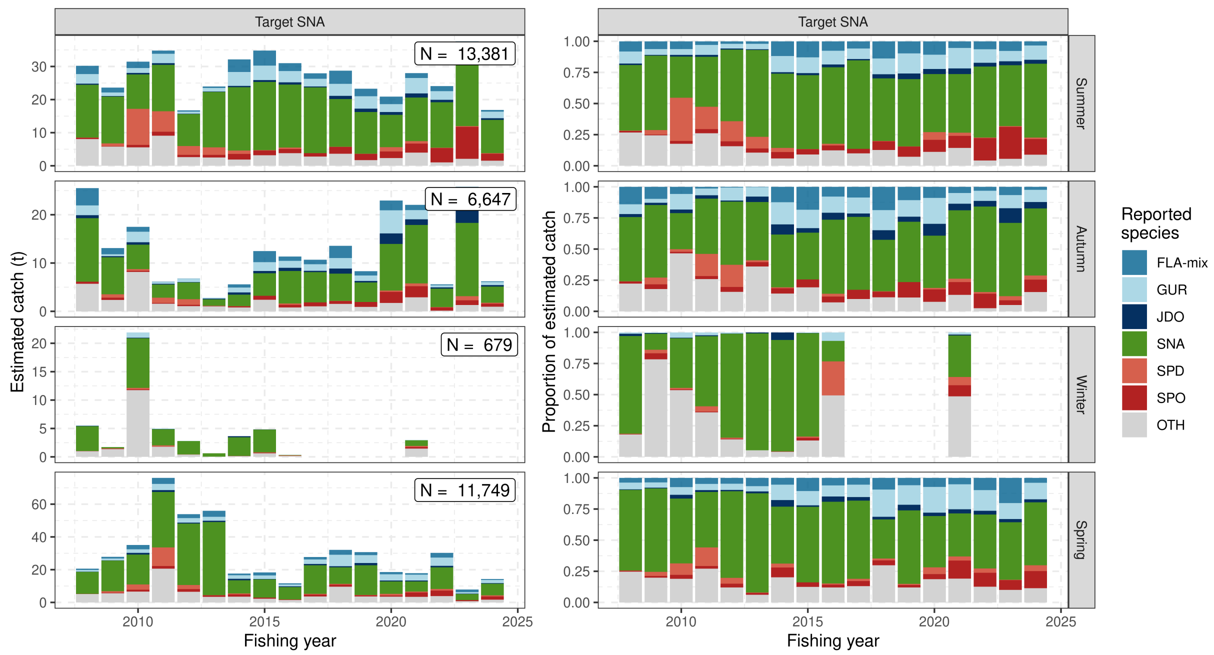


Figure C-2: Seasonal catch and proportion of catch in the snapper target fishery in Tasman Bay Golden Bay (Statistical Area 038) for species representing at least 5% of total catch in the most recent 5 years in the area, plus flatfish-species mixture group (FLA-mix); gurnard (GUR), john dory (JDO), snapper (SNA), spiny dogfish (SPD), rig (SPO). The total effort (number of events) is shown in the top right corner in the annual total catch plots.

