Stock Assessment, TAC Advice and MSC Reporting for West Coast Rock Lobster Resource

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Executive Summary

For the 2023 fishing season multiple lines of evidence indicate that the stock of western rock lobster is at an acceptable level of depletion (LOW risk of stock depletion).

- Standardised catch rates of legal lobster are at high levels but have decreased slightly over the last two seasons.
- The size composition of lobsters across the fishery is relatively large at all sites but has also declined in the most recent season.
- The most recent puerulus settlement season was slightly above average in the north of the fishery and just below in the south, which was predicted based on a weak Leeuwin current year.
- Current catch levels are less than the biomass expected to recruit into the fishery based on recent puerulus settlement levels (there should be surplus stock).
- Egg production levels (obtained from fishery independent breeding stock surveys) throughout the fishery are near to maximum levels at many sites and at moderate levels at others which does not indicate recruitment overfishing.
- Fishery-independent juvenile surveys at all locations showed consistent catches of pre-legal sized lobsters (65 – 70 mm) indicating that survival from puerulus to this size range has been relatively consistent, i.e., there has been no marked change in juvenile survival in recent years.
- Estimates of relative legal biomass from a biomass dynamics model indicate that levels are very high, and the fishery-wide harvest rate is relatively low (~0.23).
- Estimates of legal biomass from the integrated population model have started to decline since their peak in 2020 in concert with a progressive increase in overall landings. This decline will continue in all management areas at current levels of TAC, with projected estimates to remain above historic levels through to 2029.
- Estimates of egg production from the integrated population model throughout the fishery remain high and well above threshold reference levels over the projected five years based on a continuation of the current TAC.

- Estimates of harvest rates remain low throughout the fishery and continue to increase towards the harvest strategy target of the upper level of the MEY region.
- As outlined in the harvest strategy, the Annual Harvest Level for the upcoming fishing season is determined by estimating the total catch (commercial and recreational) that would be taken in the fifth projected year if it was to fish constantly at a harvest rate of 0.39.
- Based on the above information, the harvest strategy suggests that the current TAC for western rock lobster is appropriate. The Allowable Harvest Level for the 2025/26 financial year was determined as 7630 t.
- The behaviour and biology of western rock lobster is very susceptible to variation in climatic conditions. Water temperatures for the 2024 financial year (2024/25) are predicted to be average to above average.
- The fishery remains reliant on the live export of lobster, and this linkage may strengthen if/when China again begins to import live lobster. The availability and consistency of export markets are considered a high risk.

Background

The West Coast Rock Lobster Fishery (WCRLMF) is located off the West Coast of Western Australia (Figure 1) and was certified under the Marine Stewardship Council (MSC) standard in 2000 and was the first fishery in the world to be MSC certified. Since then, it was successfully re-accredited in 2006, 2012, 2017 and 2022. This document provides (i) an update on changes to the fishery for annual audits by the MSC certification body and (ii) the annual stock assessment update for quota setting of the western rock lobster resource. A weight of evidence assessment of the resource is provided that includes information on other ecological components which may be impacted by the resource in the 2023 fishing season. This document also provides information required to inform the setting of TACs for the future seasons.

Unless otherwise stated, data summarised in this report include the 2023/24 financial year. The data-sets discussed here and synopsis of more comprehensive data can be found in *de Lestang et al. (2016)* and Bellchambers et al. (2017).

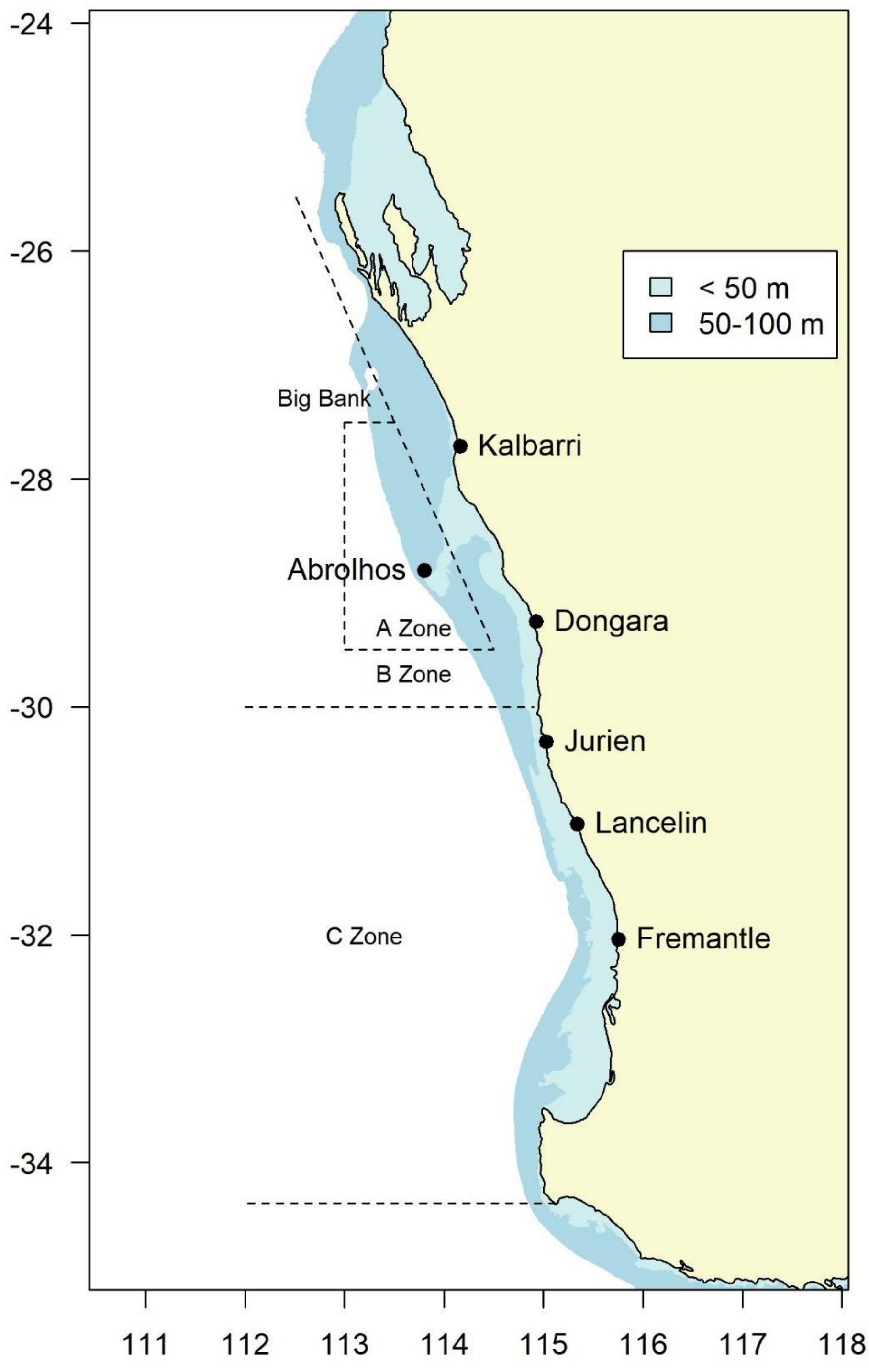

Figure 1. *Map of the WCRLMF highlighting the three management zones and the location of Big Bank.*

2023/24 Management Arrangements

In July 2023, the timing of the commercial fishing season changed to financial year, following advice from the Western Rock Lobster Council (Appendix 1). The TACC for the 2022/23 financial year (subsequently referred to as the 2023 season) was 7300 t (plus 1.5% to replace water loss, i.e. 7409.5 t). The TACC for the 2024 season has been maintained at 7300 t (plus 1.5% to replace water loss). A complete list of historical management changes is listed in Appendix 1. Additional noteworthy management arrangements for the current (2023) fishing season are:

- Exemption for the taking of setose lobsters during whale gear modifications period (May to October inclusive).

- 100% of pot entitlement units may be fished except during whale gear modifications period (May to October inclusive). A sliding scale of pot usage during May to October has been introduced to improve the economics of fishing for small unit holders that, under current usage rates, did not have enough pots to fish with during this period to make fishing economical. For more details on the pot usage sliding scale see : *https://westernrocklobster.org/new-exemption-applying-to-small-entitlement-fishers-during-whale-season-restrictions/*

Risk Based Weight-of-Evidence Stock Assessment

Weight of evidence table

Category	Line of Evidence
L0 Biology & vulnerability	Since the capture of mated females is prohibited and the size at maturity is below the minimum legal length for capture over much of the resource, most females are capable of spawning at least once before becoming available for capture. Moderate vulnerability.
L0 PSA Assessment: Low risk	
L1 Catch	The total allowable commercial catch (TACC) was obtained in the 2023 fishing season. The estimated total allowable recreational catch was obtained in the 2022 fishing season,
L1 Assessment: Resource is assessed as sustainable	
L2 Effort	Effort (pot-lifts) remain close to the historic lows. There has been a small increase in effort over the past three seasons in concert with an increase in TACC.
L2 Catch Rate	Nominal and standardised catch rates in each management zone and by latitude transect all show a slight downwards trend over

	recent seasons but remain well above historical levels. The downward trajectory is consistent with a progressive increase in TACC and poor/average puerulus recruitment in recent years.
L2 Assessment: Resource is assessed as sustainable	
L3 Size Composition	The average size composition of female and male WRL sampled in each management zone is larger than recorded when the fishery progressed to quotas in 2010. A small decline has occurred in the latest season. There is no indication of overfishing reducing the average size of lobster caught.
L3 Assessment: The stock is currently at high levels although there has been a slight reduction in the mean size of lobster caught over the last two financial years. Resource is assessed as sustainable.	
L4 Fishery-independent puerulus indices	Puerulus settlement levels in 2023/24 were around long-term median levels and better towards the northern end of the fishery. This pattern is expected in an El Niño year when Leeuwin Current flow is generally weaker. There is no indication of recruitment overfishing.
L4 Fishery-independent breeding stock indices	Fishery independent levels of egg production remain high throughout the locations sampled during 2023, although the two northern sites (Dongara and Big Bank) both show a recent decline. There is no indication of recruitment overfishing.
L4 Fishery-independent shallow indices	The fishery independent shallow survey indices only provide a short time series. They do show relatively consistent recruitment levels with strong correlations between the index and previous puerulus settlement levels. The indices do not indicate any increases in post-puerulus mortality.
L4 Biomass dynamics model	Estimates from a biomass dynamics model indicate that relative legal biomass is currently ~87% of virgin levels and the fishery-wide harvest rate is ~0.23.
L4 Assessment: The stock is currently at high levels although there has been a slight reduction in empirical egg production levels in the north of the fishery. Legal-sized biomass is estimated to be at high levels. Resource is assessed as sustainable.	
L5 Integrated population model	Estimates of legal biomass have started to decline since their peaks in 2020 in concert with a progressive increase in overall landings. This decline will continue in all management areas at current levels of TAC, with projected estimates to remain above historic levels through to 2029. Estimates of egg production throughout the fishery remain high and well above threshold reference levels over the projected five years based on a continuation of the current TAC. Estimates of harvest rates remain low throughout the fishery and

	continue to increase towards the harvest strategy target of the upper level of the MEY region.
L5 Assessment: The stock is currently at a high level although there has been a slight reduction in the legal stock biomass and egg production over the last two financial years. Resource is assessed as sustainable.	
Environmental Impacts	All life stages of the western rock lobster have been documented to be impacted by the environment. Historic information shows a marked change in the environment, especially with increasing water temperatures. This is causing changes in the timing and size of lobsters displaying certain life history stages, including differences in the magnitude and timing of puerulus settlement, whites' migration and reproduction.
Environment **Risk Rating** for the western rock lobster stock is high due to a changing climate and the strong influence the environment has on every life stage of this species.	
Economic Impacts	The key overseas market for wester rock lobster (China) remains closed but has indicated a reopening in the 2024/25 financial year. Beach prices have increased slightly recently.
Economic **Risk Rating** for the western rock lobster fishery is high due to a reliance on export markets.	
Social Assessment	The number of commercial operators continue to decline. Recreational fishers continue to have access to good catch rates of lobster. Back of Boat Sales to the public remain good and participation by industry in this program remain string.
Social **Risk Rating** for the western rock lobster commercial fishery is low due to their investment in good governance, the maintenance of high recreational catch rates and Back of Boat sales.	
Final Risk: In addition to low vulnerability, fishing practices afford protection to a large portion of the breeding population (almost all females and small maturing males). Catches, catch rates, size composition, independent surveys and modelling do not indicate overfishing. Overall, egg production is above the threshold levels (> 75% certainty) and harvest rates are below targets, therefore the resource is considered sustainable. C1 Minor (HR Below Target): Likely (L3) C2 Moderate (Biomass above Threshold): Unlikely (L2) C3 High (Biomass between Limit and Threshold): Remote (L1) C4 Major (Below Limit): Remote (L1)	

Therefore, the overall weight of evidence assessment for western rock lobster puts the current risk estimate at **Low** (C2 x L2)

Risk assessment matrix

Risk assessment matrix for western rock lobster based on the estimated egg production levels from the Level 5 integrated population model.

Consequence (Stock Depletion) Level	Likelihood			
	L1 Remote (<5%)	**L2 Unlikely (5-20%)**	**L3 Possible (20-50%)**	**L4 Likely (>50%)**
C1 Minor (above Target)			X	
C2 Moderate (below Target, above Threshold)		X		
C3 High (below Threshold, above Limit)	X			
C4 Major (below Limit)	X			

Summary

Multiple lines of evidence indicate that the stock status is above the threshold reference point with a high degree of certainty and below the harvest rate target. The stock was assessed as being at a LOW risk of overfishing. The stock is showing declines over recent years and the harvest rate is increasing. No increase in TAC is required to move the harvest rate towards the target level.

Level 0 Assessment

Biology and vulnerability

Western rock lobsters (WRL) mature at an age of about seven years post settlement (PSA score 2) and are expected to live for at least another seven to ten years. The average maximum age of WRL is, therefore, expected to be around 15 years (PSA score 2). WRL produce between one and two batches of eggs per spawning season with larger females producing over 1 000 000 eggs per batch (PSA score 1). The eggs are fertilized externally but maintained on the tail of the adult female for six to eight weeks before the larvae are released live into the environment. Even though this behaviour is consistent with that of a live bearer, lobsters are considered delayed-broadcast spawners (PSA score 1).

As WRL feed on many of the small macro-invertebrates such as polychaete worms and small bivalves they are considered to occupy the trophic position of a first-order predator, ranging in tropic position from 1.90 and 2.18 (PSA score 1). Strong positive relationships existed between recruitment levels (puerulus abundance) and subsequent catches three and four years later when the fishery was under input controls (Caputi et al., 1995; de Lestang et al., 2009). The relationships showed strong density-dependence at all locations along the coast, with increasing levels of recruitment only marginally increasing subsequent catches (PSA score 1).

Most of the geographic distribution of WRL is accessed by the WCRLMF commercial fishery, with only some research closures (e.g., Big Bank and Leeman) as well as ‘fringe’ regions such as the Ningaloo Marine Park, devoid of commercial fishing (PSA score 3). Recreational fishing occurs mainly in shallower waters close to regional centres and the Perth metropolitan region. The recreational sector therefore accesses less than 30% of the distribution of this species (PSA score 2). The southern extreme of this species’ distribution is relatively erratic in its densities of lobsters as it is highly influenced by recruitment variability. Only following years of strong Leeuwin Current does this region contain significant number of lobsters. This area represents the fishing grounds of the South Coast Crustacean Managed Fishery (SCCMF) and is only a small fraction of the overall distribution of this species (PSA score 1).

As WRL are the target species of the WCRLMF, SCCMF and the recreational lobster fishery, the fishing methods used directly target this species (PSA score all 3). All fisheries use pots as their main method to capture lobsters (the recreational sector is the only fishery where catches from diving is also permitted). Legislation requires all lobster pots to be fitted with a minimum of three escape gaps that allow the majority of undersize (<76 mm carapace length) lobster to escape entrapment. Furthermore, research has shown that lobster pots are relatively inefficient, only capturing a small proportion of those that attend a pot each night. In the northern part of the fishery, lobsters below the size at maturity are rarely caught, whereas in the south where the size at maturity is larger, lobsters below the size at maturity can be retained within a pot (PSA score 2). Lobsters that have recently mated or are carrying eggs must be returned directly to the area they were captured within five minutes. Research has shown that if handled with care and returned quickly to the water the survival of lobsters is extremely high (PSA score 1).

The total PSA score is 1.96 for the Western Rock Lobster, with the MSC PSA score being 96 out of 100. This classifies this species as being of **low risk to over-exploitation**.

Level 1 Assessment

Catch and effort of retained lobster

Pre quota (pre-2008) catches varied in response to recruitment pulses and effort varied more in response to management changes (e.g., pot reductions, see Appendix Table 1). However, in the late-2000s, due to significant management changes including the move from input to output (quota) controls, both the catch and effort declined in concert. Since 2010, changes in catch have occurred only due to changes in the allocated total allowable commercial catches (TACC) which have generally been reviewed annually. Effort needed to attain these various TACCs has therefore varied in response to lobster biomass, the timing within a year that lobsters are targeted and the level of high grading. In the most recently completed season (2023) landings of lobster were the highest since 2008 at 7400 tonnes, representing 99.9% of the 7409.5 t (7300 * 1.5% for water loss) TACC (Figure 1.1). Although catches have slowly increased since ~2012, effort remains close to its historical lows (Figure 1) and indicates that **the stock is at low risk to over-exploitation**.

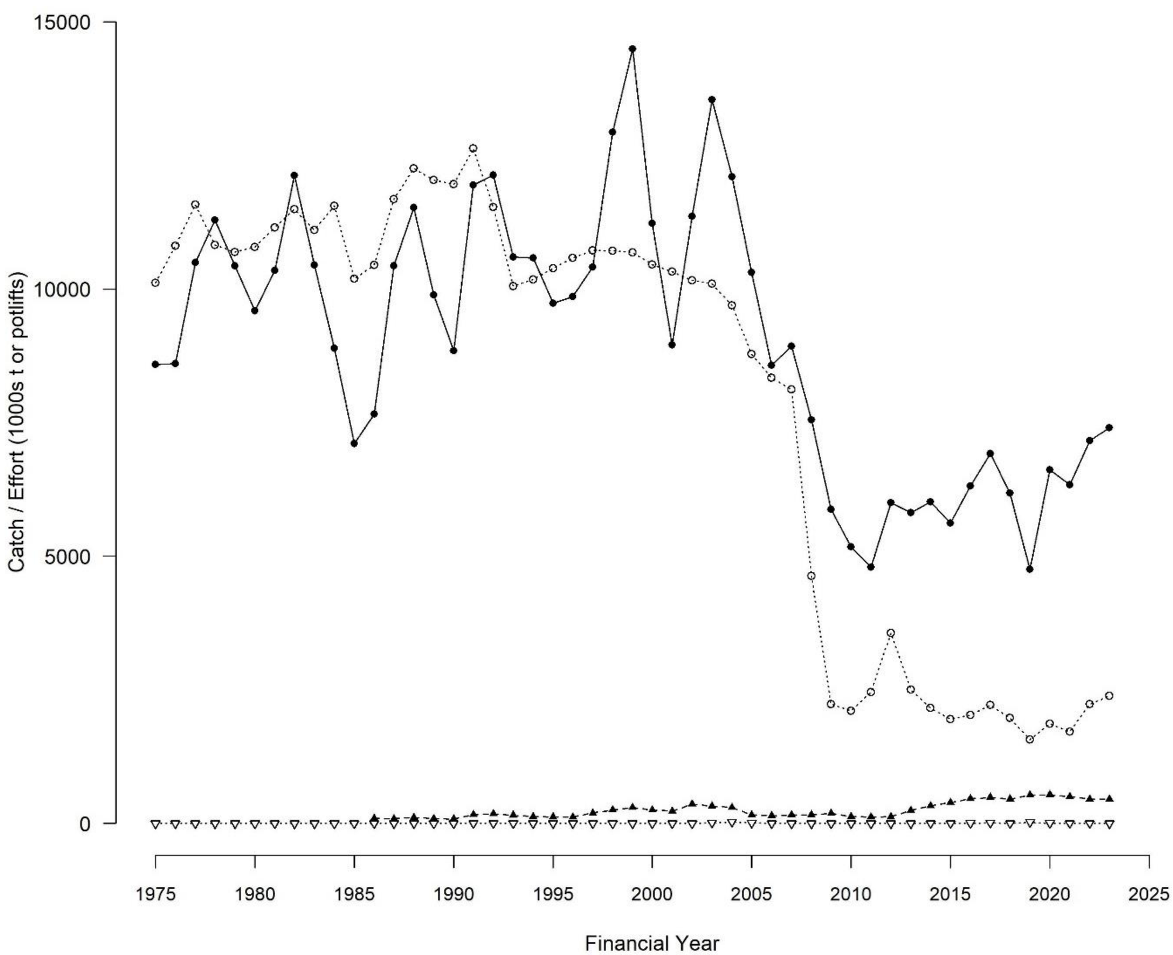

Figure 1.1 Annual west coast commercial (WCRLMF) catch (solid black) and effort (pot lifts: dotted line/open circles), stat-wide recreational catch (solid black triangles) and south coast commercial (SCCMF) catch (open triangles) of western rock lobster by financial year.

Level 2 Assessment

Standardised catch rate of legal lobster

Catch rates are standardised to account for individual fisher's behaviour including the practise of high grading of legal lobsters, which began in the 2010/11 fishing season when the fishery moved to quota management. Total catch for each fishing record is calculated by combining the weight of lobster landed with the weight of lobster high-graded (not landed and returned to the sea alive). Since only the number of lobster high-graded is recorded, this integer value is scaled by an average weight of a lobster (0.5 kg) to convert this record to a weight. Catch rate averages are restricted to data derived from fishing records in which more than 25 pots were fished and to fishing licenses (MFLs) that reported catch on more than 24 individual months (they fished for at least two years). Catch rates were calculated for each fishing zone independently as kg (landed + high-graded) per pot lift, and standardised (in log space) for financial year (fyear), month, soak time and fishing license as factors. The average response for each fyear in each zone was back-transformed from log-space using the emmeans package. These are plotted against total catch and nominal catch rates to examine the influence of standardisation.