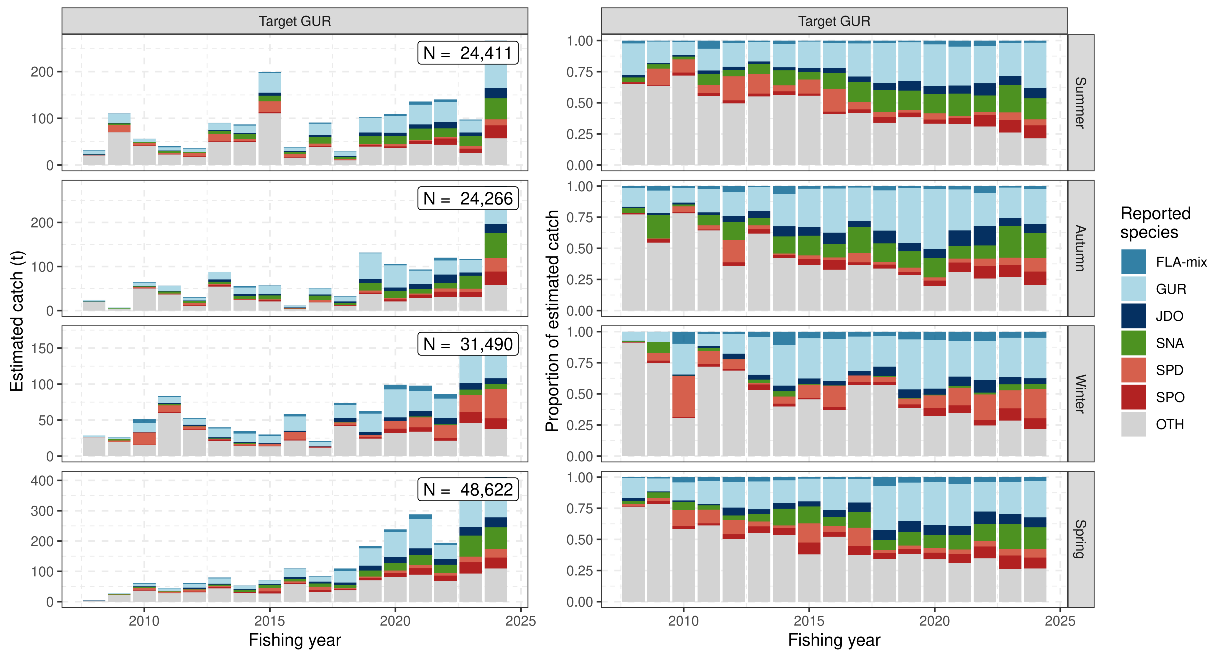


Figure C-3: Seasonal catch and proportion of catch in the gurnard target fishery in Tasman Bay Golden Bay (Statistical Area 038) for species representing at least 5% of total catch in the most recent 5 years in the area, plus flatfish-species mixture group (FLA-mix); gurnard (GUR), john dory (JDO), snapper (SNA), spiny dogfish (SPD), rig (SPO). The total effort (number of events) is shown in the top right corner in the annual total catch plots.

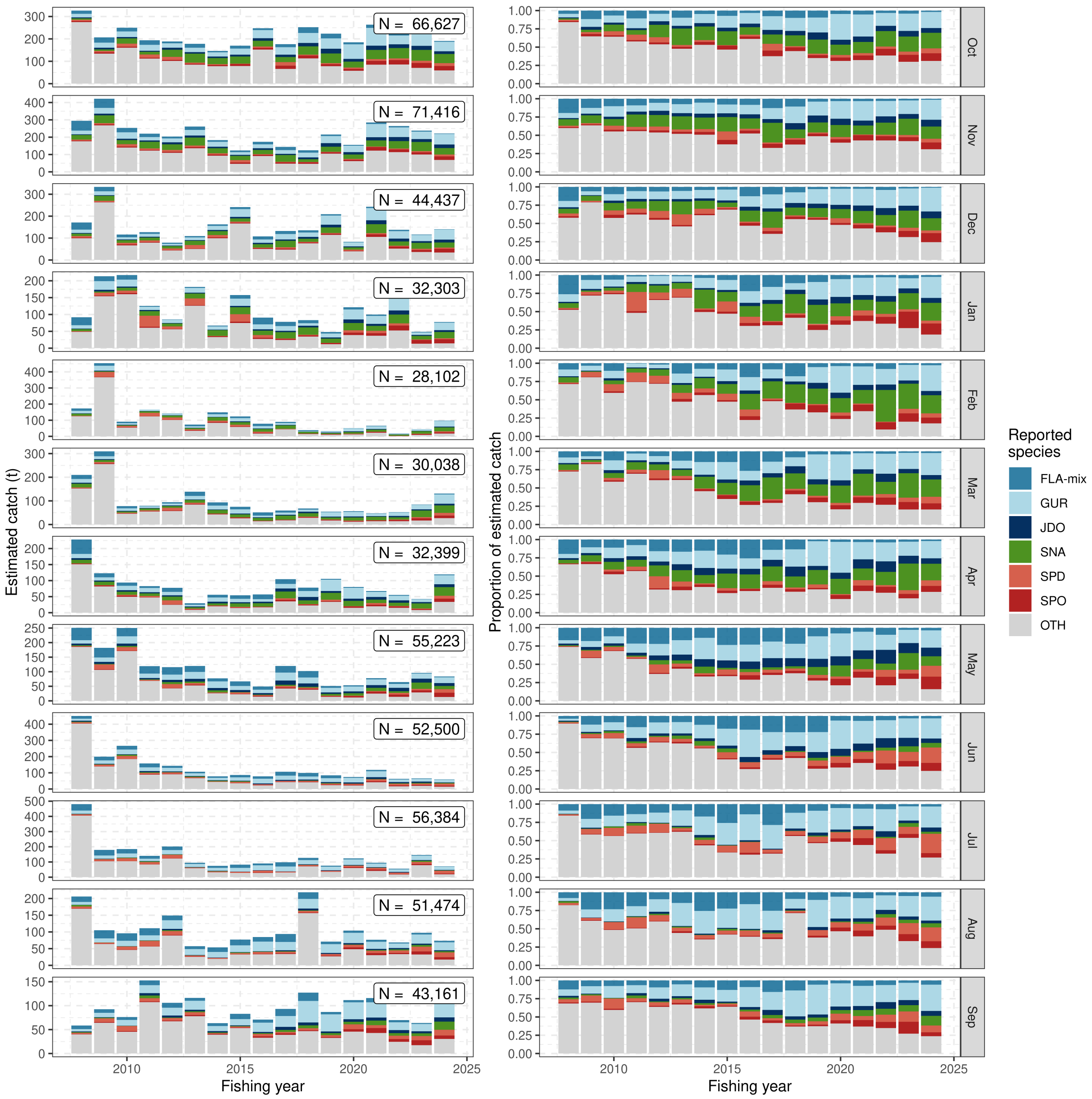


Figure C-4: Monthly catch and proportion of catch in Tasman Bay Golden Bay (Statistical Area 038) for species representing at least 5% of total catch in the most recent 5 years in the area, plus flatfish-species mixture group (FLA-mix); gurnard (GUR), john dory (JDO), snapper (SNA), spiny dogfish (SPD), rig (SPO). The total effort (number of events) is shown in the top right corner in the annual total catch plots.