Standardisation reduced the overall magnitude of catch rates in each zone (Figure 2.1), mainly due to the season length being extended in 2012 to include lower catch rate months (July – October). Some marked peaks in nominal catch rate (e.g. 2011 in A zone) were removed by the standardisation. In general, standardised catch rates (Scpue) started to increase in all zones with the marked reduction in catch in 2008. Scpue increased rapidly (350%) in A zone over three years and has essentially remained at this increased level since, whereas in the northern coastal zone (B), catch rates slowly increased following the decline in catch to peak in the 2021 financial year at 380% higher (Figure 2.1). In C zone, Scpue also increased slowly over the first six years after catches declined to peak at 340% of 2007 levels, before leveling off. In the last two seasons catch rates have shown a slight decline as commercial catches have increased and poorer puerulus settlement years (see independent surveys: Puerulus) have entered the fishable biomass). Scpues still remain well above pre-2008 levels (all zones still over 300% higher). Zonal Scpues remaining substantially higher than pre-2008 levels in all zones indicates that **the stock is at low risk to over-exploitation**.

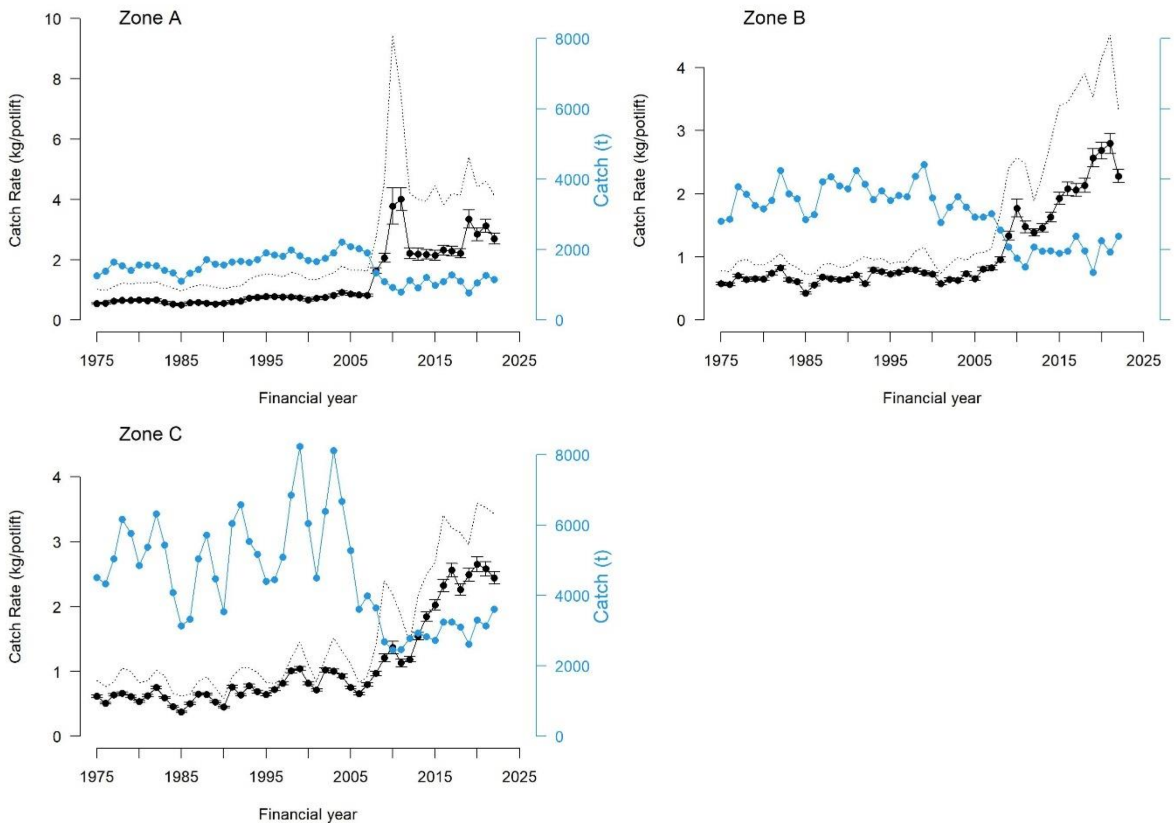

Figure 2.1. Annual commercial catch (blue), nominal catch rate (dotted black) and standardised catch rate (solid black; ± 95% CI) of legal lobster catch (kg / potlift) in each main management zone.

When examined on a latitudinal basis, standardised catch rates of non-migrating residential lobsters (data restricted to months when lobsters are not migrating; March – June) displayed a very similar pattern to those grouped by management zone and based on all months of the fishing season (Figures 2.1 and 2.2). All areas (except Latitude 27 which has limited data and associated large CIs) showed a decline in catch rate over the past season (2022 to 2023), with areas in the northern parts of the fishery (Latitudes 27-29) showing this for the past two seasons (2021 to 2023). A decline in catch rate was expected from the 2021 to 2022 seasons since a much greater catch was landed in 2022 (~4400 t) than in previous seasons since the transition to quota (ranged between 2600 – 3800 t). Similarly, in 2023 the catch landed during January – June was again relatively large (~4400 t). In all areas, catch rates of residential lobsters remain well above historical levels and therefore do not indicate the population has been overfished (the **fishery is at low risk of being overfished**).

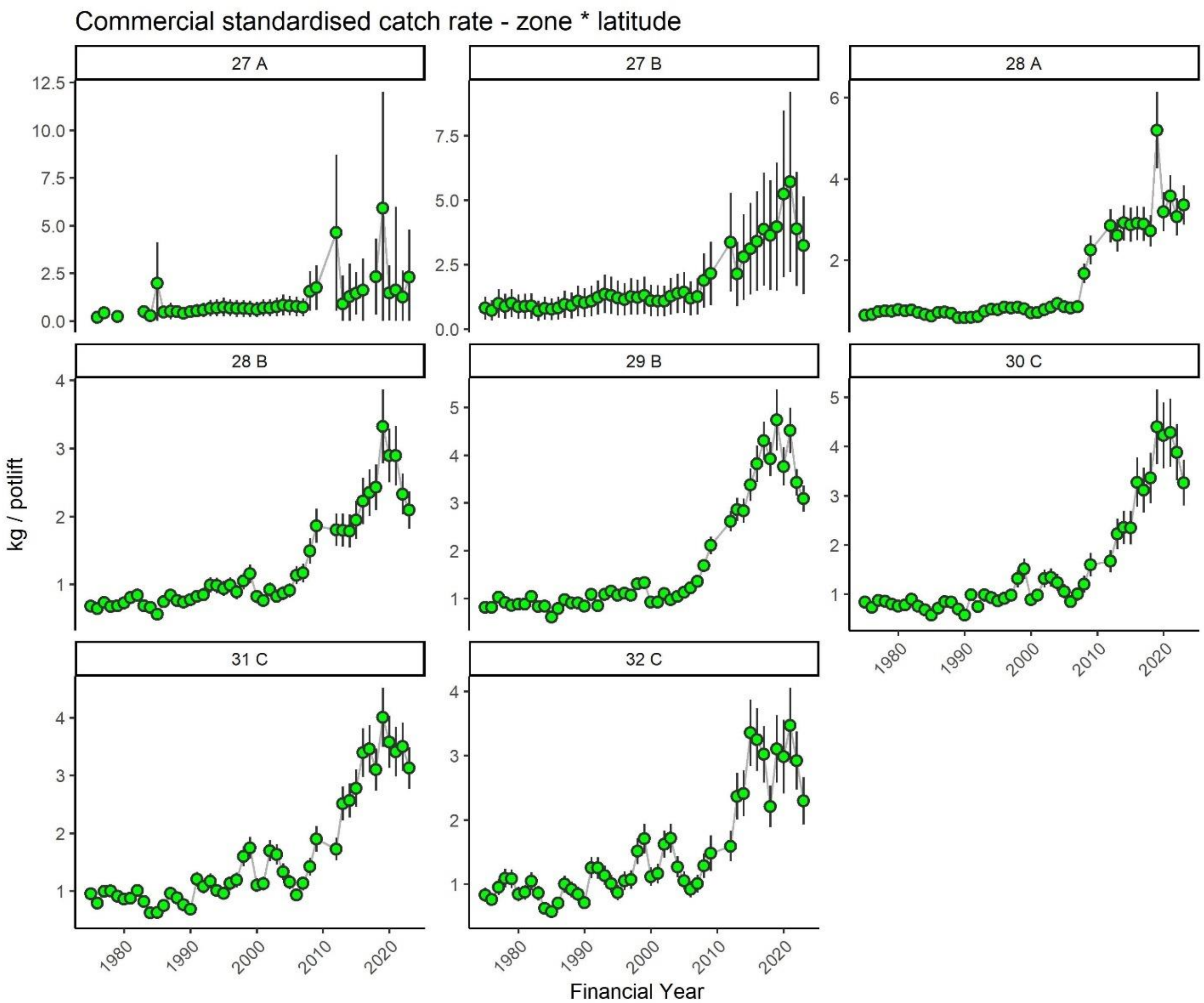

Figure 2.2. Annual standardised commercial catch rate (± 95% CI) of legally lobster catch (kg / potlift) in each main management zone split by latitudinal band.

Level 3 Assessment

Size Composition

Commercial monitoring on-board WCRLMF vessels has occurred since 1971 at five locations along the coast (Zones B and C) and since 1984 at the Abrolhos Islands (Zone A). Carapace lengths (CL) of all measured legal (>76 mm CL) female and male lobster were standardised, using a linear model, for the factors of financial year, month, soak time and water depth. Marginal mean length (averaged over month, soak time and depth of fishing) were produced using the emmeans package.

Mean CL for both females and males displayed very similar trends between the sexes and zones (Figure 2.3). All area/sex combinations showed a progressive decline from when records first started to a minimum around 1993 – 2000, after which a progressive increase occurred and has continued in most area/sex combinations until the most recent year (Figure 2.3). In recent years the mean size of both female and male lobster in each zone, respectively, is larger over the last three years than it was in the 1990s (Figure 2.3). Continued progressive increases since ~ 2000 in the mean length of both female and male lobster measured from each zone indicates that **the stock is at low risk to over-exploitation**.

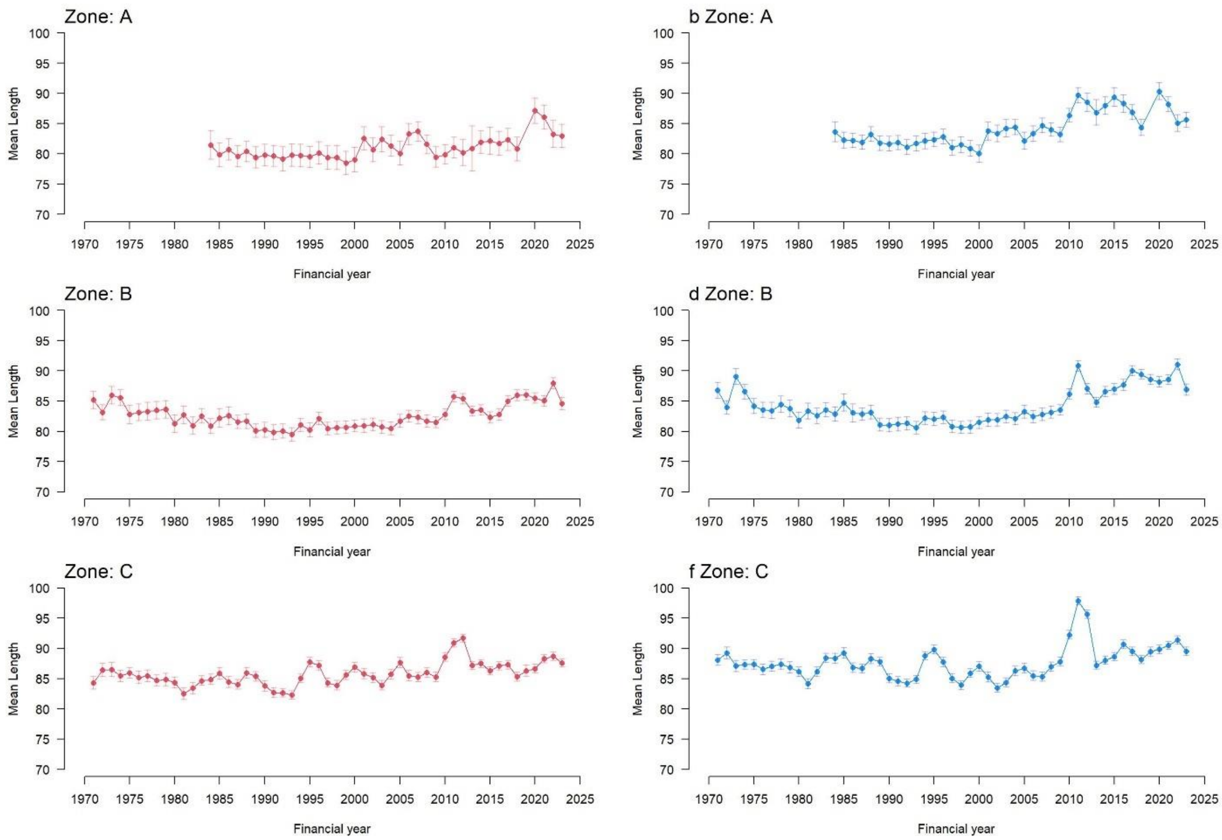

Figure 2.3. Standardised mean length (± 95% CI) of female (red) and male (blue) lobster measured during commercial monitoring in each fishing zone.

Level 4 Assessment

Fishery-independent indices

Three independent surveys are conducted each year and occur in all three management zones: 1) puerulus monitoring which examines the settlement rates of post larvae since 1968; 2) independent breeding stock survey (IBSS) which records the catch composition at up to eight deeper (20 – 60 m) water locations over a ten day period since 1991; and 3) independent shallow water survey (ISS) which records the catch composition at 12 separate sites in shallower (2 – 5 m) waters throughout the fishery over two days since 2021.

Puerulus monitoring

Puerulus monitoring occurs every new moon period (5 days either side of the new moon) at (currently) eight locations along the coast. The lunar-monthly sampling protocol has not changed since the inception of the program (see de Lestang et al. 2016 for sampling protocol). A settlement season spans May to April (as such the temporal structure of a season is offset to financial year by two months). In months when a sample was not taken (due to logistical issues and has occurred only at the start/end of a season when settlement numbers are very low), the levels of settlement are estimated using a generalised additive model (GAM) from the mcgv library). This GAM model used season as a factor and day of the season (days since 1st May of that season) as a spline. Based on correlative studies between puerulus settlement and commercial catches, it takes ~ 3 – 4 years for puerulus to grow to the minimum legal length for capture. For example, the large puerulus settlement recorded in settlement season 1995 (May 1995 – April 1996) resulted in increased catches and catch rates in financial years 1998 and 1999 (Figures 2.1, 2.2). Recruitment can also impact the mean size of the population (Figure 2.3), for example in 1998, which was three years after a good recruitment, the mean size of lobster measured was lower in both A and C zones.

Puerulus settlement at each location varies markedly between successive years, generally in response to changes in oceanic conditions, with exceptionally low levels of settlement occurring in 2008 and 2009 (de Lestang et al. 2015) (Figure 3.1). Since these years the within-season pattern of settlement has changed, with settlement occurring on-average, one-two months later each season, and declining overall in the more southern locations such as Lancelin, Alkimos and Warnbro (Kolbusz et al. 2021)(Figure 3.1). The most recent completed settlement season (May 2023 – April 2024) was average/slightly above average in Zone B, average/below average in Zone C and below average in Zone A. This settlement will enter the fishery in 2026 and 2027.

There is currently no stock-recruitment relationship known for this stock (variation in settlement is primarily driven by environmental factors), therefore below average levels of puerulus settlement does not indicate recruitment over-fishing.

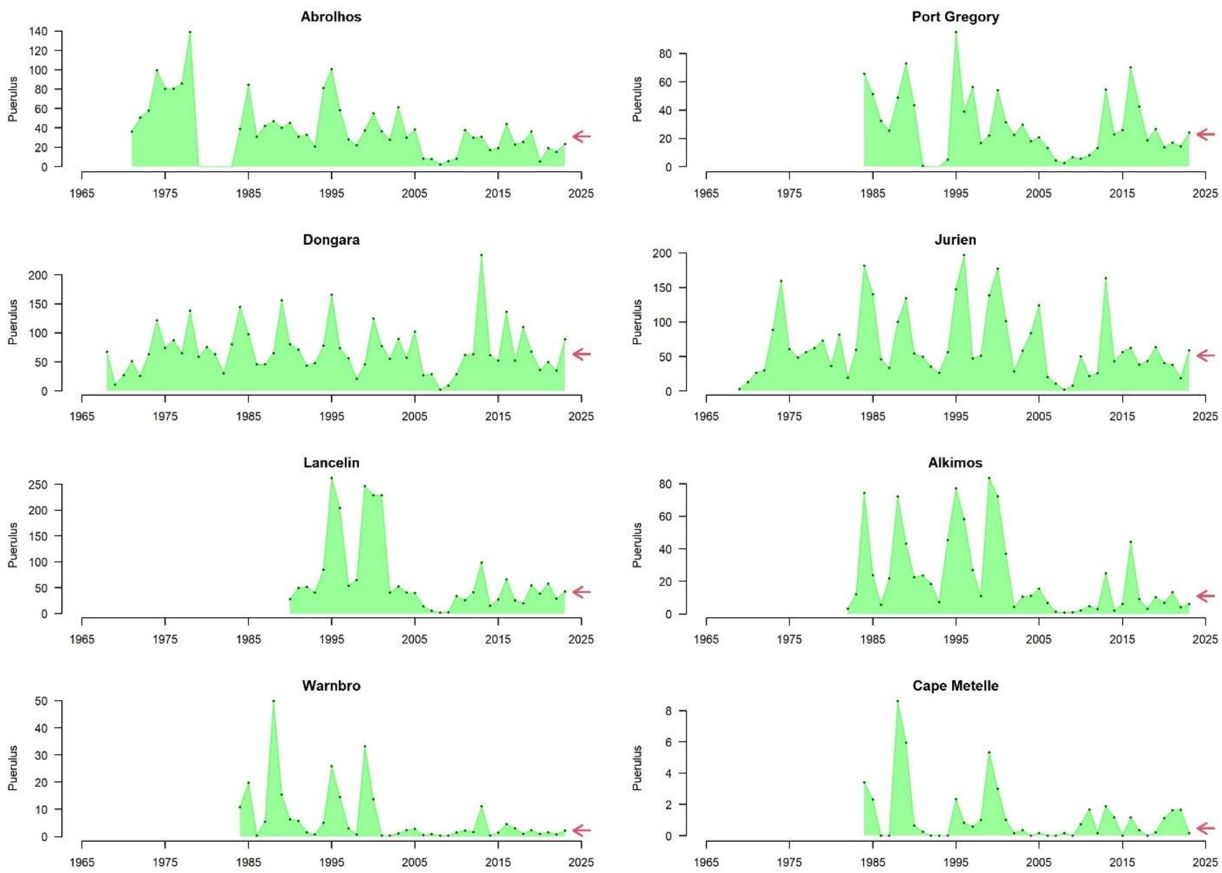

Figure 3.1. Annual average puerulus settlement (number per collector) at each sampling location with the long-term median level at each sampling location shown by a red arrow.

A strong relationship existed between levels of puerulus settlement and future commercial catches of lobster three - four years later when the fishery was managed under input controls (de Lestang & Caputi 2009). Much of the success of this relationship was due to the commercial fishery taking a relatively high proportion of lobsters growing into legal size. This relationship has been projected into post management change years (2008 onwards) to provide an indication of what the biomass of new recruits into the fishery could have been expected to be under this previous scenario.

The relationship between puerulus settlement and commercial catch was strongest in zone C and weakest in zone A (Figure 3.2). In all zones, the effort reductions in 2008 reduced commercial catches well below the expected recruitment levels (expected commercial catch based on puerulus) and by the time quotas were introduced in 2010, legal recruitment levels had dropped in B and C zone down to commercial catch levels. Since puerulus settlement levels recovered in 2010, expected legal recruitment levels in 2013 and 2014 started to increase in all zones. Since 2015 the expected legal recruitment to the fishery (i.e. puerulus settlement lagged three/four years) has remained well above commercial catches by ~ 1000 t in each management zone (Figure 3.2). This discrepancy between expected legal recruitment to the fishery and commercial catch indicates the stock is at low risk of being over-exploited.

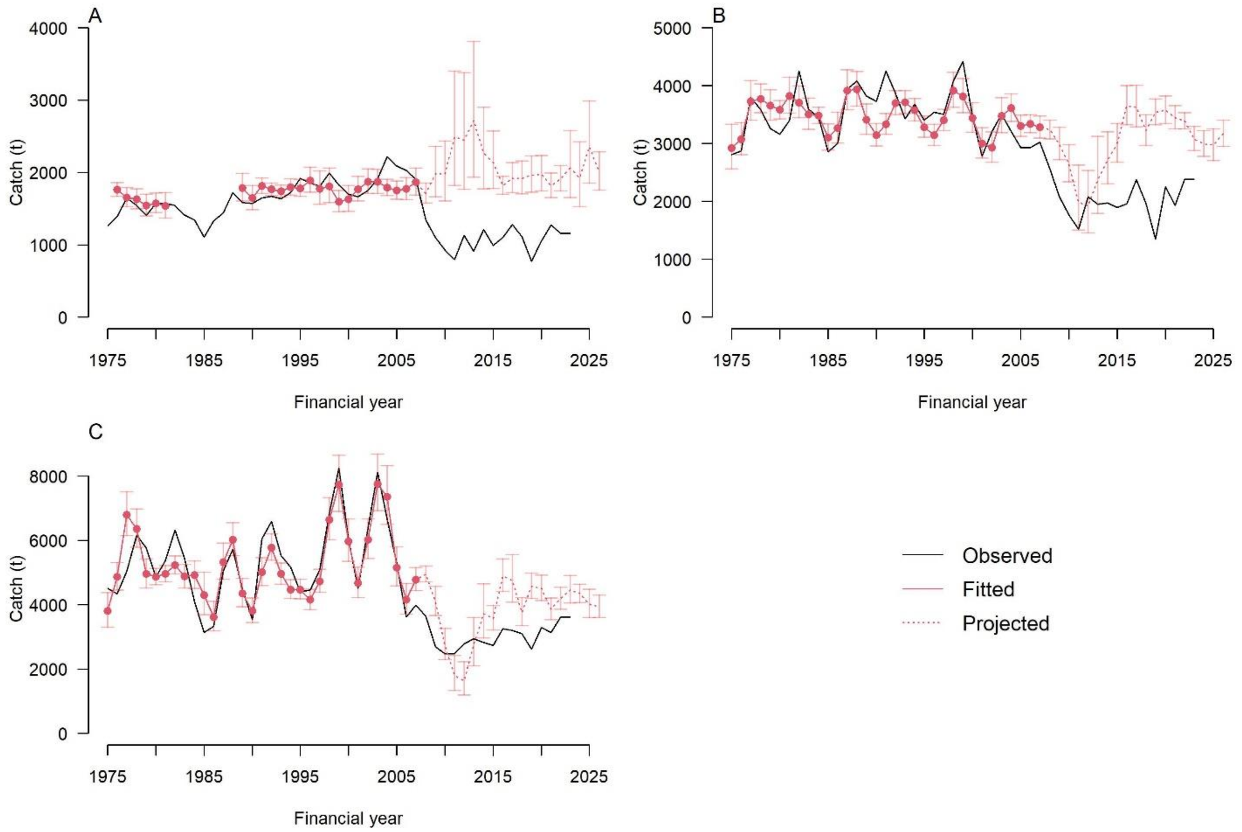

Figure 3.2. Commercial catch (black) and puerulus-based catch prediction fitted to catch years ≤ 2007 (solid red) and projected over future years (dotted red) with 95% CI in the three management zones of the fishery.

Independent Breeding Stock Survey

The Independent Breeding Stock Surveys (IBSS) occur annually over 10 days that span the last new moon periods prior to the start of the historical fishing season (15 November). Due to the staffing requirements only three-four surveys can be run concurrently, as such generally three surveys are run over the September/October new moon (either Fremantle, Jurien, Leeman, Big Bank and Kalbarri) and three over the October/November new moon (always Lancelin, Dongara and Abrolhos). Each location contains multiple (between 20 and 40) lines of pots (all pots with closed escape gaps) with each line containing 20 pots and a single line is considered a replicate sample. All pot locations are fixed sites determine by commercial fishers when the surveys were first developed (Chubb 1991). As such pots catches are averaged over each line and the line averages are used to construct a site annual index using a linear model (see below). These surveys are standardised where possible (same pot locations, pot types, bait type, soak period, moon phase) but cannot account for changes in catchability due to other factors such as moult stage, breeding stage and water temperature. Any pot that is considered to not be fishing efficiently (e.g. has a broken batten or contains a lobster predator) is removed from the analysis. Since logistical issues can result in some lines not being surveyed, pots being lost (occurs rarely), different pot types being used and longer soak periods, the index is standardised using a linear model with factors of location*year, soak period and pot type added to the model. The primary index modelled is the average number of potential eggs that can be produced by females captured in each pot, with each female lobster captured within a pot assigned a potential egg production based on her maturity status and carapace length (size-batch fecundity and size-number of batches that season) (see de Lestang et al. 2016 for more details). Marginal mean number of eggs per pot for each location*year combination are produced using the emmeans package.

IBSS egg production showed an increase following the 1993 management changes that increased protection to mature females, namely setose and maximum size rules (Appendix 1; Figure 5). These increases peaked in the early 2000s (Lancelin, Dongara, and Abrolhos) before being eroded down through until the late 2000s (Figure 3.3). In concert with management changes in 2008, 2009 and 2010, which effectively halved the commercial catch (Appendix 1) and moved the management to quota, egg production again increased, but this time to a much greater extent. In all locations except Abrolhos and Kalbarri, egg production increased markedly (over 10-fold), and then generally declined ~ 2014 when the 2008 recruitment entered the breeding stock (Figure 3.3). Egg production subsequently increased again as post 2009 puerulus recruitments, which were much larger than 2008 and 2009 recruitment years, started to attain breeding age and commercial catches remained low.

In the most recent surveys egg production has remined very high in the three southern regions (Lancelin, Jurien and Leeman), but declined rapidly in the northern Dongara and Big Bank areas (Figure 3.3), albeit at Dongara the 2023 level is still greater than the majority of pre-2010 levels. The magnitude of this decline from 2022 to 2023 is so large that it is considered biologically unlikely and possibly linked to catchability, however continued low survey results at these locations would be concerning and would result in greater scrutiny of this data.

The index at the Abrolhos showed a slight increase following the management change to quota but has continued to cycle between high and moderate levels, suggesting that catchability of lobsters in this location is the main driving factor (Figure 3.3) and further work on standardising these indices in required. Big Bank, the majority of which is closed to fishing, has shown a progressive decline since its inception, with the 2023 being the lowest on record. If not catchability related, this may reflect poor northern white migrations in recent years into this northern region.

The influence of catchability on a similar index (the abundance of female lobster caught during the IBSS and not their egg production levels) indicates that 2023 was a lower-than-average catchability year (Appendix 2; Figures A2.2). Once corrected for variable catchability, the abundance of female (and male) lobsters in all zones did not decline to nearly the extent of the uncorrected indices (Appendix 2; Figures A2.2). Generally, IBSS egg production throughout the fishery is near maximum levels at many sites and at moderate levels at others which does not indicate recruitment overfishing, therefore **the stock is considered at low risk to over-exploitation**.

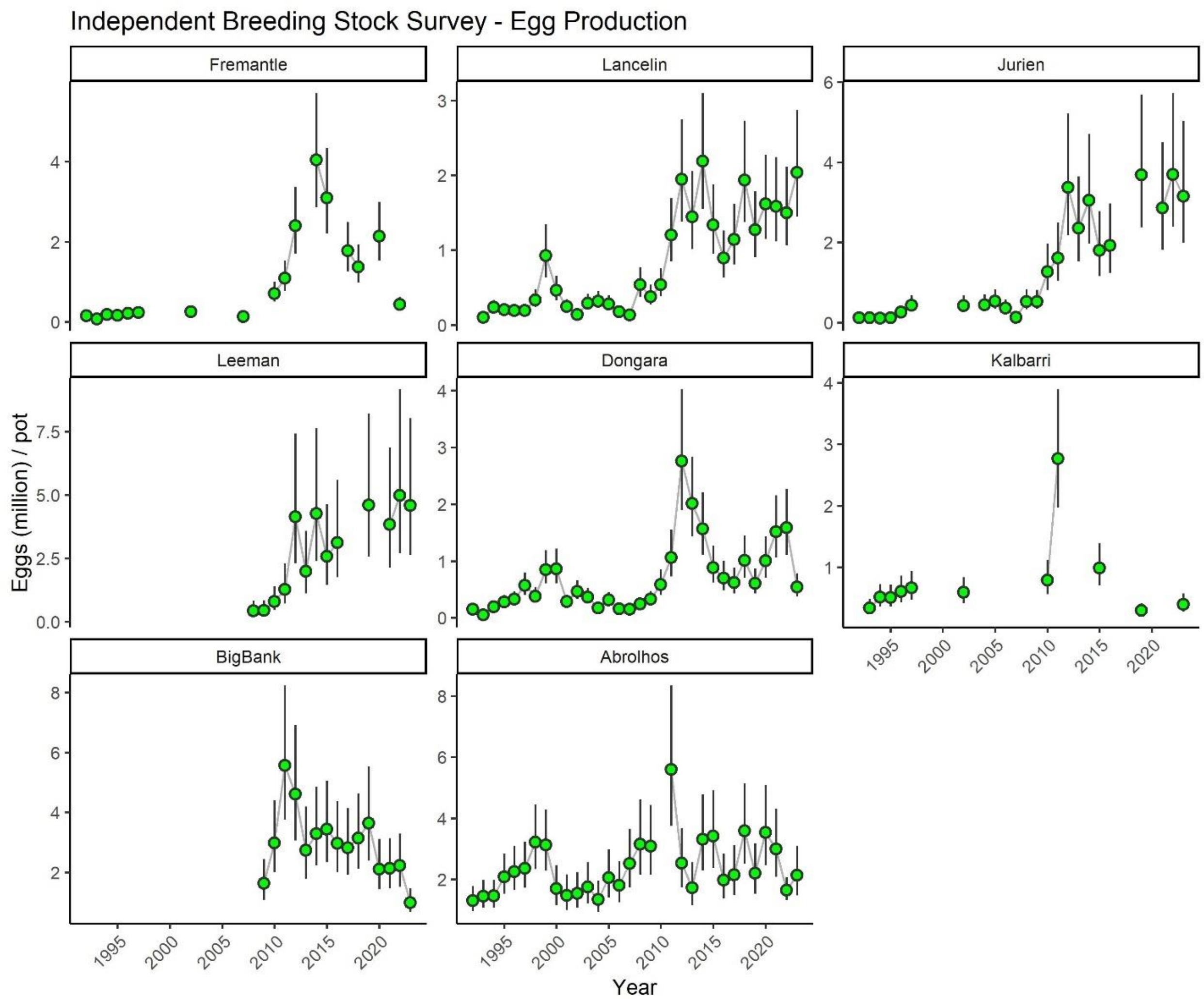

Figure 3.3. Annual fishery independent breeding stock survey (IBSS) index of egg production (±95% CI) per pot. Missing points are due to not all locations being sampled every year.

Independent Shallow Survey

The Independent Shallow-water Surveys (ISS) occur annually over two days, at 12 locations spanning the fishery. To reduce interannual variation in environmental related changes in lobster catchability the surveys are conducted within five days of the March new moon, during a period of lowest swell conditions, and use pots with closed escape gaps. The survey occurs at six locations on the first day, with pots being moved to sample the second locations on the following day. At each location, 100 pots are set on specific coordinates for a one-day soak and retrieval of pots starts at 6 am the next day. Pots are set in lines of 20 pots, and each line is considered a replicate.

Pot catches are averaged for each line and then used to construct the annual index using a linear model (see below). The surveys are standardised where possible (same pot locations, pot types, bait type, soak period, moon phase, low swell) but cannot account for changes in catchability due to factors such as moult stage and water temperature. Any pot that is considered to not be fishing efficiently (e.g. has a broken batten or contains a lobster predator) is removed from the analysis. Since logistical issues can result in some pots being lost and different pot types being used, the index is standardised using a linear model with factors of location*year and pot type added to the model. The index modelled is the average number of lobsters with a carapace length between 65 and 70 mm. Marginal mean number of lobster per pot for each location*year combination are produced using the emmeans package.

The timeseries of ISS catch rates is still very short (four years) so catch rate trends for undersized lobster (Figure 3.4) and their relationship to local puerulus settlement indices (lagged 3 – 4 years; Figure 3.5) can be heavily influenced by single point estimates. As such these indices are still treated as preliminary.

Strong positive relationships between puerulus settlement indices lagged three to four years and juvenile catch rates were exhibited at seven locations (Mandurah, Fremantle, Two Rocks, Cervantes, Fresh Water, Dongara, and the Wallabis), albeit based on only four observations (Figure 3.5). Greater contrast in puerulus settlement will improve these relationships. All locations surveyed show consistent catches of prelegal-sized lobsters (65 – 70 mm) indicating that survival from puerulus to this size range has been relatively consistent, i.e. there has been no marked change in juvenile survival in recent years, therefore there is a low risk that a change in post puerulus settlement mortality has occurred within this timeframe.

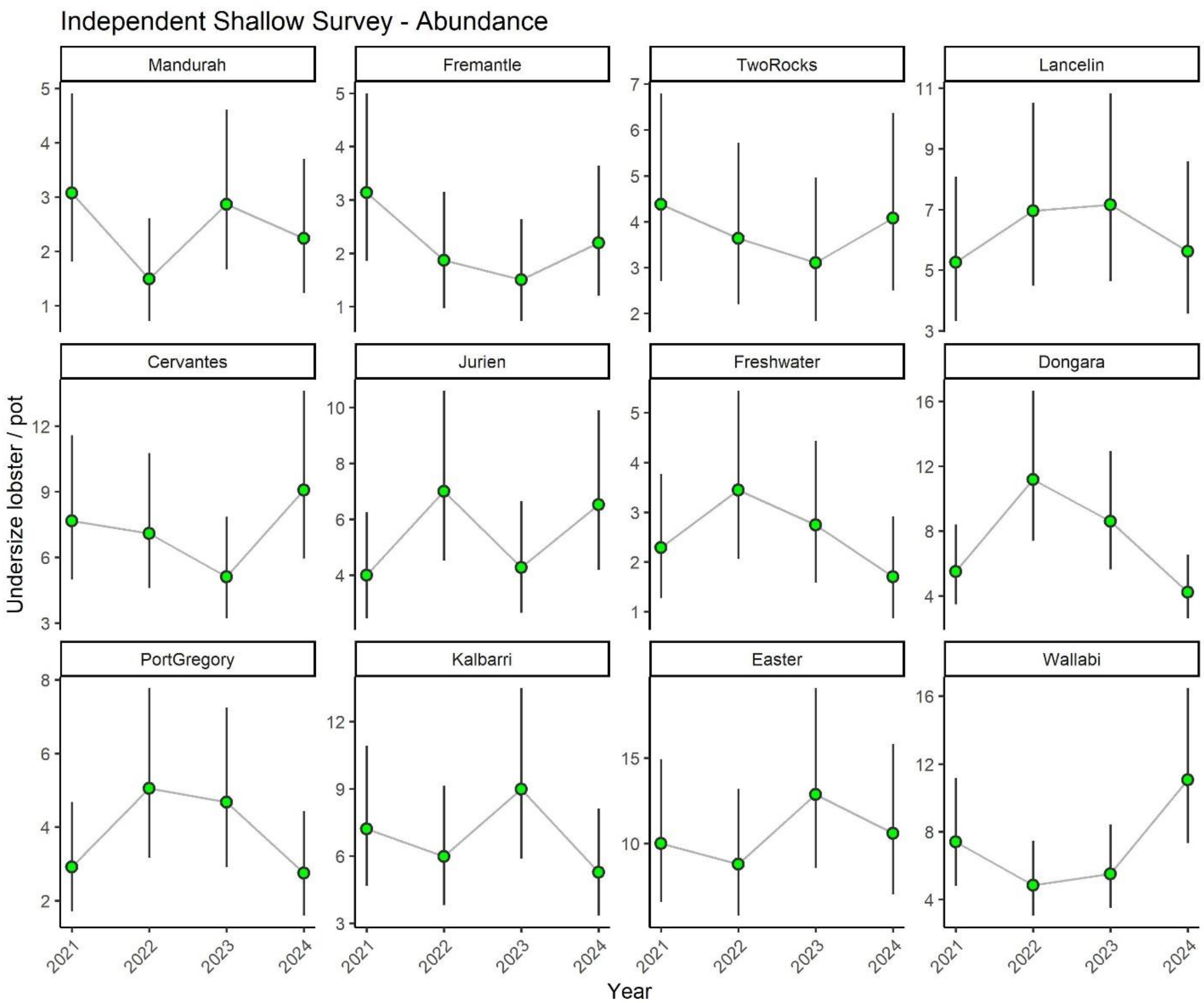

Figure 3.4. Catch rate of undersize lobster (±95% CI) sampled during the annual fishery independent shallow survey (ISS) at 12 locations throughout the fishery.

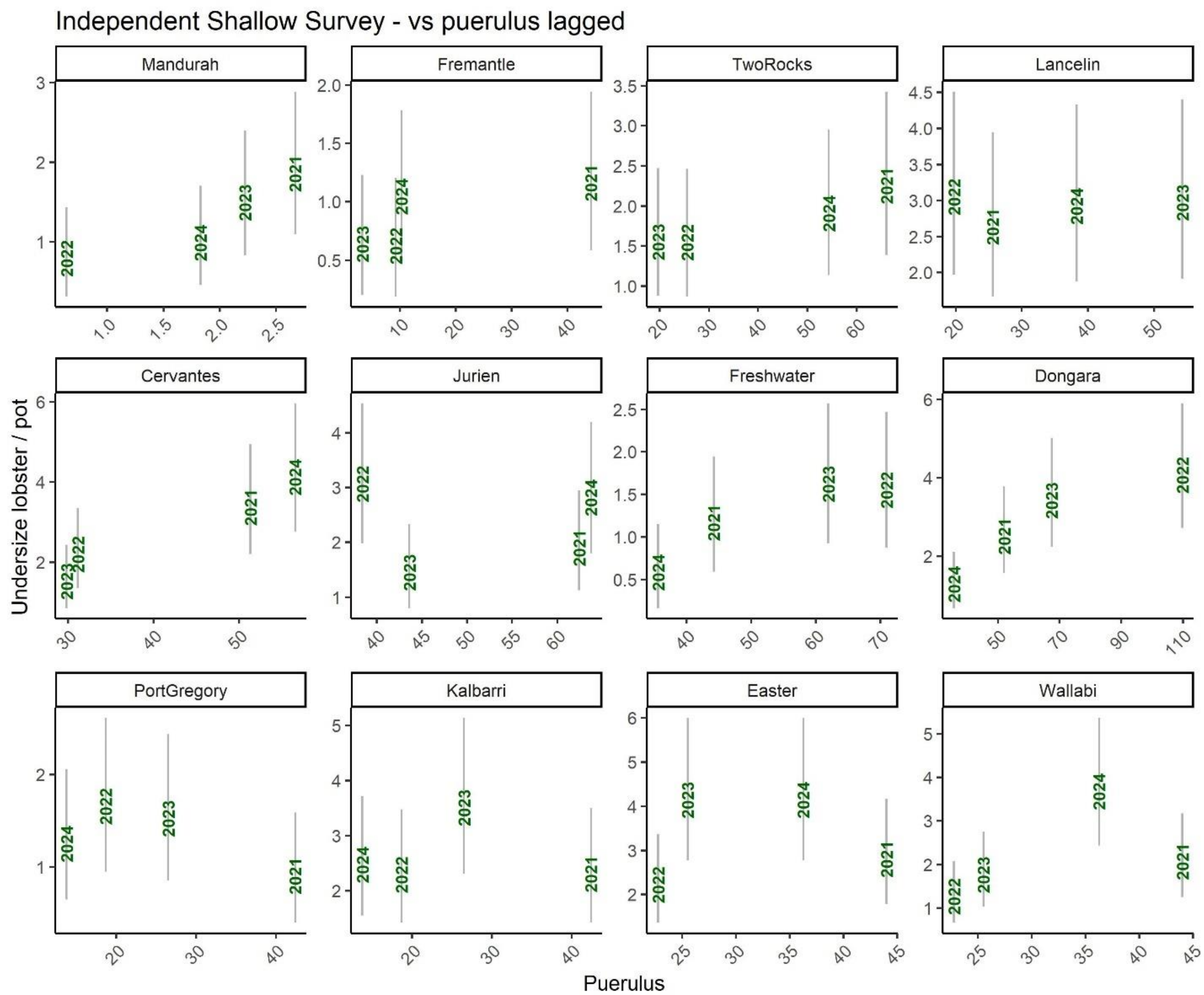

Figure 3.5. Relationship between the catch rate of undersize lobster (±95% CI) sampled during the annual fishery independent shallow survey (ISS) and annual puerulus indices at 12 locations throughout the fishery.

Biomass dynamic model

A Schaefer biomass dynamics model (Tuffley, 2023) was used and fitted using TMB (Kristensen et al. 2015), as a non-equilibrium model that spans 1945 until present. In addition to catches, the BDM was fitted to three time series of abundance; (i) standardised mean commercial fishing catch rate (kg/pot lift) and mean catch rates of females (ii) and males (iii) from the IBSS (both also kg/pot lift). The model accounted for annual variation in lobster catchability during the IBSS and changes in fishing efficiency in the commercial fisheries data. For a full description of the model see Appendix 2 and Tuffley (2023).

The BDM estimated that relative legal biomass in all zones gradually declined between the start of fishing in 1945 and 2007. Biomass then increased rapidly between 2007 and

2012 in all zones (in concert with reduced catches due to management changes) and has remained relative stable / declined slightly since (Figure 3.6). Estimated relative biomass is currently ~ 87% of virgin levels on a fishery-wide basis. Model estimated harvest rates followed a similar trajectory, peaking at 0.66 in 2006, before dropping to around 0.2 in 2017 (Figure 3.7). In 2023, the harvest rates are estimated to be ~0.23.

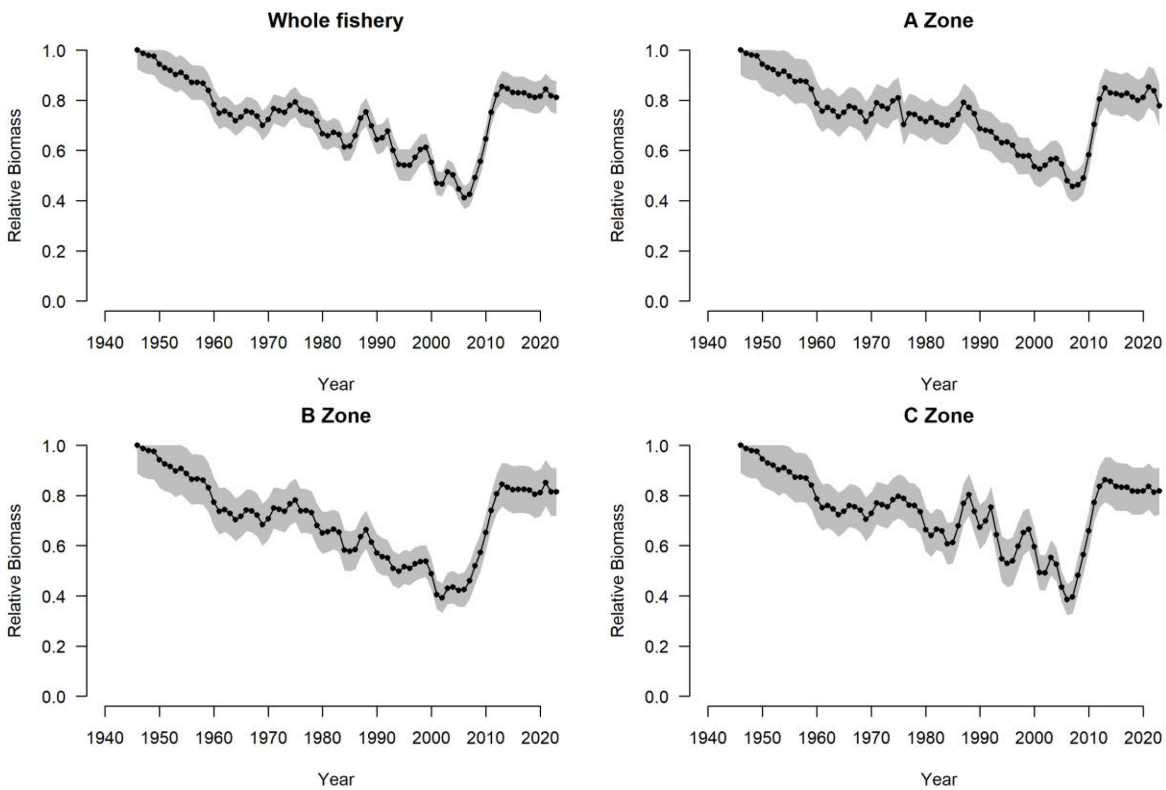

Figure 3.6. Estimated relative biomass (±95% confidence intervals), fishery wide (whole fishery) and in A, B, and C, zones

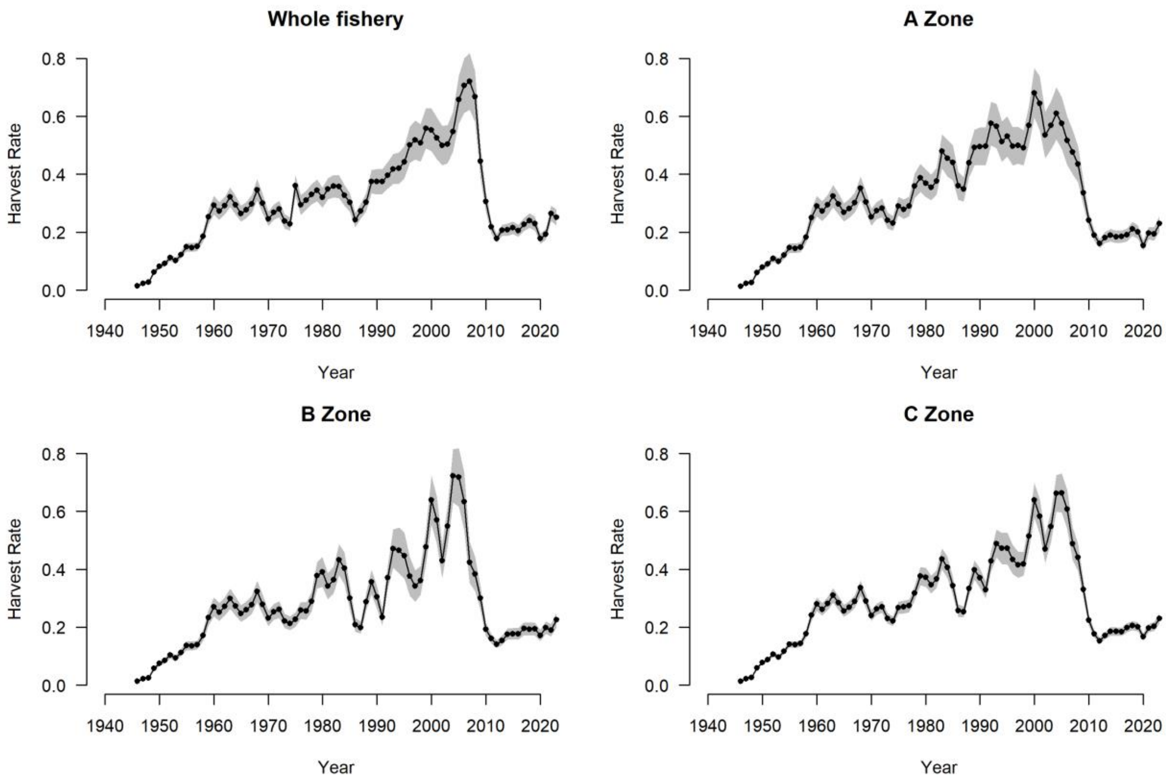

Figure 3.7. Estimated harvest rates (±95 confidence intervals) fishery wide (whole fishery) and in A, B, and C, zones.