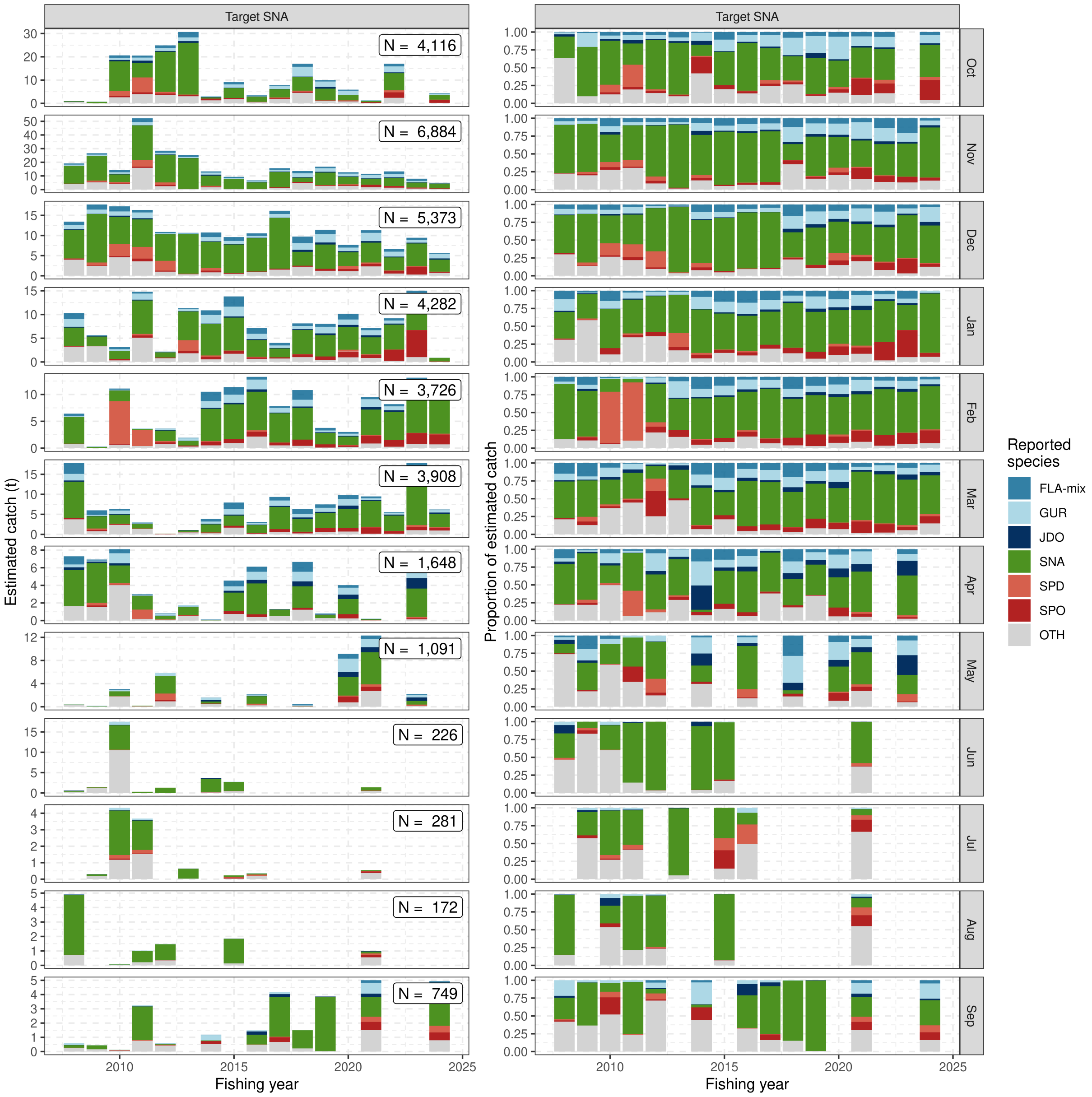


Figure C-5: Monthly catch and proportion of catch in the snapper target fishery in Tasman Bay Golden Bay (Statistical Area 038) for species representing at least 5% of total catch in the most recent 5 years in the area, plus flatfish-species mixture group (FLA-mix); gurnard (GUR), john dory (JDO), snapper (SNA), spiny dogfish (SPD), rig (SPO). The total effort (number of events) is shown in the top right corner in the annual total catch plots.

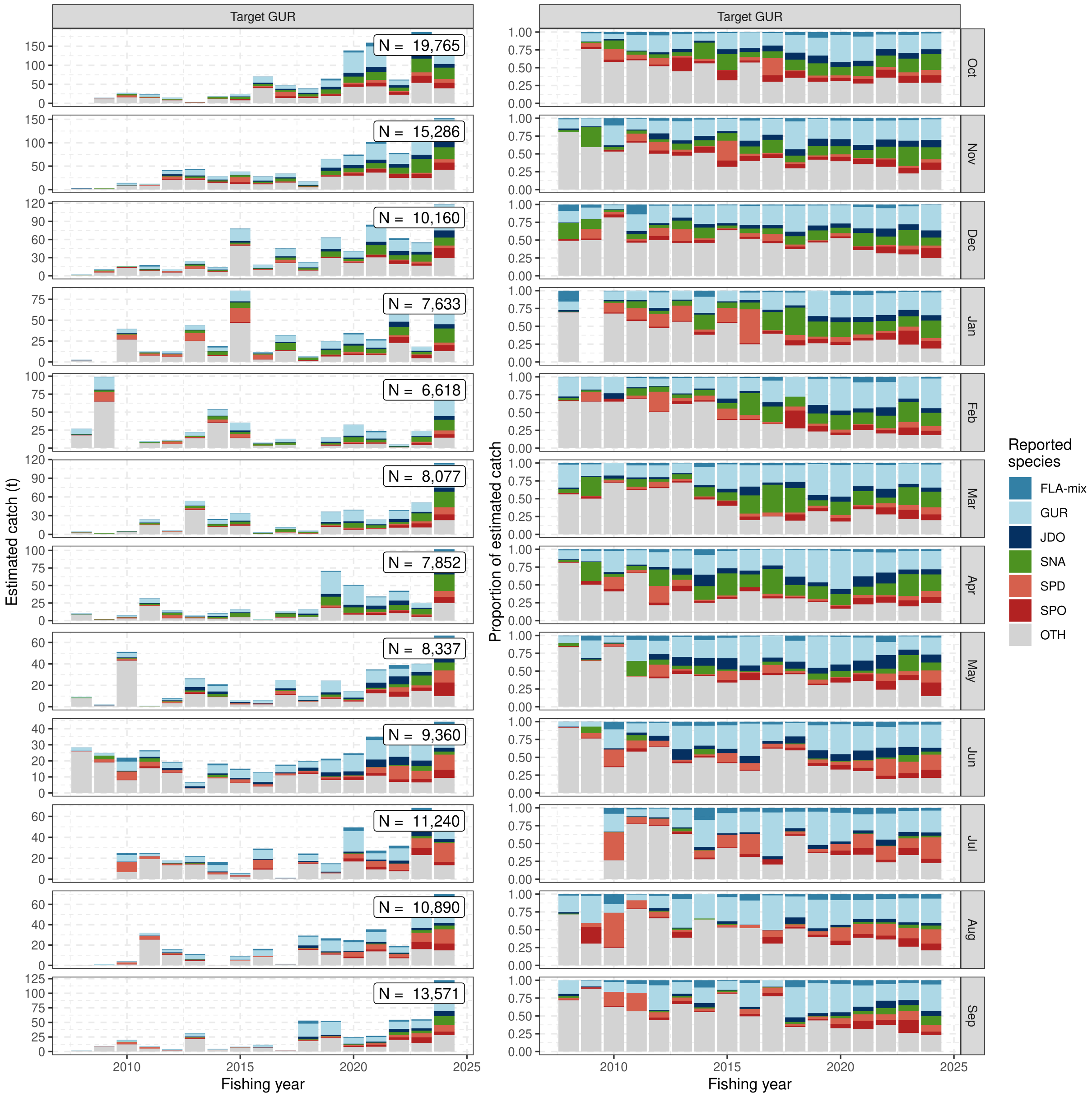


Figure C-6: Monthly catch and proportion of the catch in the gurnard target fishery in Tasman Bay Golden Bay (Statistical Area 038) for species representing at least 5% of total catch in the most recent 5 years in the area, plus flatfish-species mixture group (FLA-mix); gurnard (GUR), john dory (JDO), snapper (SNA), spiny dogfish (SPD), rig (SPO). The total effort (number of events) is shown in the top right corner in the annual total catch plots.