Level 5 Assessment

Integrated population model

Model description

The western rock lobster integrated assessment model is used to derive indices that represent the condition of the lobster stock and fishery. The model (implemented in ADMB; Fournier et al. 2012) is length-based and tracks the west coast population of western rock lobster from 1975 until present in 11 spatially explicit areas over 11 within-year timesteps. The development and implementation of this model has been externally reviewed three times (Fisheries 2008, 2010, de Lestang et al. 2019) and is fully described in de Lestang et al. (2016). Data sets fitted to by the model are shown in Table 5.1.

Table 5.1. Data sets used as co-variates in the integrated model and their temporal coverage..

Data set	Temporal coverage
Commercial Catch and Effort	November 1975 – December 2023
Commercial Catch rate	November 1975 – December 2023
Commercial Size composition	November 1975 – December 2023
Commercial High Grading rate (%)	November 2009 – December 2023
Recreational Catch	November 1975 – December 2023
Independent Deep water catch rates	October 1992 – October 2023
Independent Deep size composition	October 1992 – October 2023
Independent Shallow water catch rates	March 2020 – March 2024
Independent Shallow water size composition	March 2020 – March 2024
Independent Puerulus Settlement	May 1973 – April 2024
Tag-Recaptures	November 1988 – December 2023
Water temperature	November 1975 – December 2023

A new model (which differs in implementation software, spatial and temporal structure as well as implementing a contemporary form of stock dynamics) is currently being developed by DPIRD in conjunction with University of Washington/CSIRO and the Institute for Marine and Antarctic Studies (IMAS). It is envisaged that this (TMB version) will eventually replace the current ADMB model version.

The current model is updated annually and used to assess several future harvesting (quota) scenarios. The model assumes that the current (2023) season's biological controls (e.g. minimum size at 76 mm and no maximum size limit or setose protection rules) are maintained in future seasons. Five-year projections of stock levels use the most recent four completed seasons of puerulus settlement data, with a fifth season of puerulus settlement data being based on the 25^{th} percentile of the historical data range (a five-year projection is required by the Harvest Strategy). Projections are used to derive the Annual Harvest Level (AHL) for the upcoming fishing season (2025 financial year) by estimating the total catch that would be taken by the fishery in the fifth projected year if it was to fish constantly at a harvest rate of 0.39. Recreational catches for projected years are set at 500 t based on the current allocation in the harvest strategy (Smallwood et al. 2023, Department of Primary Industries and Regional Development, Western Australia Government 2024).

Model updates

Since the last assessment, the model has been modified slightly to incorporate additional flexibility based on an improved understanding of the stock's behaviour. The added functionality is common in many contemporary stock models such as Stock Synthesis and Gmacs (Methot & Wetzel 2013, Whitten et al.). The changes were: (1) Gear selectivity: the ability to estimate escape gap selectivity within the model (previously this was hard-wired). Model outputs were not found to vary due to this modification; (2) Proportion of whites annually migrating north: the ability to estimate annual changes in northwards migration (previously this proportion was constant across years). Tag-recapture information and commercial landings both support anecdotal information from commercial fishers of substantial inter-annual variation in the magnitude of white lobsters undertaking a deepwater northwards migration. Reductions in this migration result in lower number of lobsters moving towards the northern end of the fishery. When implemented into the model framework, northwards migration was estimated to vary between years. This change in dynamics resulted in changes in model estimates of relative biomass between mainly A and B zones (Figure 5.1). The addition of variable northwards migration resulted in minimal changes prior to ~2015, whereas after this time a greater proportion of the combined A and B zone legal biomass has been accumulated in A rather than B zone. This structural change to the model allows it to better replicate the abundance indices for these areas. A stand-alone examination of northwards lobster migration (e.g. examining tag recaptures and catch rates during the migration) is planned to occur during the 2024/25 financial year. The 2024 model run description can be found in Appendix 3.

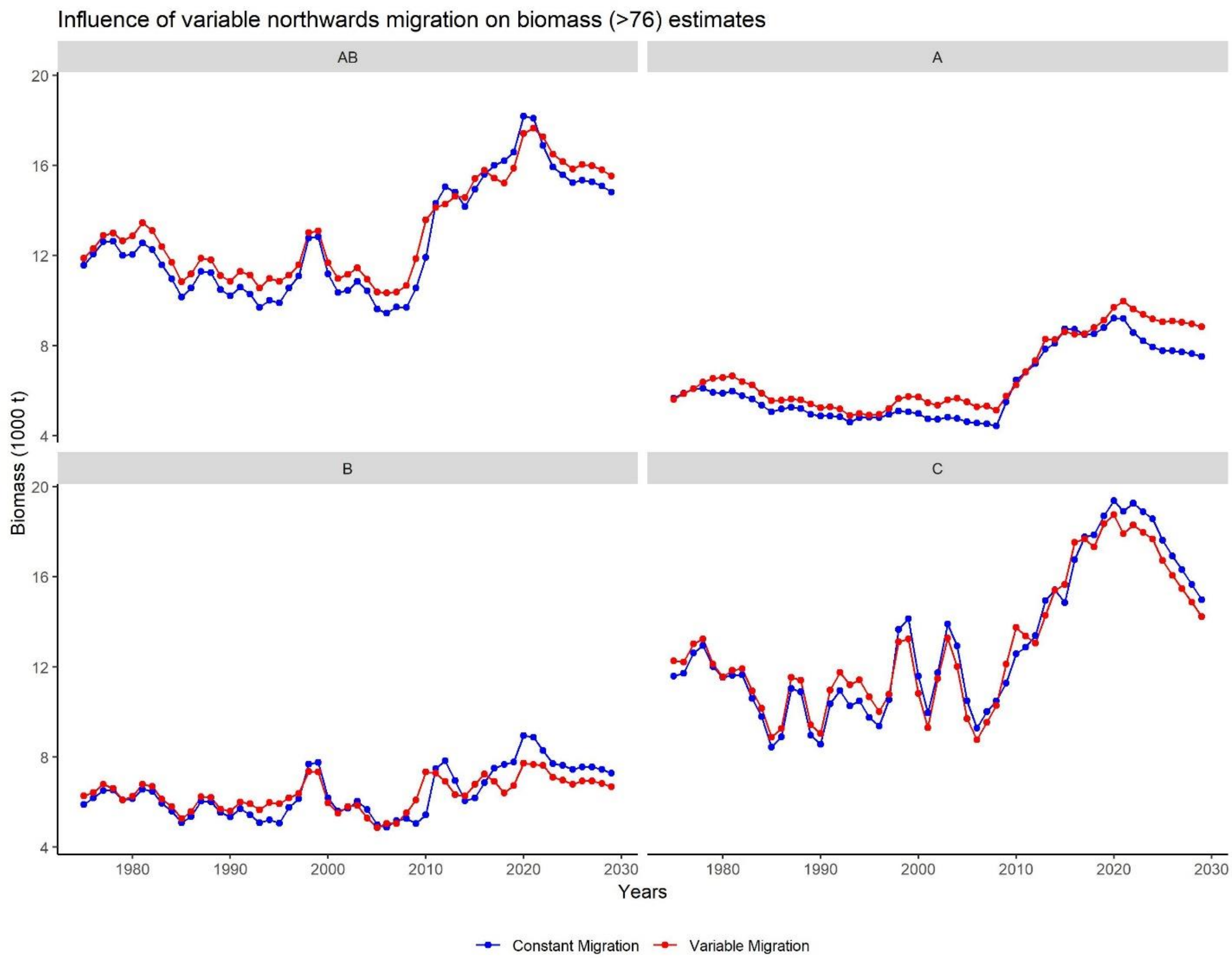

Figure 5.1 Compositions between model estimated biomass levels in each management zone as well as in a combined A and B zone (required by the harvest strategy) from model runs with (red) and without (blue) the ability for the model to vary the annual proportion of lobster migrating northwards.

The model's ability to fit commercial catch, independent survey catch rates, puerulus settlement levels, lobster movement patterns, and lobster size composition on fine spatial and temporal scales (i.e. diagnostics) are shown in Appendix 4. The largest discrepancies exist between observed and expected size compositions in some areas and year combinations (Appendix 4). In the model, within a model area growth is constant across years but it does vary between some model areas (de Lestang et al. 2016). Research has shown that the growth rates of lobster are variable and have changed with a warming climate as well as in response to increased lobster densities (de Lestang 2018). This variation has not been incorporated into the current model. It is planned for decadal changes in growth to be implemented into the new (TMB version) model build.

Model output legal biomass

Model estimated mean legal biomass has increased throughout the fishery since management changes in 2008/2009, reaching a peak in ~2020 (Figure 5.2). This peak occurred because of a combination of low TACs since 2008 and a drop in catches during the Covid 19 pandemic. Since the 2020 fyear, biomass has started to decline in concert with a progressive increase in overall landings (Figure 15.2). Biomass levels will continue to decline in all management areas at current levels of TAC but are projected to remain above historic levels by 2029 fyear.

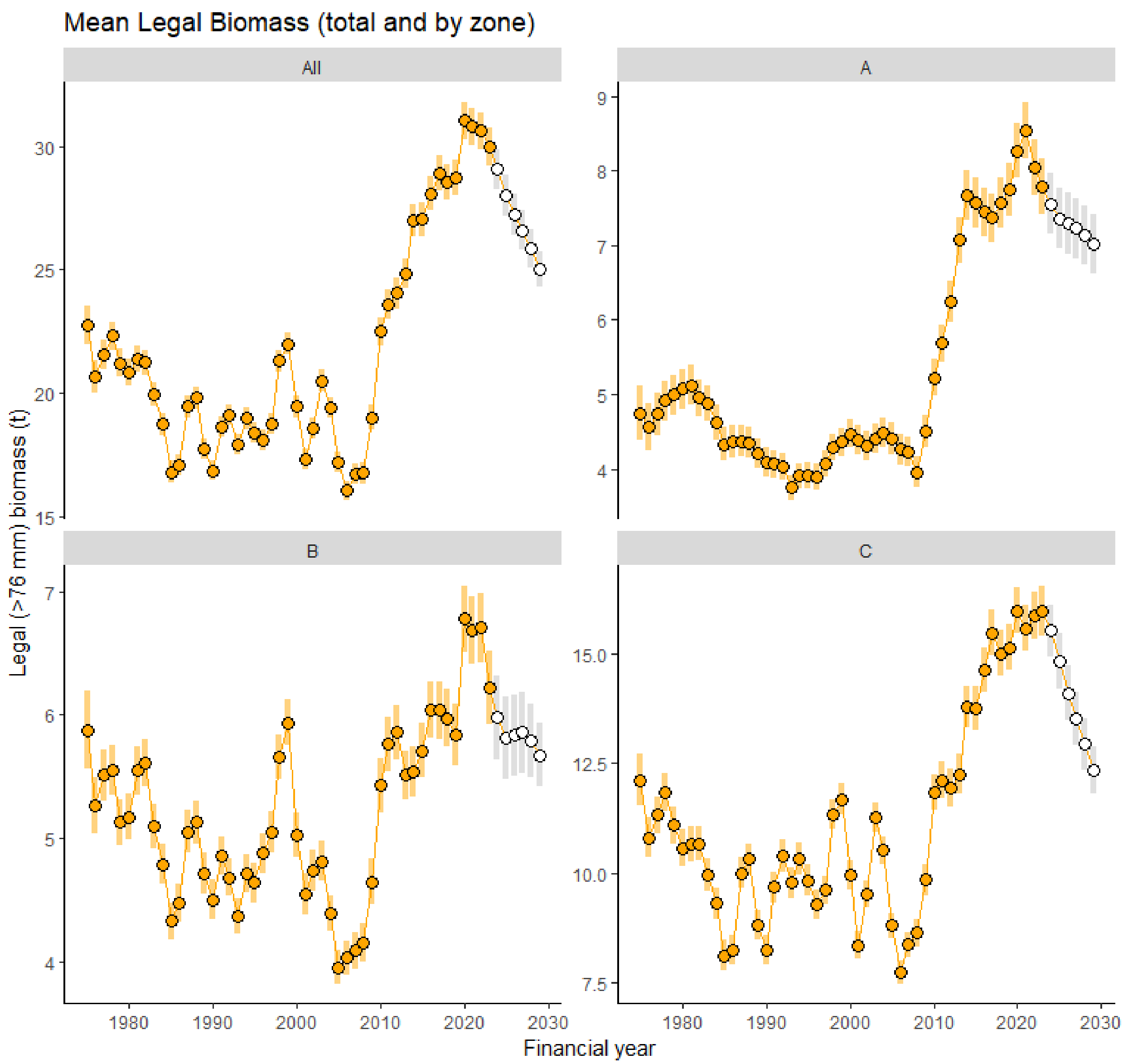

Figure 5.2 Model estimated mean legal (≥ 76 mm CL) biomass (± 95% CI) of lobster combined over the fishery (all) and in each management zone. Solid orange points represent years the model has observed data and open points are projections based on a continuation of current TAC settings.

Model output egg production

Egg production is determined in the model for four breeding stock management areas; Abrolhos (model areas 9, 10 Figure A3.1); North (model areas 8 and 11); Central (model area 6); and South (model areas 2,4). This spatial aggregation is required by the Harvest Strategy and egg production is used as the primary indicator for sustainability (Department of Primary Industries and Regional Development, Western Australia Government 2024). Estimated relative egg production progressively declined in most breeding stock management areas since the start of the timeseries, through until the 1993 management changes when protection of breeding females was increased (Figure 5.3). A second marked increase in egg production (to levels well above the threshold) occurred following the 2008/2009 management changes when commercial catches declined by 50%. After reaching very high levels in ~2013 fyear, egg production dipped as the low puerulus recruitment in 2008/2009 started to enter the breeding stock at an age of five to six years post-settlement (Figure 5.3). Subsequent levels increased again in concert with increased puerulus settlement but have started to decline slightly over the past two seasons. Egg production throughout the fishery remains high and well above threshold reference levels over the projected five fyears based on a continuation of the current TAC.

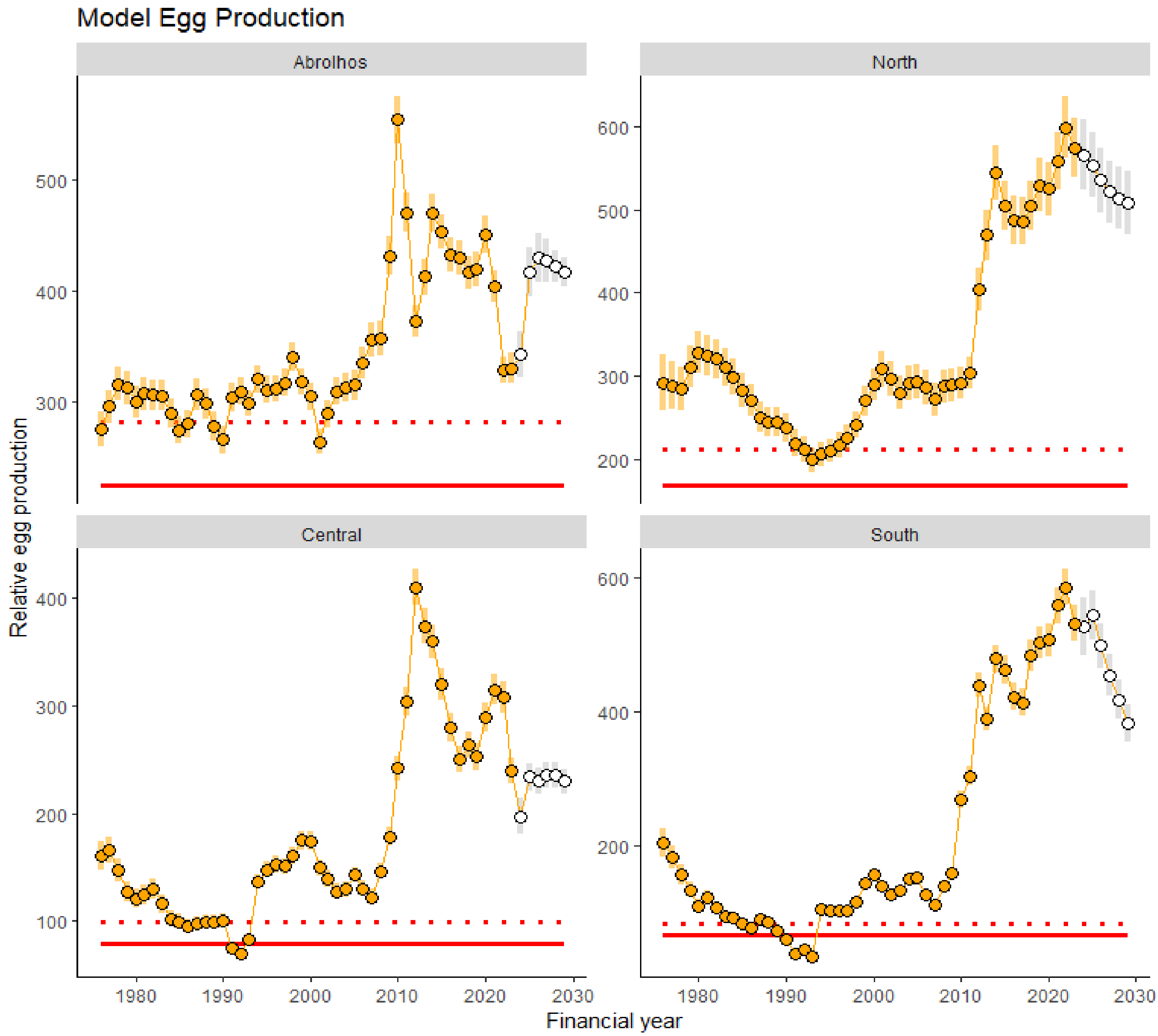

Figure 5.3 Model estimated egg production (± 95% CI) of fishing in the four breeding stock management areas. Solid orange points represent years the model has observed data and open points are projections based on a continuation of current TAC settings. The dotted and solid red lines represent the threshold and limit reference points.

Model output harvest rate

Model estimated harvest rates are presented in two areas: AB which represents the northern half of the fishery (model areas 5 – 11), and C zone which represents the southern part of the fishery (model areas 1-4, Figure 5.4). This spatial aggregation is required by the Harvest Strategy and harvest rates are used as a secondary indicator.

Harvest rates increased rapidly throughout the fishery across the first ~30 fyears of the time series as total catches increased, and legal biomasses decreased (Figure 5.4). The interannual variation in harvest rates were due to relatively constant effort and variable recruitment entering the fishery. By the mid-2000s harvest rates had reached very high levels with ~70% of all lobster being taken each fyear. Following the significant management changes in 2008/2009, when lobster catches halved, harvest rates dropped rapidly to historical lows of ~25% as then biomass rapidly increased (Figure 5.4). Harvest rates then started to increase, but dropped again following Covid 19, mainly due to the very low catches in this fyear, before again starting to increase with increasing catches. Harvest rates remain low throughout the fishery and are starting to increase into the maximum economic yield (MEY) region of 0.29 – 0.39 (Caputi et al. 2015, 2018). Projections indicate that harvest rates continue to progress towards the harvest strategy target of the upper level of the MEY region.

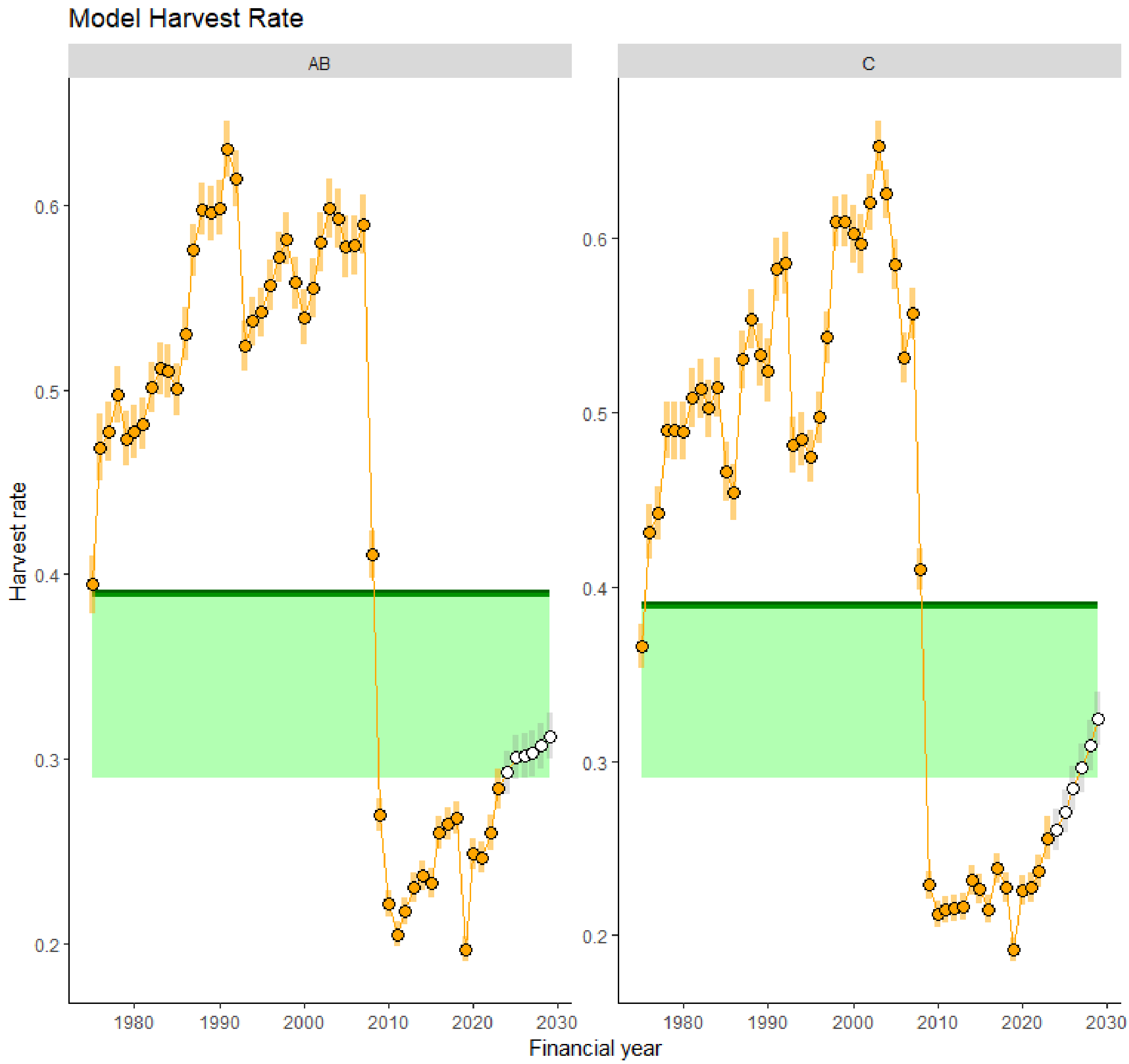

Figure 5.4 Model estimated mean harvest rate (± 95% CI) of fishing in the northern (management zones A and B) and southern (management zone C) areas of the fishery. Solid orange points represent years the model has observed data and open points are projections based on a continuation of current TAC settings. The light green box represents the harvest rates associated with MEY and the dark green line the upper margin of this region and the current harvest rate target.

Environmental Assessment

Western rock lobsters are ectothermic animals and thus their metabolic rate and the timing of various life stages are intrinsically linked to their surrounding environment. Water temperatures are a dominant driver (in terms of relationships described in the literature), and the impacts of changes are exhibited by a range of biological traits exhibited by this species. For example, factors include size at maturity (Figure 6.1), the timing of the onset of spawning (Figure 6.2), the timing of the onset of migration (Figure

6.3) and the microsporidium infection rate for lobster (Figure 6.4; Table 1). In addition to water temperatures the biology and behaviour of this species is also markedly influenced by moon phase, ocean swells, ocean turbidity and food sources (Table 6.1).

Table 6.1. Summary of environmental drivers known to impact the various life stages of western rock lobster.

Life stage/behaviour	Environmental driver	Reference
Larval survival	Water temperature and ocean currents	(Säwström et al. 2014, Wang et al. 2015)
Puerulus settlement	Water temperature and ocean currents, winter storms	(Caputi & Brown 1993, de Lestang et al. 2015, Kolbusz et al. 2022)
Juvenile growth	Water temperature, lobster density and food availability	(Edgar 1990, de Lestang 2018)
Migration: timing, lobster size, direction, and distance.	Water temperature, swell and Leeuwin current	(Caputi et al. 2010, de Lestang 2014, de Lestang & Caputi 2015)
Maturity: size and timing of reproduction	Water temperature	(de Lestang & Melville-Smith 2006, Melville-Smith & De Lestang 2009, Melville-Smith & de Lestang 2010, Caputi et al. 2010)
Catchability	Moon phase, swell, water temperature	(Srisurichan et al. 2005, Melville-Smith & Beale 2009)

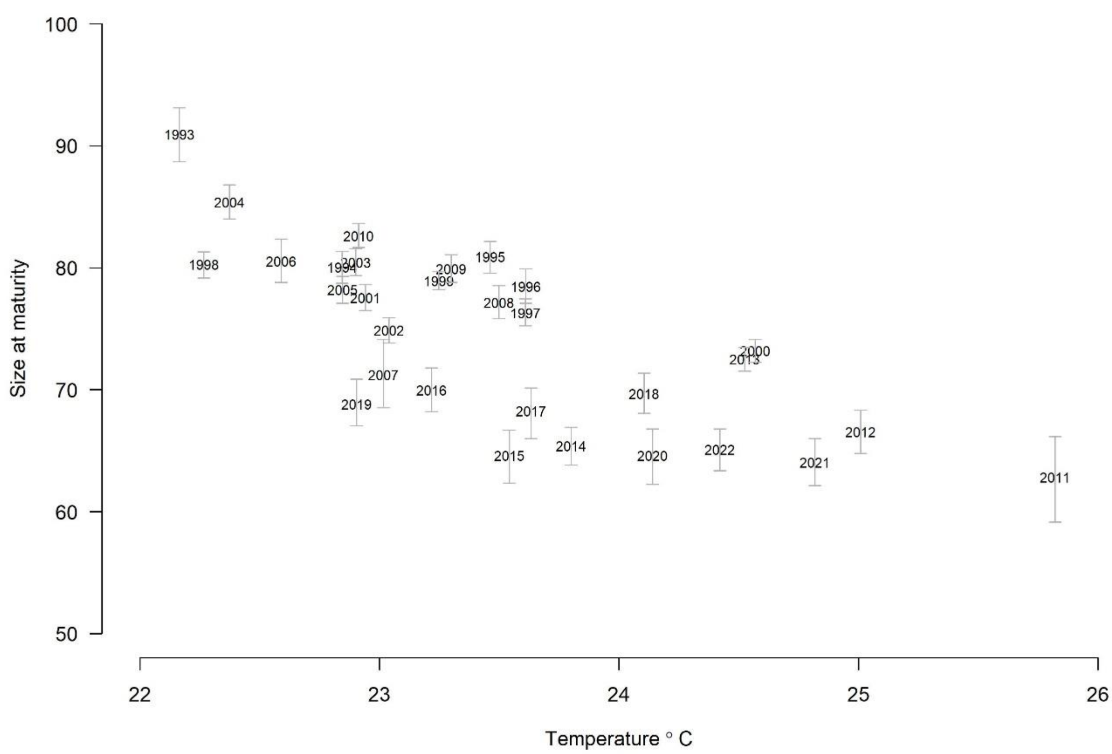

Figure 6.1. Plot showing relationship between bottom water temperature near Dongara averaged over January to March and size at maturity (±95% CI) of female lobsters at Dongara measured later (in September – November) that same year.

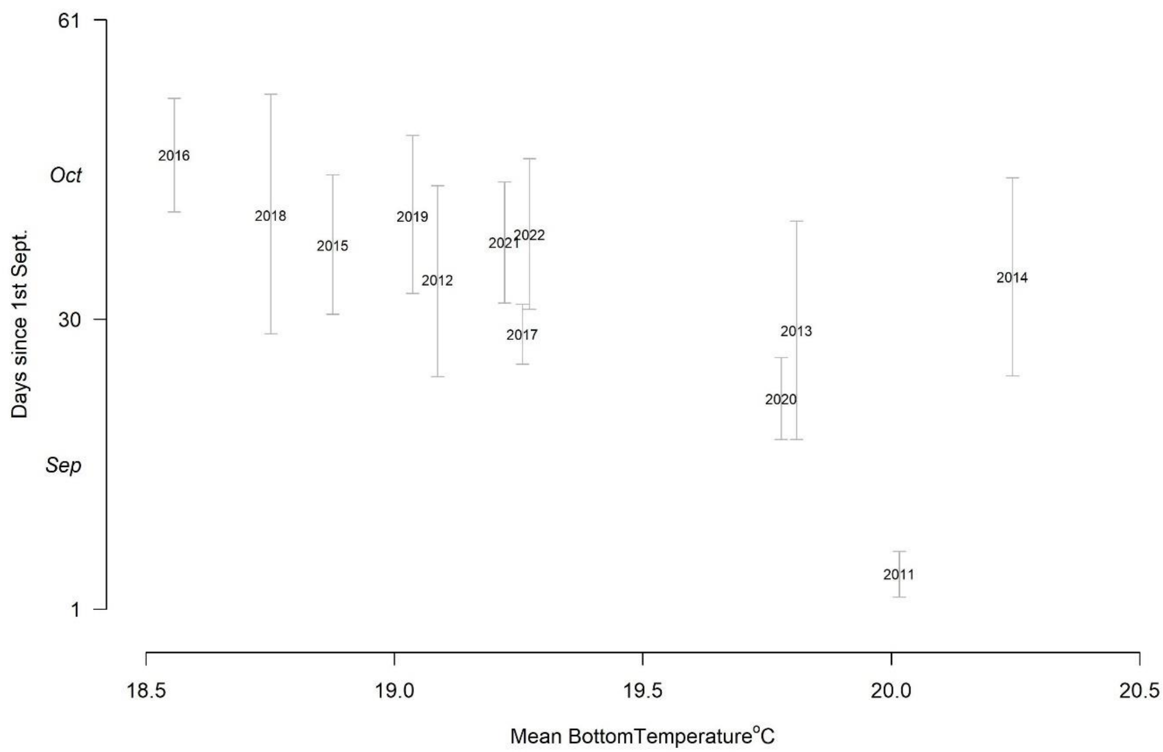

Figure 6.2. plot showing relationship between mean bottom water temperature off Jurien from August/September and the mean timing of onset of spawning. Grey error bars represent 95% CI.

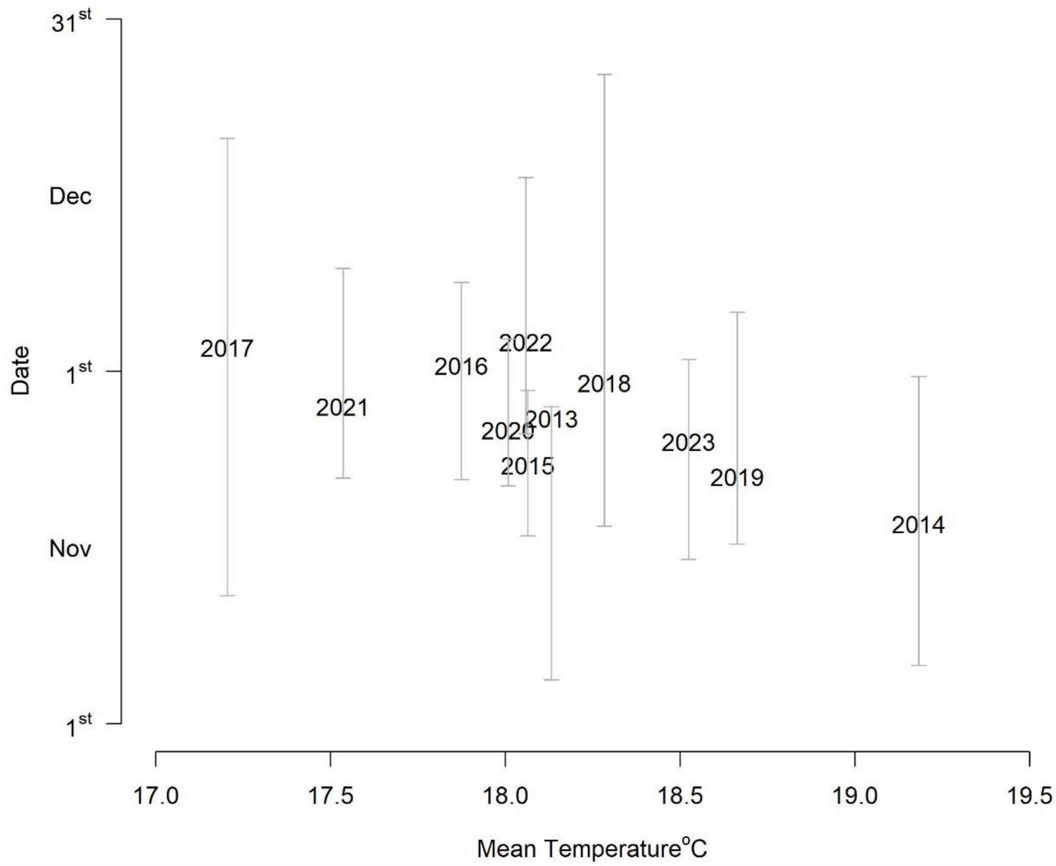

Figure 6.3. Plot showing relationship between mean shallow water temperatures in June to September and the mean (± 95% CI) timing of the start of the annual white lobster migration.

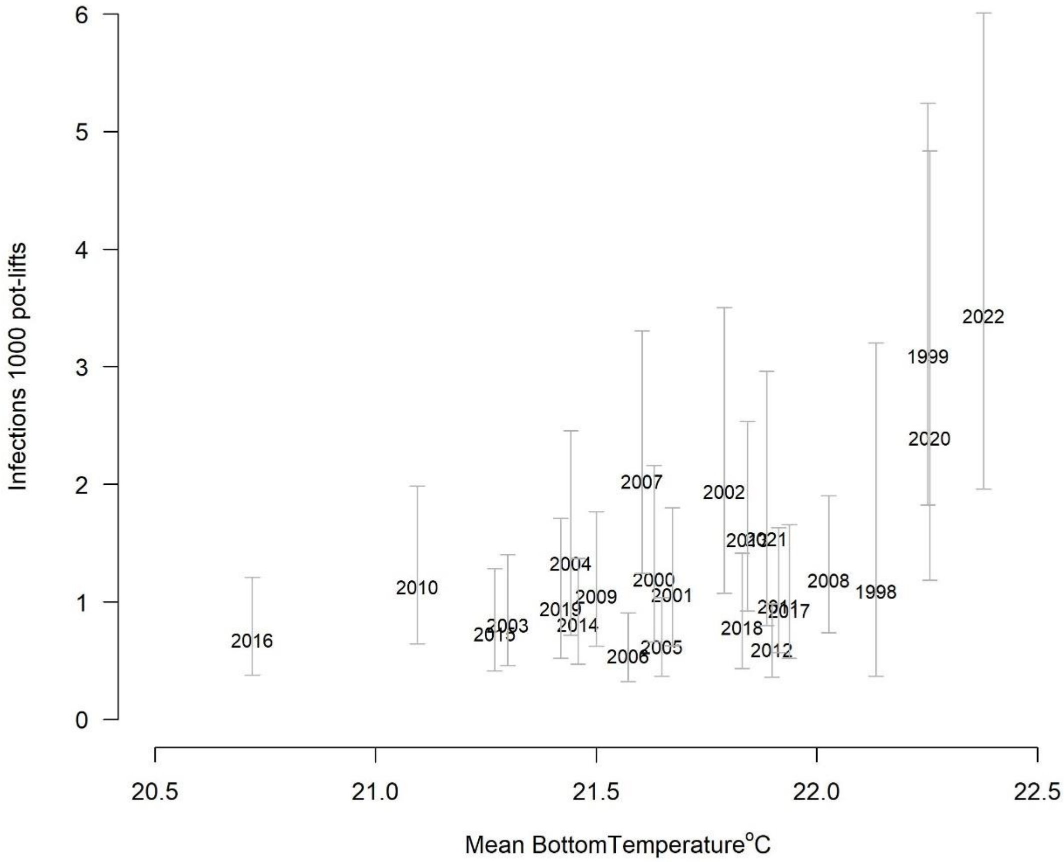

Figure 6.4. Plot showing relationship between mean bottom water temperatures in June/July and the annual mean (± 95% CI) catch rate of lobsters infected with microsporidium.

Water temperature observations

Average annual sea surface temperatures (SST) were sourced from *https://www.metoffice.gov.uk/hadobs/hadisst/* (Rayner et al., 2003). This data set contains spatial 1° measurements of SST from 1870 until 2023. An annual average SST was calculated from a subset of this data set, restricted to the area adjacent to and overlapping the lobster fishery, with the bounds of -26 to - 34° S and 111 to 115° E. These data span almost 150 years and show great inter-annual variability of up to 0.5° C between successive years (Figure 6.5). Within the time series two main patterns exist, a shorter-term cyclical trend with a wavelength of ~ 40 years (blue line), being high over the first 20 years (1870 – 1890), then low over the subsequent 20 years (1890 - 1910) and continuing this pattern throughout. Over the longer-term, water temperatures showed a slight decline over the first 40 years, before a rapid rise started in 1950, and has continued through to the end of the timeseries. Over this periods there has been an increase of ~1° C in SST from ~ 20.25° C in 1950 to ~21.25° C in 2023 (Figure 6.5, red line).

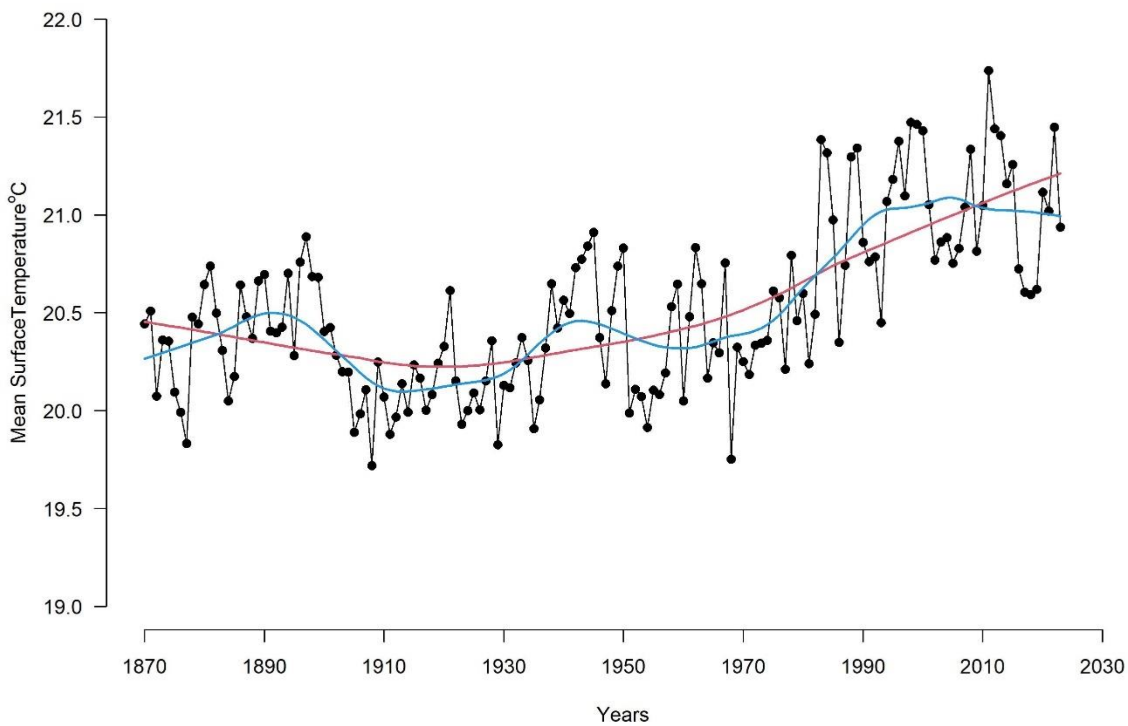

Figure 6.5. Average annual sea-surface average water temperature adjacent to and overlapping the Western Rock Lobster fishery. Two lowess smoothers were fitted with either a short (blue line) or longer span (red line) to show the general trends.

Over the past 12 months water temperatures in shallow regions at the northern (Kalbarri) and southern (Fremantle) ends of the main fishing grounds have shown similar variation from the long-term average (Figure 6.6). In both locations SST changed from below average in June / July (delaying the timing of mating) to above average from September to December (possibly the cause of an early whites migration). SST then remained at the same level through summer and autumn, failing to display the average pattern of peaking in February (Figure 6.6). In fact, from late March to the end of May SSTs have increased (not decreased as is normal) with levels in May being up to 1½°C above average. A continuation of this anomaly may lead to precocious mating and possibly spawning later in 2024.