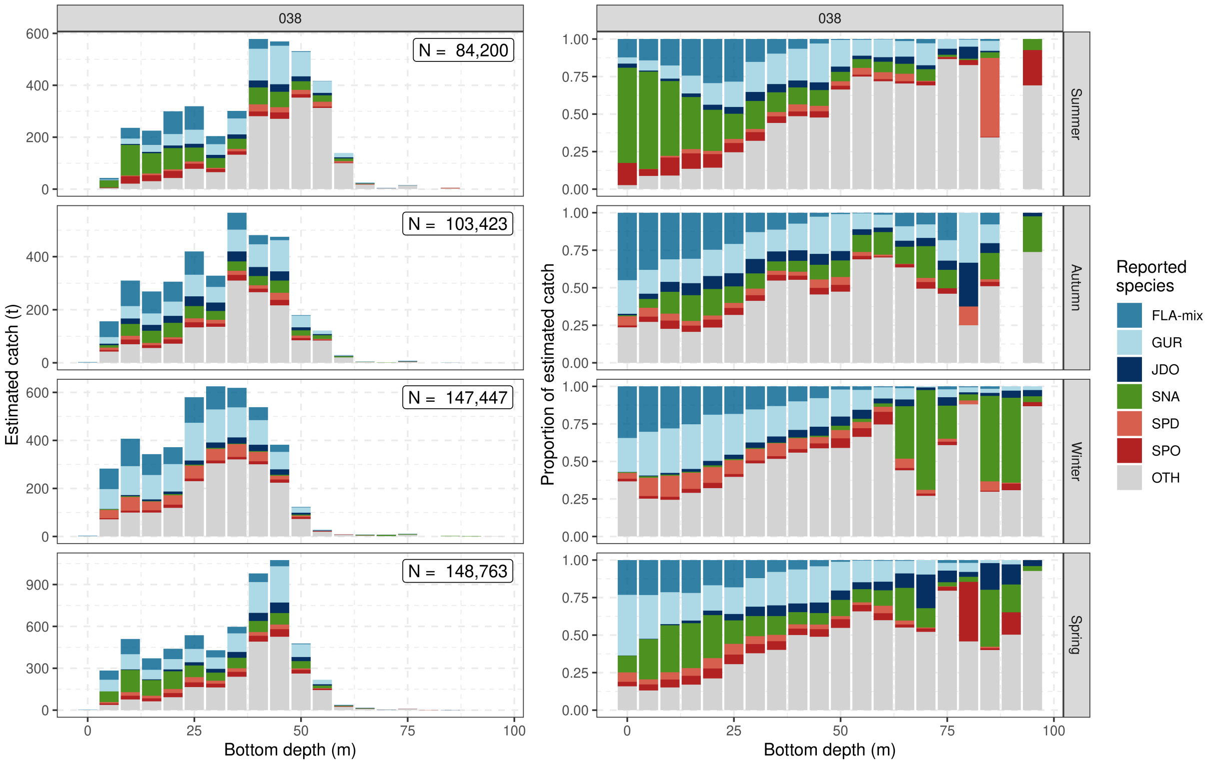


Figure C-7: Seasonal catch and proportion of the catch by depth stratum in Tasman Bay Golden Bay (Statistical Area 038) for species representing at least 5% of total catch in the most recent 5 years in the area, plus flatfish-species mixture group (FLA-mix); gurnard (GUR), john dory (JDO), snapper (SNA), spiny dogfish (SPD), rig (SPO). The total effort (number of events) is shown in the top right corner in the annual total catch plots.

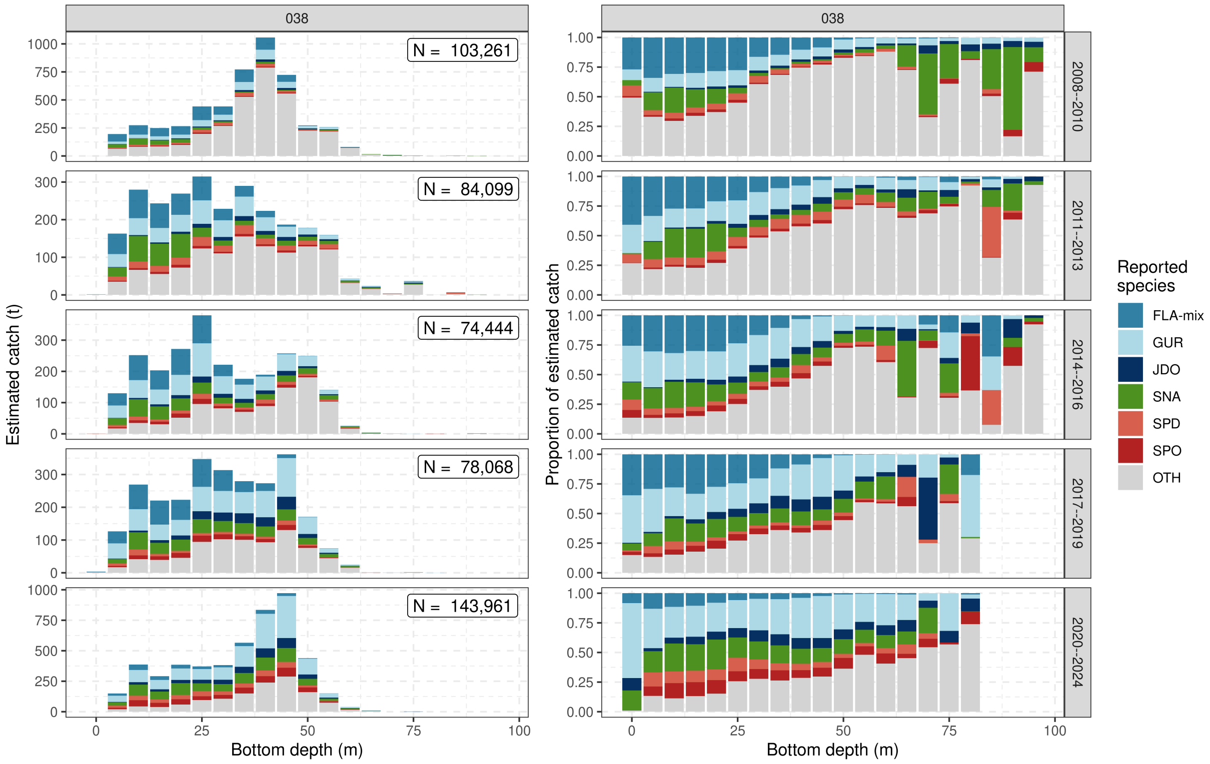


Figure C-8: Catch and proportion of the catch by depth stratum over 3-year blocks in Tasman Bay Golden Bay (Statistical Area 038) for species representing at least 5% of total catch in the most recent 5 years in the area, plus flatfish-species mixture group (FLA-mix); gurnard (GUR), john dory (JDO), snapper (SNA), spiny dogfish (SPD), rig (SPO). The total effort (number of events) is shown in the top right corner in the annual total catch plots.