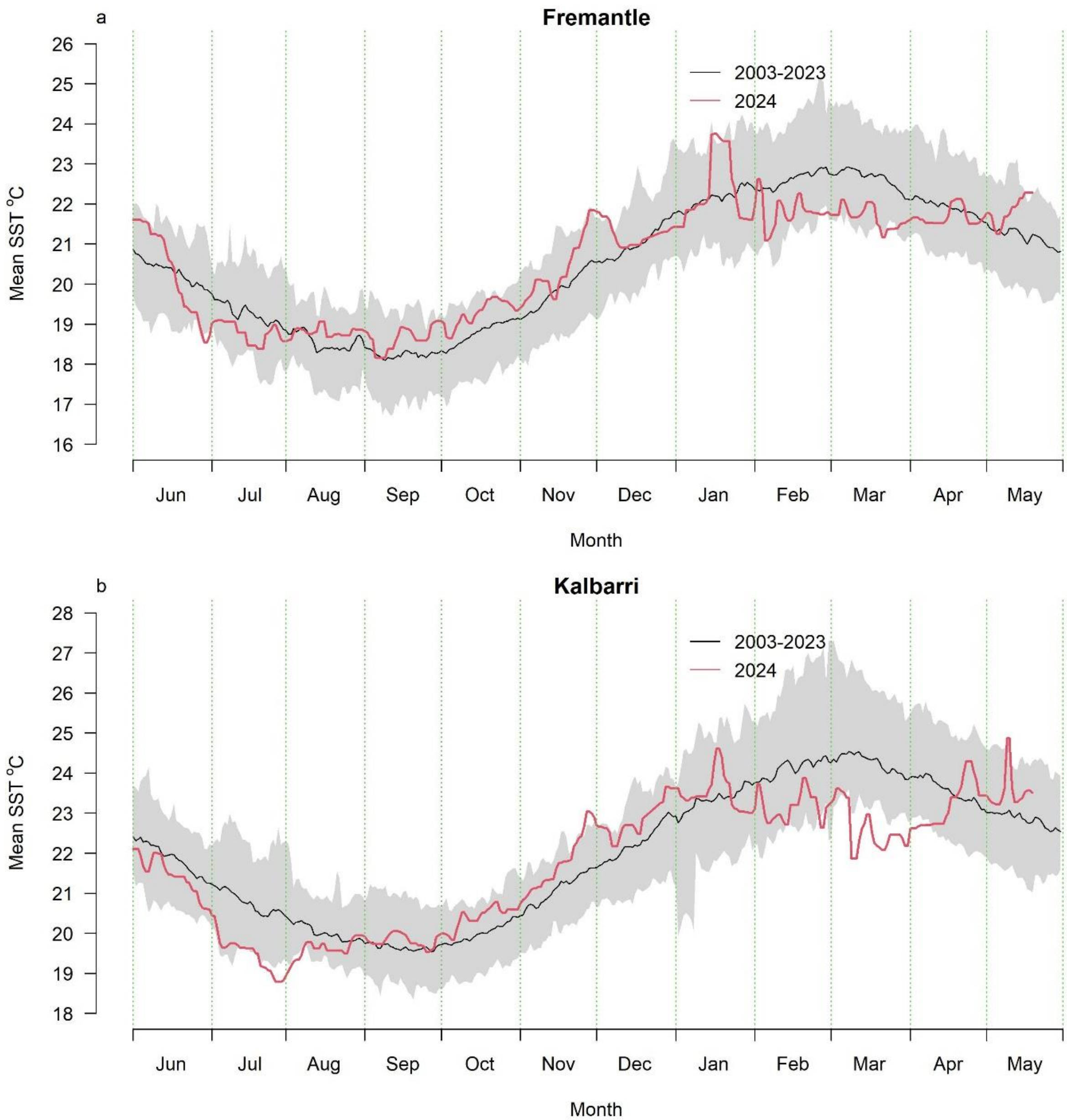

Figure 6.6. Daily sea-surface average water temperature inshore at Fremantle (a) and Kalbarri (b) over the past 12 months (red) and as an average (black ± 95% CI [grey]) across the last 20 years.

Ocean Currents

To be added in the future.

Indian Ocean Dipole

One of the key drivers of Australia's climate (especially that on the west coast) is the Indian Ocean Dipole (IOD). This index is the anomaly between sea surface temperatures of the tropical western and eastern Indian Ocean, which impact the movement of weather patterns across this region. During the positive phase of IOD westerly winds weaken along the equator allowing warm water to shift towards Africa and cool water to rise up from the deep ocean in the east (offshore of Australia). This temperature difference results in less moisture than normal in the atmosphere to the northwest of Australia and changes the path of weather systems coming from Australia's west, often resulting in less rainfall and higher than normal temperatures (including SST on the shelf) over Western Australia during winter and spring.

Over recent years the IOD has progressively been moving more towards positive levels, especially since ~ 2010 (Figure 6.7). A significant linear relationship ($p < 0.01$; $R^2 = 0.11$) exists between the annual average of the IOD lagged one, two and three years and the annual SST experienced by the WRL fishery (Figure 6.8). Note due to the autocorrelation that exists within oceanographic temperature data the orcutt-package in R was used to first remove all auto-correlation from our dataset.

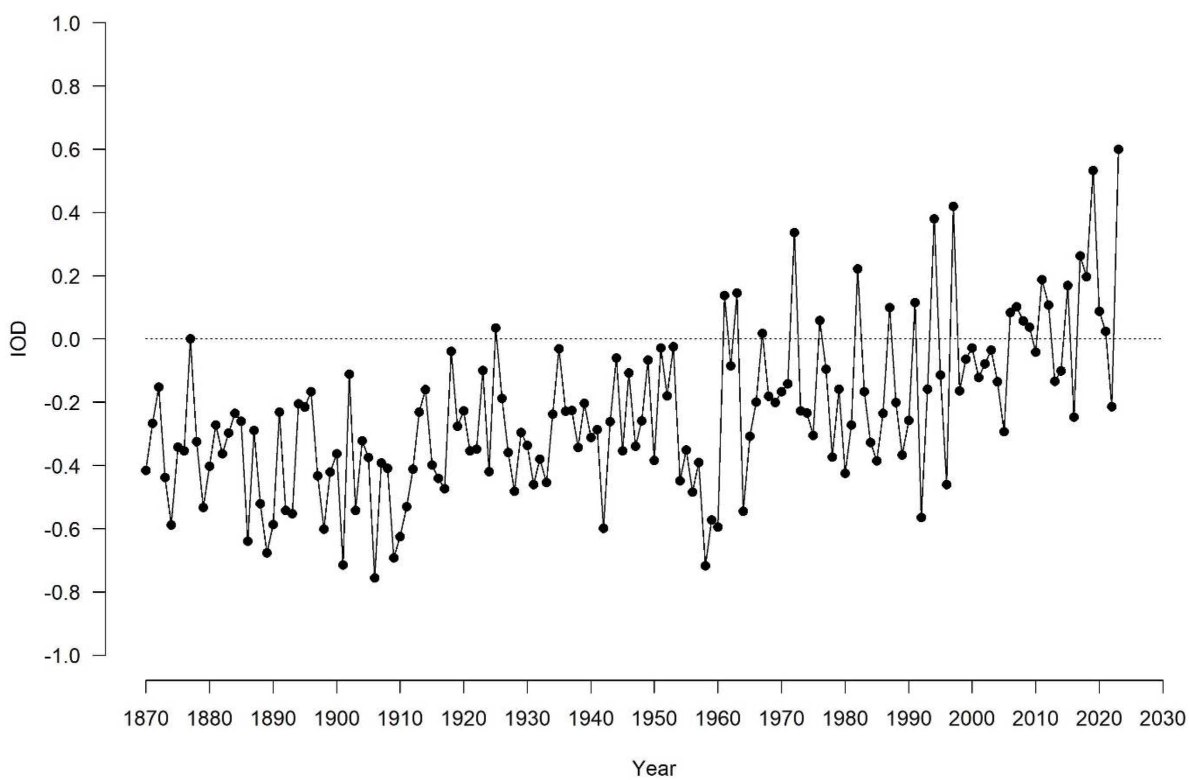

Figure 6.7. Annual average Indian Ocean Dipole.

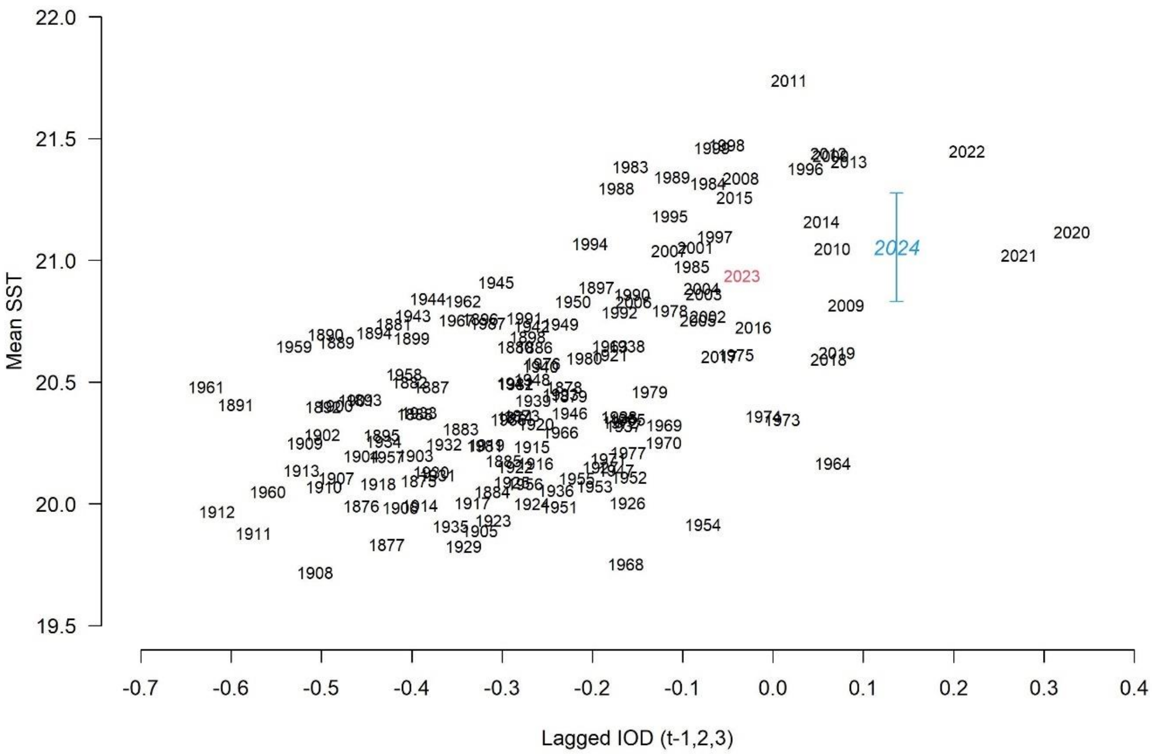

Figure 6.8. Relationship between average Indian Ocean Dipole (combination of annual indices lagged one, two and three years) and SST for the area covering the WRL fishing grounds. The most recent year is shown in red, with a linear model derived prediction of SST in the following year shown in blue (±95% CI of prediction).

Environmental prediction

Water temperatures for the 2024 fishing season (2024/25) are predicted to be average to above average based on three sources: (1) The average of international model forecasts for NINO3.4 (*http://www.bom.gov.au/climate/enso/*), which forecasts a move back towards *La Niña* conditions (stronger Leeuwin current and water temperatures); (2) Projections based on the trends displayed by the two smoothers fitted to the annual SST (Figure 6.5); and (3). A forecast based on the relationship between SST and the Indian Ocean Dipole (IOD) (Figure 6.8). Above average water temperatures **increase the risk of a marine heat wave** occurring, as was the case in 2011, which had negative impacts on the juvenile habitats at the northern end of the fishery.

Ecosystem Based Fisheries Management

Economic Assessment

The beach price paid to fishers increased after the introduction of quotas in 2010 and peaked at around \$80 kg^{-1} between 2017 and 2020 (Figure 8.1). When the Covid 19 pandemic occurred in 2020 shipping of lobsters to China declined and the beach price followed, dropping to between \$35 and \$40. There has been a slow increasing trend in beach price since 2021, but values remain well below those obtained between 2017 and 2020 (Figure 8.1). Based on reports that China will start to import Australian lobster at some point in the 2024/25 financial year, it is likely that increases in beach price will be realised in the following 12 months. With both beach prices and the TACC increasing, the gross value of production (GVP) has also increased slightly over recent years.

The fishery remains reliant on the live export of lobster, and this linkage may strengthen if/when China again begins to import live lobster. The availability and consistency of export markets are considered a **high risk**.

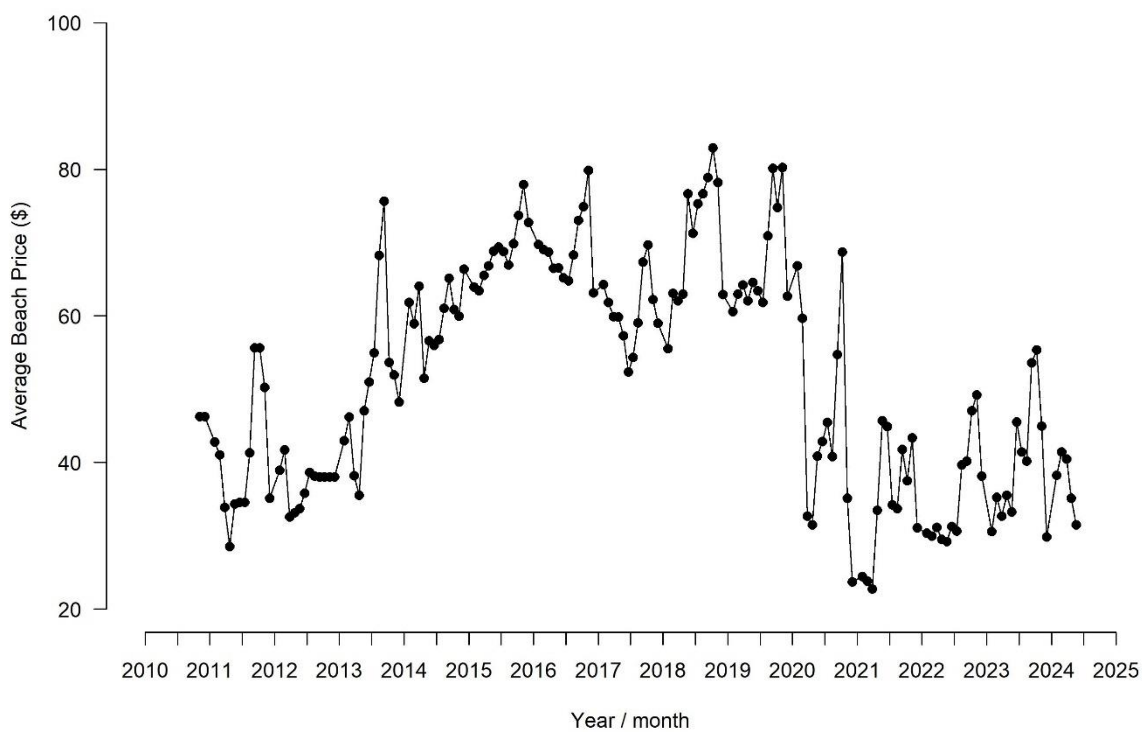

Figure 8.1. Monthly average beach price paid to fishers in the WRL fishery.

Social Considerations

Commercial western rock lobster fishing is the largest fishing employer in Western Australia. The number of fishing operators is determined as the number of Managed Fishery Licenses (MFLs) reported on at least five times within a season in catch reporting records. The numbers of fishing operators have declined since the start of the timeseries, initially progressively, then rapidly, following the marked management changes during 2008/2009 (Figure 8.2). Over the past 10 financial years the number of MFLs have continued to decline at a similar rate to that in the 1980s and 90s.

The commercial sector implemented the Back of Boats sales (BoBS) in 2020 to both provide additional income to fishers when traditional markets were impacted by Covid 19 and to increase public interaction with the commercial sector. Since the program began, a total of 107 different vessels have landed BoBS lobsters at 21 landing areas, which equates to 153,237.4 kg of lobsters being sold directly to the public (this represents over 250,000 lobster). Currently 0.6% of the commercial catch landed since September 2020 has been BoBS lobsters. Participation in this program remains strong with ~25 commercial vessels actively selling lobsters each month.

Fishing for western rock lobster is the most popular recreational fishery in Western Australia, with over 35,000 people participating between February 2022 and January 2023 (Smallwood et al. 2023). The majority (69%) of recreational fishing for western rock lobster occurs in the metropolitan region with 80% of the catch being landed by potting and most of the remainder by diving (very small amounts by hand collection from shore). During the 2022/23 season fishers landed an estimated 438 t (401-476 t 95% CI) statewide. The five-year average recreational catch (for licensed and tour operators combined) was 498 t in 2022/23, equating to 4.7%, which is below their total allowable recreational catch (TARC) of 5%. This sector not obtaining their TARC is not considered to represent a lack of stock, but rather is more reflective of participation rates by this sector.

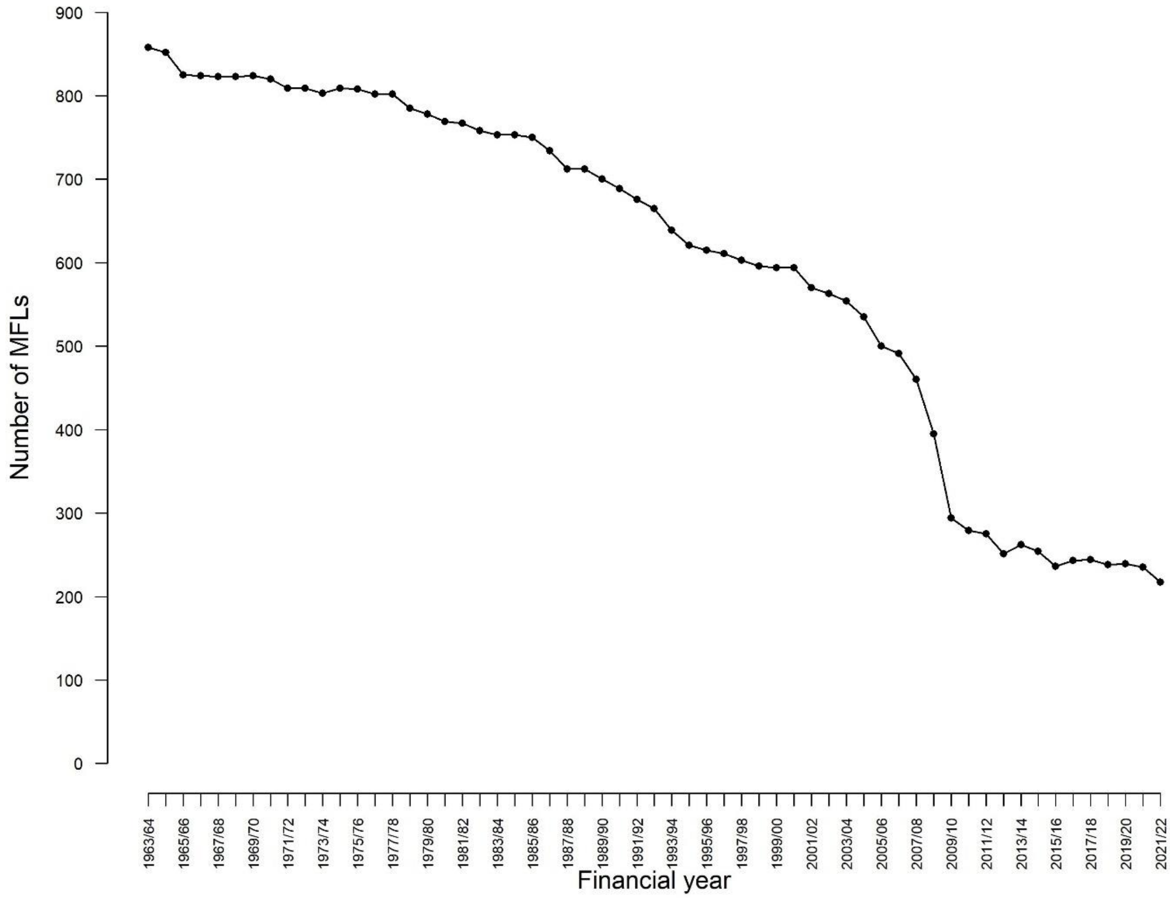

Figure 8.2. Total number of Managed Fishery Licenses used each financial year.

Retained (non-target) species

By-product

Commercial lobster fishers can retain other rock lobsters, octopus and champagne crabs that are caught as by-product of lobster fishing. All catch of these species must be detailed in catch disposal records. These data are included in the stock assessments for the West Coast Deep Sea Crustacean Managed Fishery (champagne crab) and Interim Octopus Managed Fishery (octopus). Both of these stocks are classified sustainable (https://www.fish.gov.au/). The catches by the WCRLMF reported during the 2023 financial year are detailed in Table 8.1.

Table 8.1. Species and quantity of by-product (kg) retained during the 2023 financial year.

Species	Catch (kg)
Champagne Crab	1339
Octopus	21854
Southern Rock Lobster	341

By-catch (non-ETP) species

Other species captured in lobster pots that are not available to be sold are defined as "by-catch species" and may be retained by the fisher for personal consumption or returned to the sea. All by-catch must be detailed in catch disposal records (CDR), which can result in the use of non-standard names. As such, records in the CDR have been summarised to combine, where possible, the same species under an official common name. For example, "Bluebone", "Baldys" and "Groper" have all been pooled under the common name of "Baldchin Groper".

During the 2023 fishing season, Baldchin Groper and Pink Snapper contributed 56.1% and 23.7% of by-catch, respectively (Table 8.2). It should be noted that not all by-catch caught is retained, with the majority being returned to sea alive (noting they would experience some level of discard mortality).

Table 8.2. Common name and catch (kg) caught during the 2023 financial year of species with a annual catch >10 kg.

Species	Catch (kg)
Baldchin Groper	4868
Pink Snapper	2060
Wobbegong Shark	507
Cuttlefish	320.9
Red Throat Emperor	300.6
Breaksea Cod	270.4
West Australian Dhufish	187.5
Chinamen Cod	57.4
Leather Jacket	20.5
Coral Trout	15.3

Endangered, threatened and protected (ETP) species

Compliance checks are undertaken on both commercial and recreational sectors to educate and ensure adherence to current management arrangements. In an average year compliance conducts over 500 and 4000 checks on each sector, respectively.

Sea Lions

Accidental drowning of Australian sea lion pups in western rock lobster pots instigated the implementation of sea lion exclusion devices (SLED) in areas where these interactions were occurring (*Campbell et al. 2008*). An ecological risk assessment (*ERA*) re-assessed this issue after the implementation of SLEDs as a low risk. Prior to SLED implementation, the historical level of sea lion drownings was three per season. In 2023 there were zero interactions recorded. The performance measure for the fishery is that there is no increase in the rate of capture of sea lions. Therefore, **the fishery met this performance measure**.

Compliance checks are undertaken on the adherence of fishers to SLED regulations. In the 2023 financial year the fishing gear of 310 recreational fishers and 105 commercial operators were checked for compliance. This resulted in the issuing of zero infringements, with two warnings for SLED compliance.

Dusky Shark

To address concerns over the impact of entanglement on the Dusky shark (*Carcharhinus obscurus*) population from discarded bait bands, a state-wide ban on bait bands on fishing vessels was implemented on the 15 November 2011. An ERA re-assessed this issue after the implementation of the state-wide ban as no longer being a credible threat (*Stoklosa 2022*) and was therefore not assessed any further. Compliance checks are undertaken on the adherence of fishers to bait band regulations and in 2023 these resulted in zero infringements and one warning.

Whales

The largest population of humpback whales (*Megaptera novaeangliae*) in the southern hemisphere (Leaper et al. 2008) migrates along the West Australian coast annually. Traditionally this population has had a small interaction with the western rock lobster fishery. Entanglements between 1990 and 2010 ranged from 0 to 6, averaging just over 1 entanglement annually. However, in 2011 there was an increase in whale entanglements which ultimately peaked with 17 in 2013 due to increased fishing during the whale migration period when the season was extended to 12 months.

In July 2014 a series of gear modifications were introduced to mitigate entanglements between humpback whales and western rock lobster gear (How et al. 2021). These modifications are implemented during the whale migration period (May-October) each year since. An ERA re-assessed this issue after the implementation of these mitigation measures as being a low risk (*Stoklosa 2022*). The performance measure for this fishery is that entanglements in western rock lobster gear is within historic range. In the 2023 financial year, only one entanglement was recorded, and therefore, **the fishery met this performance measure**. Compliance checks are undertaken on the adherence of fishers to whale gear mitigation regulations and in 2023 these resulted in the issuing of 1 infringement and 3 warnings.

Habitat

To assess the main habitats encountered by the WCRLMF *POTBot* cameras are deployed in the pots of interested commercial fishers. These fishers are chosen (based on their fishing locations and willingness to participate) to extend this monitoring across the extent of the commercial fishery. POTBots are retrieved from fishers, typically on a monthly basis, their text data (dates, deployment positions and water temperature) are recorded into a database and videos onto a hard drive. Videos are scanned by a trained staff member and the visible habitat classified in conjunction with the presence of any key interesting species (e.g. Dhufish, Break Sea Cod, Baldchin Grouper, Shark). In the 2023 financial year 117 geo-positioned videos were collected and analysed (Figure 8.3). Due to camera development this is expected to grow to > 500 in the 2024 financial year.

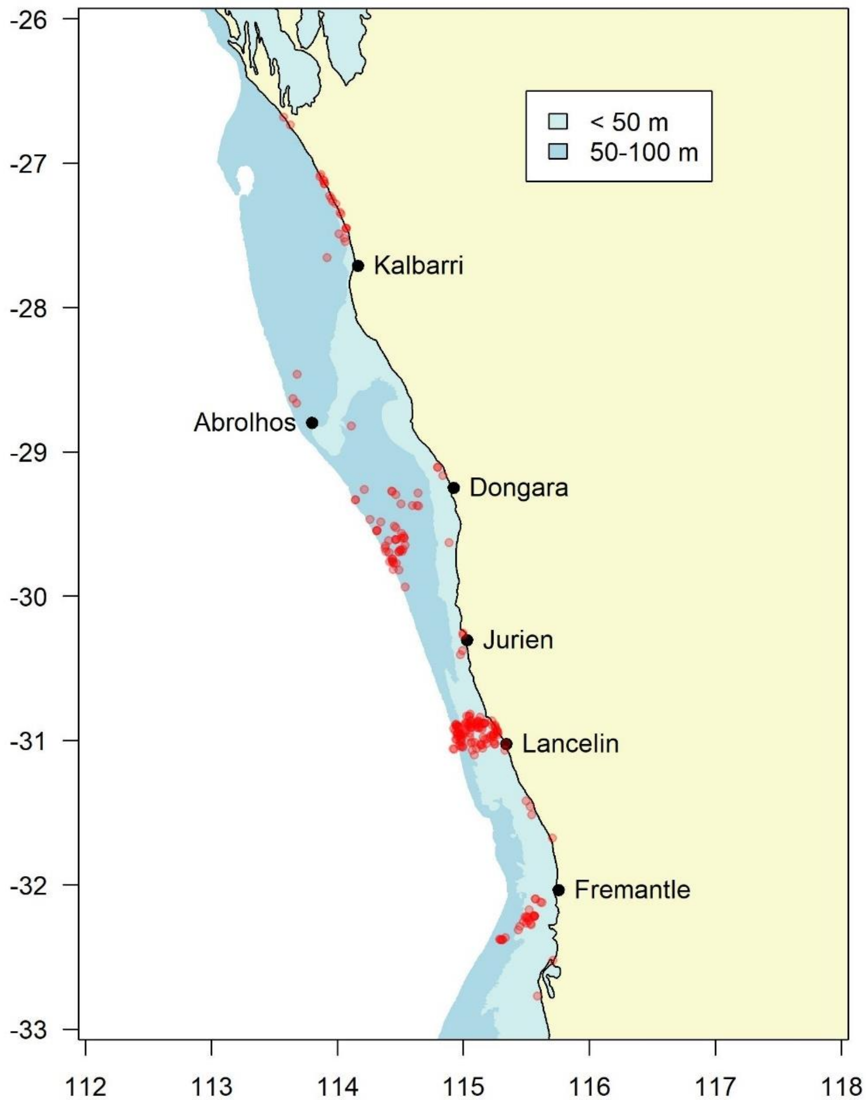

Figure 8.3. Map showing all POTBot deployment locations since 2021. Note points show over plotting, with intensity of red representing multiple points.

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Appendix 1. Management timeline

Table 1. Timeline of major management regulatory changes introduced into the WCRLMF.

Year / Season	Regulation
1897	Minimum legal whole weight of 12 oz (340 g). This measurement is equivalent to, and eventually evolved into, the 76 mm carapace length minimum size currently in force in the fishery (Figure 3.2 for measurement detail).
1899	Females carrying spawn were given full protection by requiring them to be returned to the sea.
1962	Closed seasons: coastal fishery 16 August–14 November; Abrolhos Islands fishery 16 August–14 March.
1963	Limited entry introduced: boat numbers were fixed (858) and the number of traps per boat was limited to three per foot (0.9 m) of boat length.
1965	Boat replacement policy required a boat to be replaced with one of exactly the same length. This stopped fishers replacing a boat with a larger one and hence obtaining additional traps to use under the three traps/foot of boat length regulation. This froze the number of traps in the industry at 76 623.
1966	A 51 x 305 mm escape gap was introduced into all traps to allow sub-legal size lobsters to escape before the trap is brought to the surface.
1971/72	Escape gap increased to 54 x 305 mm.
1973	Multiple entrance traps were banned.
1977/78	Fishing season was shortened by 6 weeks from (15 November–15 August to 15 November–30 June) to protect newly mated females and to constrain fishing
1979	Boat replacement policy was changed to allow a boat's trap quota (entitlement) to vary from seven to ten traps per metre of boat length. This gave fishers the flexibility in the size of replacement boats that they could have for a given trap
1984	Maximum size of traps was established; based on a maximum volume of
1986	Number of escape gaps (54 x 305 mm) in traps was increased (from one) to three or four (depending on the positions of the gaps).
1986	Trap numbers of all licence holders were reduced temporarily by 10% for the 1986/7 season. Total trap numbers were reduced from 76 623 to 68 961 for one
1987–1991	Trap numbers were reduced permanently by 10%, at 2% per year for 5 years.
1992/93	10% reduction in traps in Zone B (15 November–9 January) Closure of Zone B (10 January–9 February) Return of setose females required (November–February) Maximum size for females of 115 mm (Zone C) and 105 mm (Zones A&B) introduced. Home porting in Zone C. Access to Big bank after 24th February
1993/94	18% reduction in traps Minimum size increased to 77 mm in November–January Required return of females that are setose or above a maximum size (105 mm Zone A and B; 115 mm Zone C) Home porting in Zone C restriction lifted

2000/01	Unitisation of the fishery to more explicitly incorporate the 18% pot reduction in the current pot entitlements Individual numbering of pot entitlements The ability of those with access to 63 or more pot entitlements and a fishing boat licence to apply for a new managed fishery licence The ability of fishermen to retain an inactive managed fishery licence by retaining an inactive fishing boat licence and one or more inactive pot entitlements Provision for temporary pot transfers
2001/02	Use of animal hide as bait prohibited
2003/04	Removal of 150 pot rule
2005/06	Three-year effort reduction package 15% effort reduction in Zone B 10% pot reduction 15 November–15 March 10% pot reduction in Zone A 15 March–15 April Summer closure in Zone B 15 January–9 February Sundays off in Zone B 15 March–30 June Closed Christmas and New Year's day 5% effort reduction in Zone C Closed 15 November–24 November Five three-day moon closures 1 February–30 June Closed Christmas and New Year's day
2006/07	A and B Zone fishers who nominate to fish the Big Bank from 10 February must remain in Big Bank until midday on the last day of February of the season. Big Bank then becomes part of the B Zone fishery and any Zone A or B fisher can go there or leave it as they please.
2007/08	Effort reduction: unit values (number of pots per unit) of Zone A – 0.74 from 15 November to 15 April then 0.82 til season end Zone B – 0.74 from 15 November to 15 March then 0.82 til season end Zone C – 0.82

2008/09	15 November - Effort reduction: unit values (number of pots per unit) of Zone A – 0.66 Zone B – 0.66 Zone C – 0.74 Sunday closure for all zones and all season with the exception of the first two weeks in Zone A 30 November - Effort reduction: unit values (number of pots per unit) of Zone A – 0.54 Zone B – 0.54 Zone C – 0.62 24 February - Closure of Big Bank for the remainder of the season 1 March - Effort reduction: unit values (number of pots per unit) of Zone A – 0.42 Zone B – 0. 42 Zone C – 0.50 6 March – Saturday and Monday closures for all zones and all season Sunday closure for the first two weeks of Zone A continuing all season Removal of Zone C moon closures 15 March - Maximum size of female lobsters in Zone A and B reduced to 95mm Minimum size in Zone C increased to 77mm 1 May - back to 5 fishing days per week (Saturday and Sunday closures)

2009/10	Effort reduction: unit values (number of pots per unit) of: Zone A – 0. 36 Zone B – 0.40 Zone C – 0.44 Temporal closures: Zone A – 4 days a week all season Zone B & C – 4 days a week during "whites" and "reds" peaks (December 1 to December 31 and March 15 to April 14) Zone B & C – 5 days a week for rest of the season Changes in maximum female size: Zone C – 115 mm to 105 mm Minimum size of 77 mm all season All pots must have at least three escape gaps 55 mm high and 305 mm wide Nominal Total Allowable Commercial Catch (TACC) of 5,500 tonnes set for the 2009/10 season. Removal of soaking periods prior to the start of the season (provision made to load and bait pots and move in the Fishery 7 days before the start of the season) Big Bank to remain closed Rock Lobster processors to submit weekly catch (only) returns, to be received by the Department no later than COB Tuesday, each week of the season (in addition to monthly reporting requirements) Carrier boats permitted to carry more than 4 rock lobster pots. December 2009 Prohibit fishing in Zone B between 25 December 2009 and 10 January 2010 inclusive; Continue the prohibition on fishing on Friday, Saturday and Sunday each week throughout the remainder of the first half of the season in Zone B; Prohibit fishing in Zone C between 25 December 2009 and 3 January 2010 inclusive; and B Zone summer closures removed. January 2010 Closure in Zone B extended to 25 January; and Prohibit fishing in Zone C between 16 January and Prohibit fishing on Fridays in Zone C from 1 Feb to end of season. February 2010 Prohibit fishing in Zone C between 12 March and 21 March Change unit value to 0.30 for Zone C effective 21 March; Zone A prohibited from fishing in Zone B for the remainder of the season as of 15 February 2010; and Prohibit fishing in Zone B between 12 March and 11 April. 17 February 2010 Zone B permitted to fish Friday's for the remainder of the season. May 2010 Zone C closed for the remainder of the season – effective 10 May; Zone A closed for the remainder of the season – effective 17 May. June 2010 Zone B closed for the remainder of the season – effective 15 June

2010/11	Total Allowable Commercial Catch (TACC) of 5,500 tonnes set for the 2010/11 season. Individual catch limits introduced with the following number of kilograms per unit: Zone A – 36kg from 15 November to 14 March Zone A – 51kg from 15 March to end of season Zone B – 81kg for entire season Zone C – 75kg for entire season Pot usage set at 0.5 pots per unit for all zones. Fishing prohibited weekends Big Bank to remain closed Season extended to 31 August Zone C start date moved from 25 November to 15 November 20 fathom rule removed Implementation of Sea Lion Exclusion Devices at the Pelsaert and Easter Groups of the Abrolhos Islands Introduction of crate tags catch and disposal records (Appendix A), authorised receivers, holding over book and catch weighing procedures to monitor fishers' catch.
2011/13	TACC of 6938 tonnes. Extended 14 month season 15 November 2011 to 14 January 2013 with closure between 1 October and 14 November
2013	TACC of 5554 tonnes (Zones = 1076, B = 1921, C = 2557 t). Changes to the Harvest Strategy such that there is a 50:50 share of catch between the north (A&B Zones) and the south (C Zone)
2014	TACC of 5859 tonnes (Zones A = 1076, B = 1921, C = 2862 t). Gear modifications for whale entanglement reduction introduced (see Bellchambers et al. in press)
2015	TACC of 6000 tonnes (Zones A = 1076, B = 1921, C = 2997 t). TARC of 404 t (2014/15 season). Access to Big Bank granted under research exemption (no access to research closure).
2016	TACC of 6300 tonnes (Zones A = 1134, B = 2016, C = 3150 t). TARC of 422 t (2015/16 season). • Restriction on the retention of maximum size females removed. • Introduced paying market price of rock lobster (per kilogram) in respect to exceeding entitlement. • Holding Tags removed • Holding areas described and pot storage areas removed. • Weighing points outlined • Insert the correct minimum unit holding, of 300 • Change whale season end date to 31 October

2017	TACC of 6300 tonnes (Zones A = 1134, B = 2016, C = 3150 t). TARC of 480 t (2016/17 season). • Extension of Leeman Closure to 2023 Big Bank re-opened for fishing outside of research closure.
2018	TACC of 6300 tonnes (Zones A = 1134, B = 2016, C = 3150 t). TARC of 507 t (2017/18 season). • Prohibition on Fishing for Rock Lobster Order 2018 – Mitigation measures for whales and night fishing ban
2019	TACC of 6000 tonnes (Zones A = 1190.7, B = 3116.8, C = 3307.5 t). TARC of 506 t (2018/19 season). • Reg amendments - Lobster fishing without a licence when on a charter boat and change • Setose rules for recreational fishers. • Escape gap changed.
2020 (Covid 19)	TACC of 9000 tonnes (Zones A = 1620, B = 2880, C = 4500 t) over 18 month season from 15 Jan 2020 to July 2021. TARC of 490 t (2019/20 season). • BoBs Mechanism introduced. • Increase quota over runs to 60kg. • CEO to sell forfeited entitlement. • Amend pot usage rules over winter. • Inclusion of Augusta, Mangles Bay, Pigeon Island as Approved Landing Area Big Bank research closure reduced in size to the southern half only.
2021 (2021/23 season)	TACC of 9000 tonnes (Zones A = 1620, B = 2880, C = 4500 t) over 18-month season until January 2023. TARC of 533 t (2020/21 season). • Delete reference to holding tags. • Allow to transition pots between zones with written permission. • Schedule 8 – Unit Value method amended.

2022 (2021/23 season)	TARC of 562 t (2021/22 season). • Prohibition on false or misleading information on CDR forms • Extension of Leeman Closure to 2027 • Inclusion of Port Coogee Marina as Approved Landing Area
2023	TACC of 4300 tonnes (Zones A = 774, B = 1376, C = 2150 t) over short season from 15 January 2023 and ending on 30 June 2023. TACC of 7300 tonnes (Zones A = 1314, B = 2336, C = 3650 t) usual season from 1 July 2023 and ending on 30 June 2024. TARC of 585 t (2022/23 season).
2024	TACC of 7300 tonnes (Zones A = 1314, B = 2336, C = 3650 t) usual season from 1 July to 30 June 2025. TARC of 500 t (2024/25 season). • amend the definition of net weight • increase back of boat sales to 999 • require the reporting of lost rock lobster pots through Fish Eye • allow for errors in both under declaration and over declaration of weights in a Catch and Disposal Record (CDR) form, registered receiver consignment form, or form submitted using Fish Eye, to be corrected by the Department of Primary Industries and Regional Development.

Appendix 2. Biomass Dynamics model

Model description

A Schaefer biomass dynamics model was used and fitted using TMB (Kristensen et al. 2015), as a non-equilibrium model that spans 1945 until present, fitting to three time series of abundance; (i) standardised mean commercial fishing CPUE, and mean independent survey CPUE for females (ii) and males (iii). The annual standardised commercial CPUE data spans 1975 until present, whilst the independent survey data spans 1993 until present. Commercial catch rates were standardised, via linear models, for month, soak time, and vessel.

The model estimated biomass (*B*) of the lobster population in a zone (*z*) and year (*t*) was derived from the biomass in the previous year and the additional biomass produced minus the catch removed during the previous year, based on the biomass equation:

$$B_{z,t+1} = B_{z,t} + \left(r_z B_{z,t}\left(1 - \frac{B_{z,t}}{KR_z}\right)\right) - F_{z,t}B_{z,t}$$

This biomass component of the BDM contains the estimated parameters: *r* which is a zone-specific rate of intrinsic population growth (estimated in log-space to keep positive; n = 3). *K* is the unfished biomass of the entire resource (scaled by $1e^{+3}$ to keep on a similar scale to other parameters; n = 1). *R* allocates *K* into zonal allocations (estimated in log-space to keep positive and forced to sum to 1 across the three zones using the equation $R_z = e^{R_z`} / \sum(R_z` + 1))$, where *R*` is a parameter vector (n = 2) estimated for zones A and B and set to 1 in Zone C. *F* is the zone and year specific harvest rate (logit transformed to remain between 0 and 1 by the equation $F_{z,t} = 1/(1 + e^{F_{z,t}`})$; n = 231). An estimated harvest rate was used in place of directly removing commercial catches as it was found to improve the minimalization algorithm's ability to search across the multi-dimensional likelihood profile (Pers. Comm. Andre Punt). Weighting on this likelihood component (λ_1; see later) ensured that estimated and observed catches remained very similar (variation was < 0.1%) for each timestep.

Model estimated CPUE indices were derived from the model estimated biomass using an index-specific calculated scaling factor. As recent research has indicated that catchability in the IBSS may be effected by several biological and environmental factors (Tuffley 2023), the IBSS CPUE indices were first adjusted for catchability (*q*) using the equation:

$$q_{s,z,t} = e^{\dot{W}_{z,t}w_{s,z}} + e^{\dot{D}_{z,t}d_{s,z}} + e^{\dot{M}_{z,t}m_s} + e^{\dot{G}_{z,t}g_s},$$

where *w*, *d*, *m* and *g* (swell (n = 6), sea surface water temperature (n = 6), proportion of mated legal sized females (n=2) and proportion of ovigerous legal sized females (n = 2), respectively) are parameters and $\dot{W}, \dot{D}, \dot{M},$ and $\dot{G}$ their respective normalised data sets. Lobster sex, management zone and year are denoted by *s, z and t,* respectively.

To account for temporal increases in fishing efficiency, commercial CPUE was adjusted by year-zone specific fishing efficiency prior to calculating the commercial index scaling factor. Fishing efficiency compounded from the first year by zone-specific constant parameters in three separate time periods, 1975 – 2007, 2008 – 2012 and 2013 – 2023, which represented: (1) pre significant management changes which reduced fleet size; (2) acclimation to quota fishing; (3) changes to pot dimensions post quota acclimation.

The scaling factor (C) used to rescale model biomass estimates ($\hat{B}$) onto the same mean scale as the observed index (U_i) was determined by the equation:

$$C_i = \sum_{j=y}^{1} U_j^i \Big/ \sum_{l=z}^{1} \sum_{j=y}^{1} \hat{B}_j^i Q_{s,z,y}^i ,$$

where i is the catch rate index and Q is the model estimated catchability, which for independent indices $Q = q$, and for the commercial catch rate index (which does not have variable lobster q) $Q = 1$.

The model contained four likelihood components, one for each the commercial catch (λ_1), commercial CPUE (λ_2), and independent female (λ_3) and male CPUE (λ_4), and were all based on the same general likelihood equation:

$$\lambda_{1-4} = \sum_{j=z}^{n} \sum_{i=y}^{n} 1/(\hat{\sigma}\sqrt{(2\pi)})e^{(-((\log(U_{y,z})-log(\bar{U}_{y,z}))^2/(2\hat{\sigma}^2)))}$$

where σ was a common parameter for the three catch rates indices and unique for the commercial catches (estimated in log-space; n = 2), and $\hat{U}$ is the model estimated index for each respective data set used in the fitting of the model (catch, commercial CPUE, female independent CPUE and male independent CPUE).

The total log-likelihood was the sum of each likelihood multiplied against an index specific weighting factor (commercial CPUE = 1, female independent CPUE = 5, male independent CPUE = 5, and commercial catch = 200). These weightings were based on the prior assumptions that:

1. The timeseries of commercial catch rates was less representative than independent survey indices due to factors such as progressive temporal changes in targeting.
2. The weighting on commercial catch was increased to the point that catches were accurately replicated by the model.

Estimation of the model parameters was conducted by minimising the negative of the total log-likelihood using the nlimb() function in R, and estimates of the variance around parameters and derived indices (e.g. zone-specific biomass) were determined using the sdreport() function from the TMB library. Assessment of model fit was based on the convergence criteria supplied by the nlimb() function and the attainment of a maximum likelihood gradient < 1e-5.

Model diagnostics

The BDM replicated both the IBSS and commercial catch rates with concordance correlation confidents ranging from 0.827 – 0.965 (Figures A2.1 and A2.2).

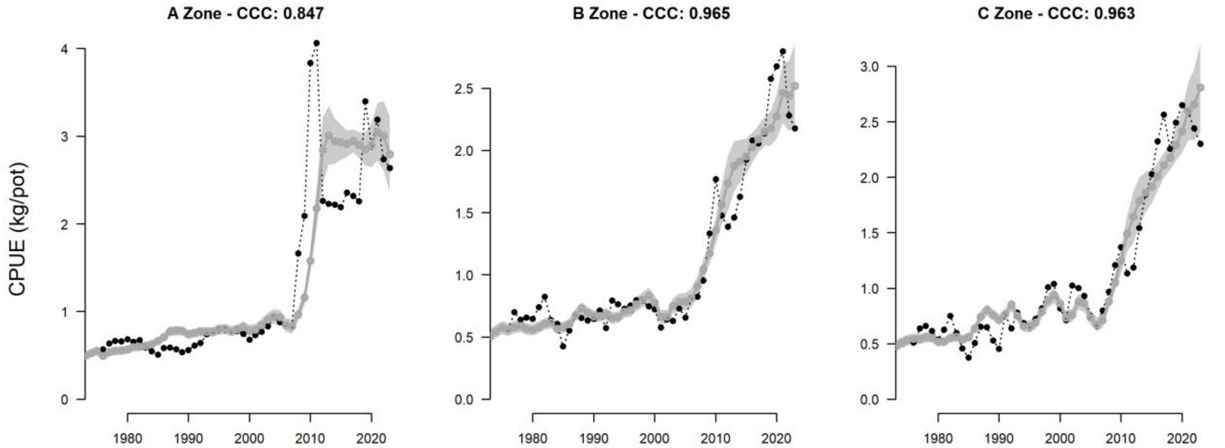


Figure A2.1. BDM fit (and 95% confidence intervals) (grey points and shading) to the commercial CPUE (black points and dashed line). CCC = concordance correlation coefficient.

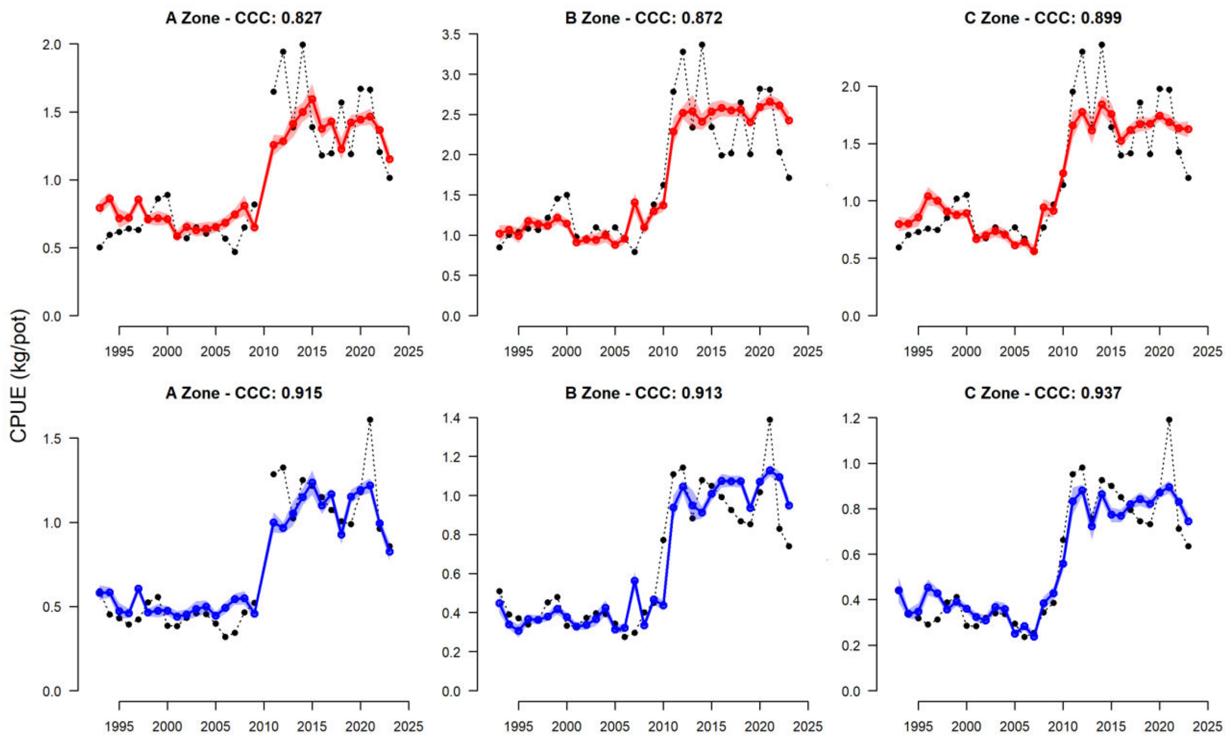


Figure A2.2. Female (red) and male (blue) BDM fits (and 95% confidence intervals) to the observed (black) female and male IBSS CPUE. CCC = concordance correlation coefficient.

Within the BDM male and female catchability in the IBSS showed similar trends across the reproductive cycle; increasing with the proportion mated and decreasing with the proportion ovigerous (**Error! Reference source not found.** 11). There was a significant positive relationship between female and male catchability and the proportion of females mated (P < 0.001) and a significant negative relationship between female and male catchability and the proportion of females ovigerous (P < 0.05). There were significant relationships between catchability and the environmental factors, however, the impacts were more complicated, varying between sex and location (Figure 12).

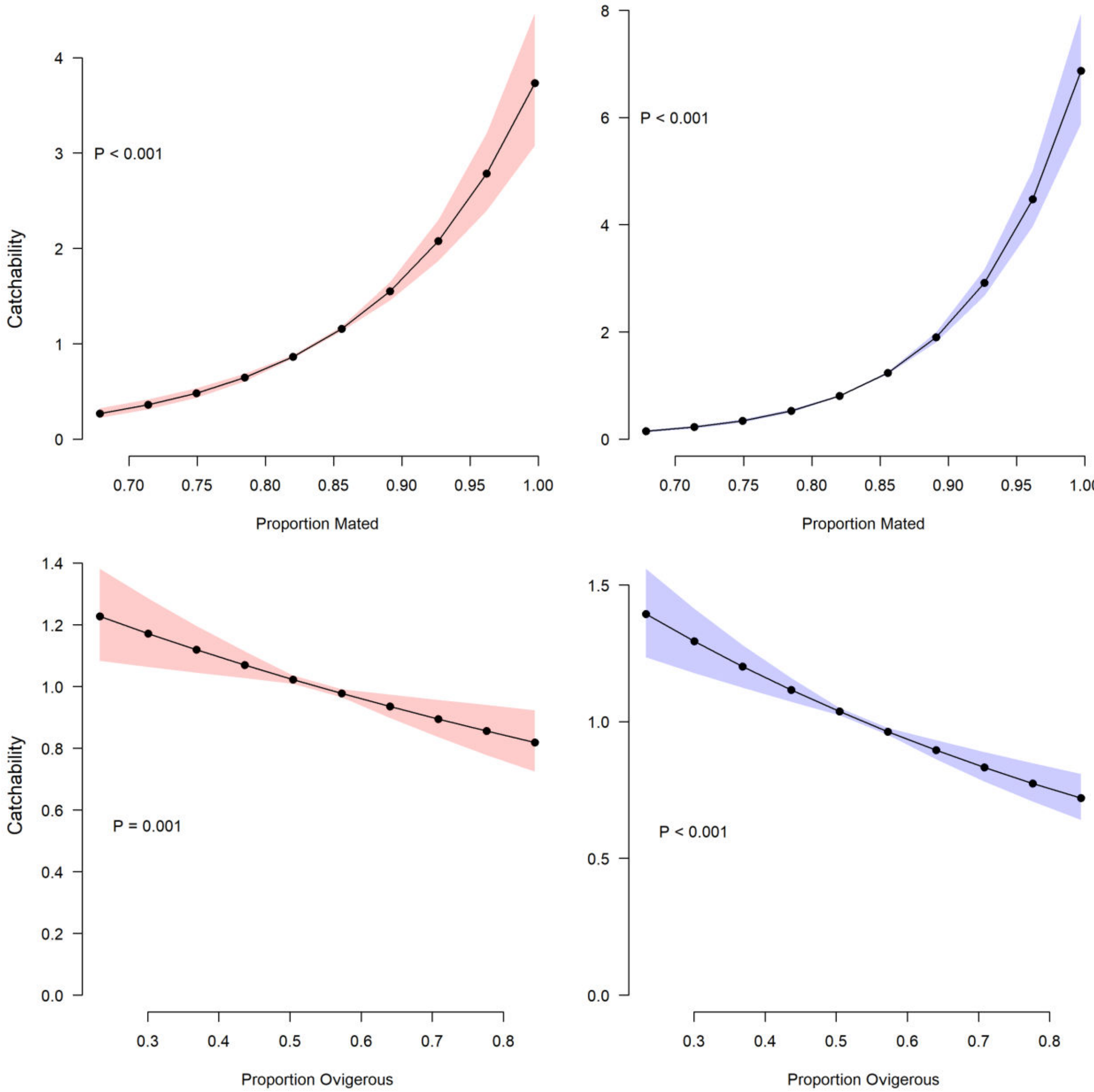


Figure 11. Effects of the reproductive factors; proportion mated (top) and proportion ovigerous (bottom), on the catchability of females (red) and males (blue), plus p values and 95% confidence intervals.

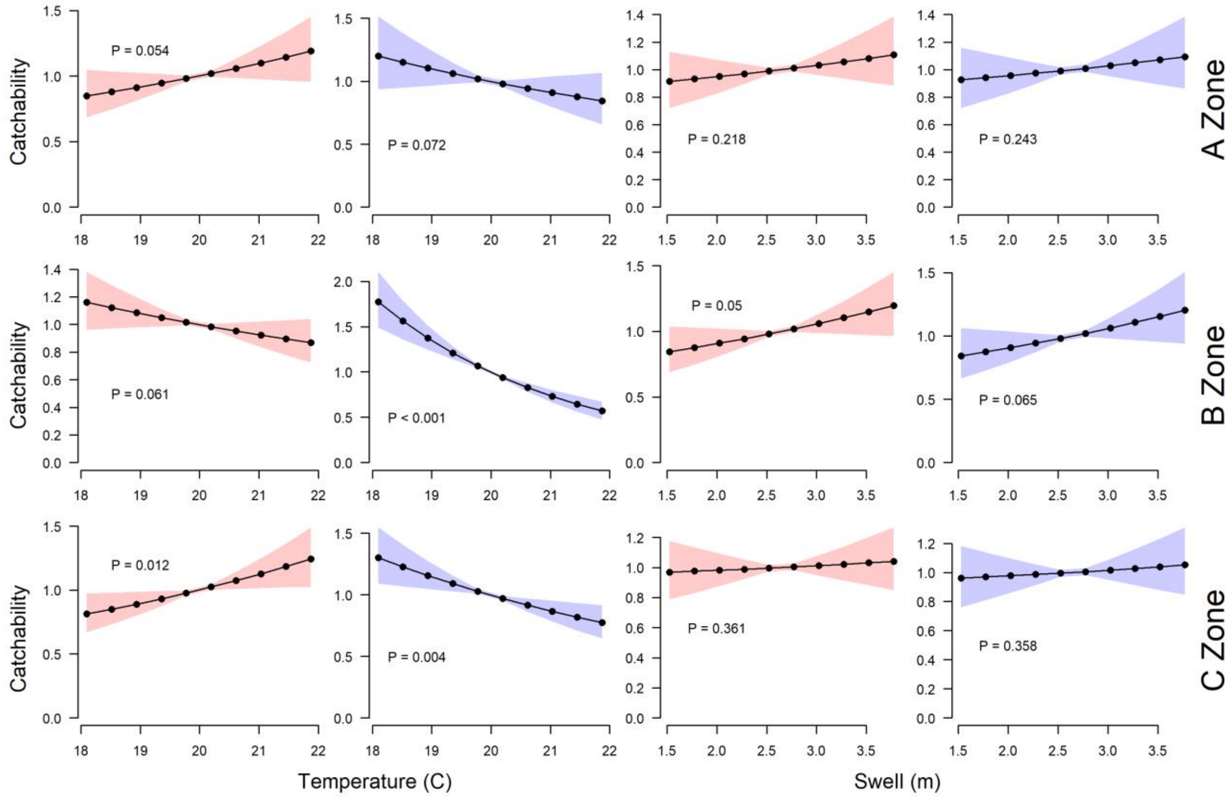


Figure 12. Effects of the environmental factors; temperature, and swell height, on the catchability of females (red) and males (blue), plus p values and 95% confidence intervals.

Appendix 3. Integrated Model fitting running sheet

This document is the annual "running sheet" associated with the update of the integrated stock assessment model (IM) and the development of the annual stock assessment. It is updated annually in conjunction with the stock assessment describing any structural modifications to the IM, updated data inputs, and the location of the source code. It is used as a record keeping process to ensure that all the required data files are updated each year efficiently (source code easy to find and run).

Changes to 2023 Model build

- Lob11.dat file updated for additional year: Last year (ly = 2023); Last IBSS (libss=2023); last Puerulus (lpuer=2024) and projected year (projy=2029). Done
- Lob11.pin file updated to account for changes in years requiring deviations: Recruitment deviations (1975-2026); catchability deviations (1975-2023); (no changes needed to pin file for following) natural mortality deviations (five years); future recruitment deviations (five years) and future egg production deviations (five years). Done

- Added ability for model to estimate pot selectivity (no escape gap, 54 and 55 mm escape gaps).
- Added ability for model to estimate annual variation in proportion of lobsters migrating north.
- Added ability for model to account for spatial variation in *M*. This has not been used / turned on but has been built in for future testing.

Current management arrangements

- Minimum size limit 76 mm
- Maximum size limit removed.
- Setose protection removed for May - October

Data updates

- Puerulus ("data_puerulus_2021dat"). Updated with 2023/24 settlement season. The majority of 2023/24 areas were based on the 25th quantile because their respective 2021/22 values were above the 25 quantile. "M:\Fisheries Research\Invertebrates Fisheries\Rock Lobster\Puerulus Database\Annual index\Puerulus input for ADMB model.csv". Done
- Commercial Catch and Effort data ("data_catcheffort2021.dat"). Updated with a bunch of files. ("code.R" is in "C:\Users\snd\Rock Lobster\Data\Environmental measurements\LengthMonitoring", running this file updates the standardised water temperatures for the model. "catch_effort_for_model.csv" is produced by "!! Simons make CE4Model.r" in "M:/Fisheries Research/Invertebrates Fisheries/Rock Lobster/CDR" is used to update "A Summary Data.csv" which is located in "C:\Users\snd\Rock Lobster\Data". In the folder "C:\Users\snd\Rock Lobster\Data\Make data file for model" use R script "mkdF.r" to make new datafile for model "dataForModel.csv"). Only catch which fell within the 2023 year and January 1-14 2024 was added. The most recent 12 months of effort distribution data (15 January 2023 - 14 January 2024) was used to project effort distribution into the future. Done
- Commercial length frequency data ("data_Lenfreq2021.dat"). Updated with 2022 season ("mk.lf.input(45.135).r" in "M:\Fisheries Research\Invertebrates Fisheries\Rock Lobster\Length Monitoring\Analysis"). Done
- IBSS catch rates ("data_IBSS_CPUE_above75.dat"). All lobsters >= 75 mm CL. (C:\Rock Lobster\Data\IBSS\catch rates greater than 76 mm). Done
- IBSS length frequency data ("data_IBSSlenfreq(2021).dat"). (C:\Rock Lobster\Data\IBSS\catch rates greater than 76 mm). Done
- High grading data updated (C:\Rock Lobster\Data\CDR\Current) "data_hgForModel.dat". Done
- Tag-recapture data ("data_movement for model(2018).dat"). C:\Users\snd\Rock Lobster\Data\IBSS\Analysis\recaptures for model.r Done
- Recreational catch data ("data_recreational_catch.dat"). Updated. Done

Stock Assessment Modelling Process

Conducting the current assessment

- The model is fitted with all parameters using the fitting argument ”lob11 -maxfn 2000”, which extends the maximum number of iterations needed to reach convergence.
- The diagnostics and output files are produced and saved three separate Rmardown files “FittoData.Rmd”, “Parestimate.Rmd” and “Outputs.Rmd”.

Running future scenarios

- R code “Run ADMB and do scenarios.r” which is located in the model file is used to run a number of scenarios. This code adjusts the last six years of known effort data (pro rata between regions in each zone) to match observed catches exactly. This ensures that in recent years the correct amount of biomass is removed from the model. This process is conducted using the “target(past).dat” file as an input to automate the effort adjustment. When running this code the dummy parameter is turned on and all other parameters turned off. This stops a re-adjustment of estimated parameters and speeds up the fitting process.
- Effort in the future five fishing seasons (current year+1 to 5) is then adjusted to predefined harvest rates or catch levels to produce specific scenario projections using the same code file “Run ADMB and do scenarios.r”. This process is controlled using this code and the “target(future).dat” input file to designate the correct future years to model. The results of this analysis are recorded in a file “catch_effort_out.csv”.

Appendix 4. Integrated model diagnostics

The IPM is fitted to commercial and recreational catches, fishery-independent deep-water (IBSS) catch rates, puerulus settlement rates, tag-recaptures and lobster size compositions measured during either commercial monitoring or IBSS. All comparisons are conducted at the fine area (Figure A3.1) and temporal (11 timesteps) scale. Diagnostics are provided at this same spatial scale and if required (high number of comparisons) diagnostics are provided at a grouped scale (e.g. by zone or decade).

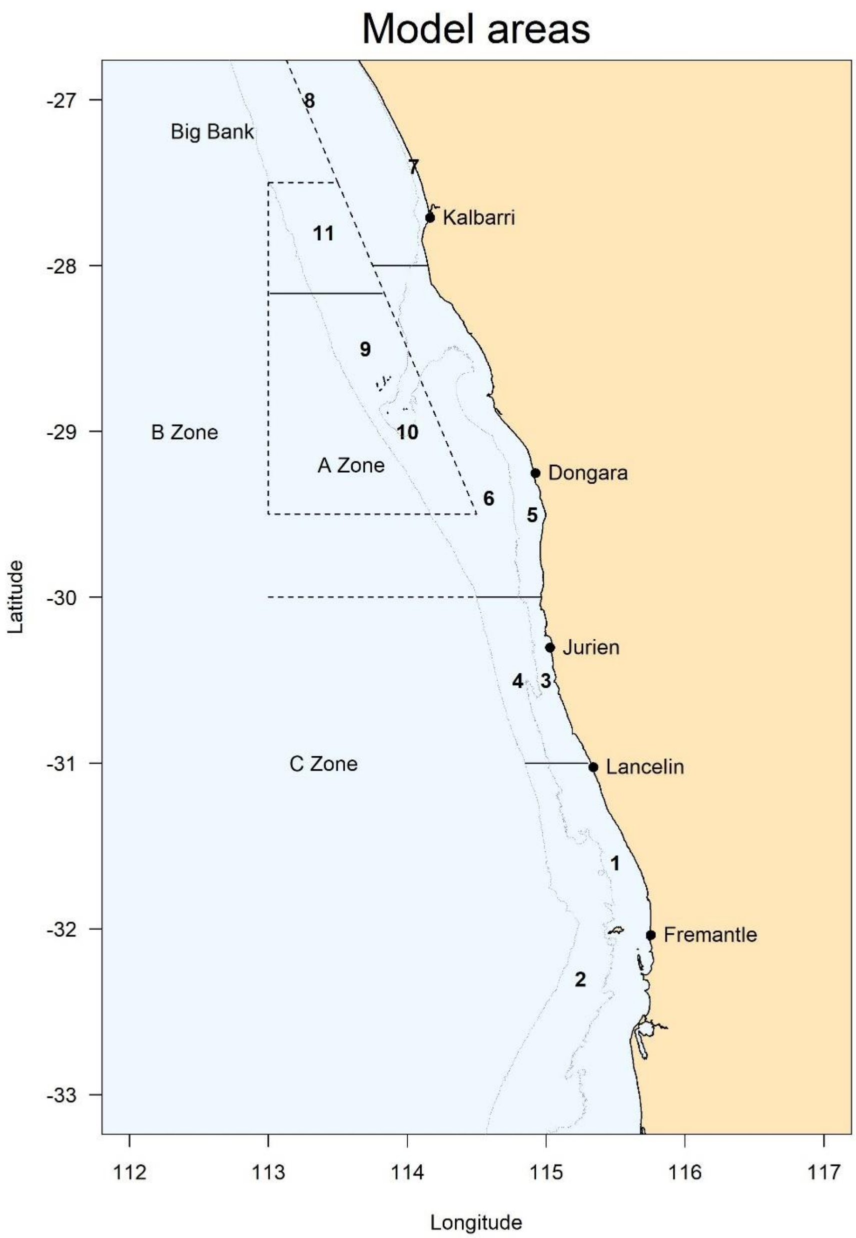
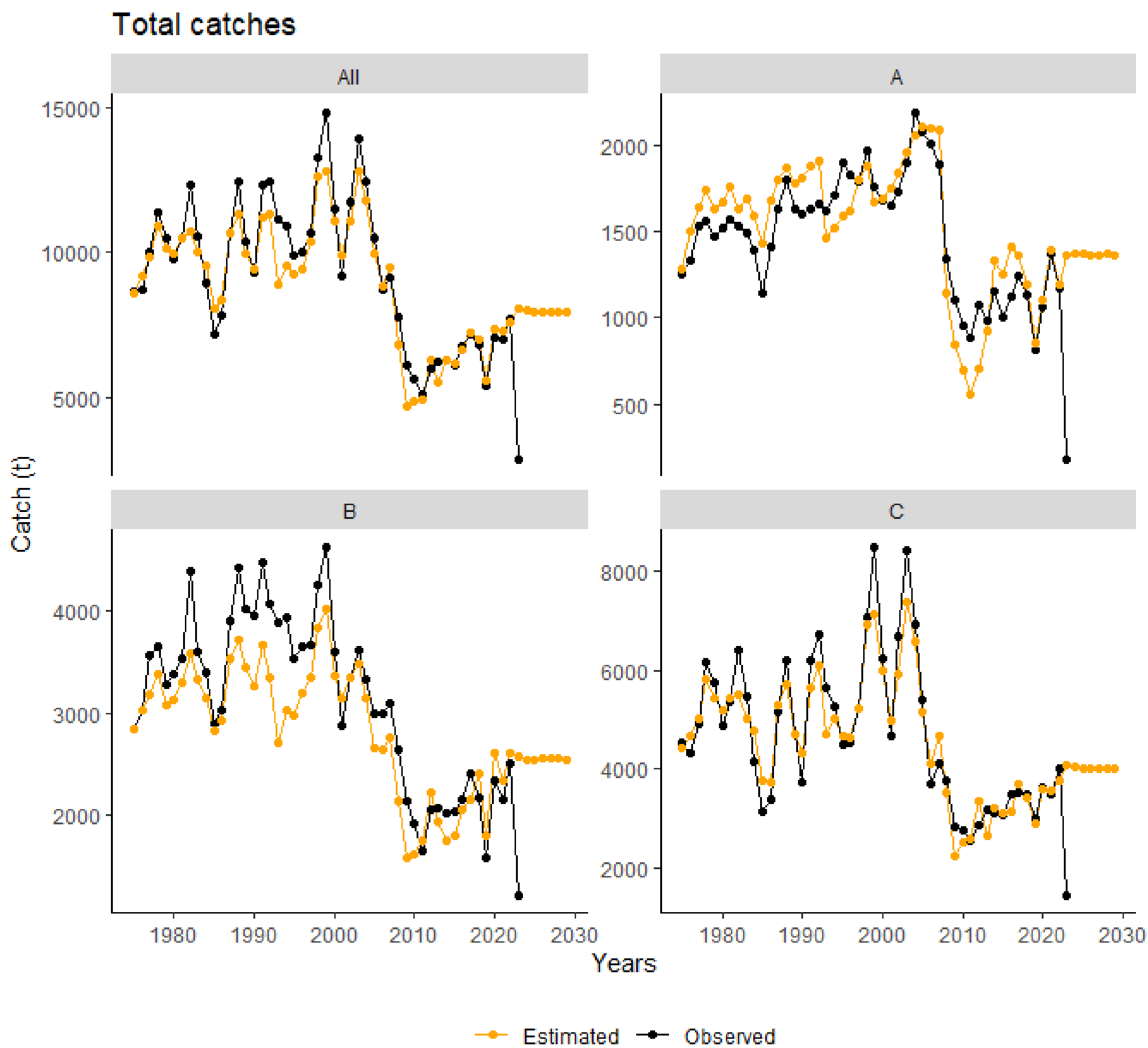
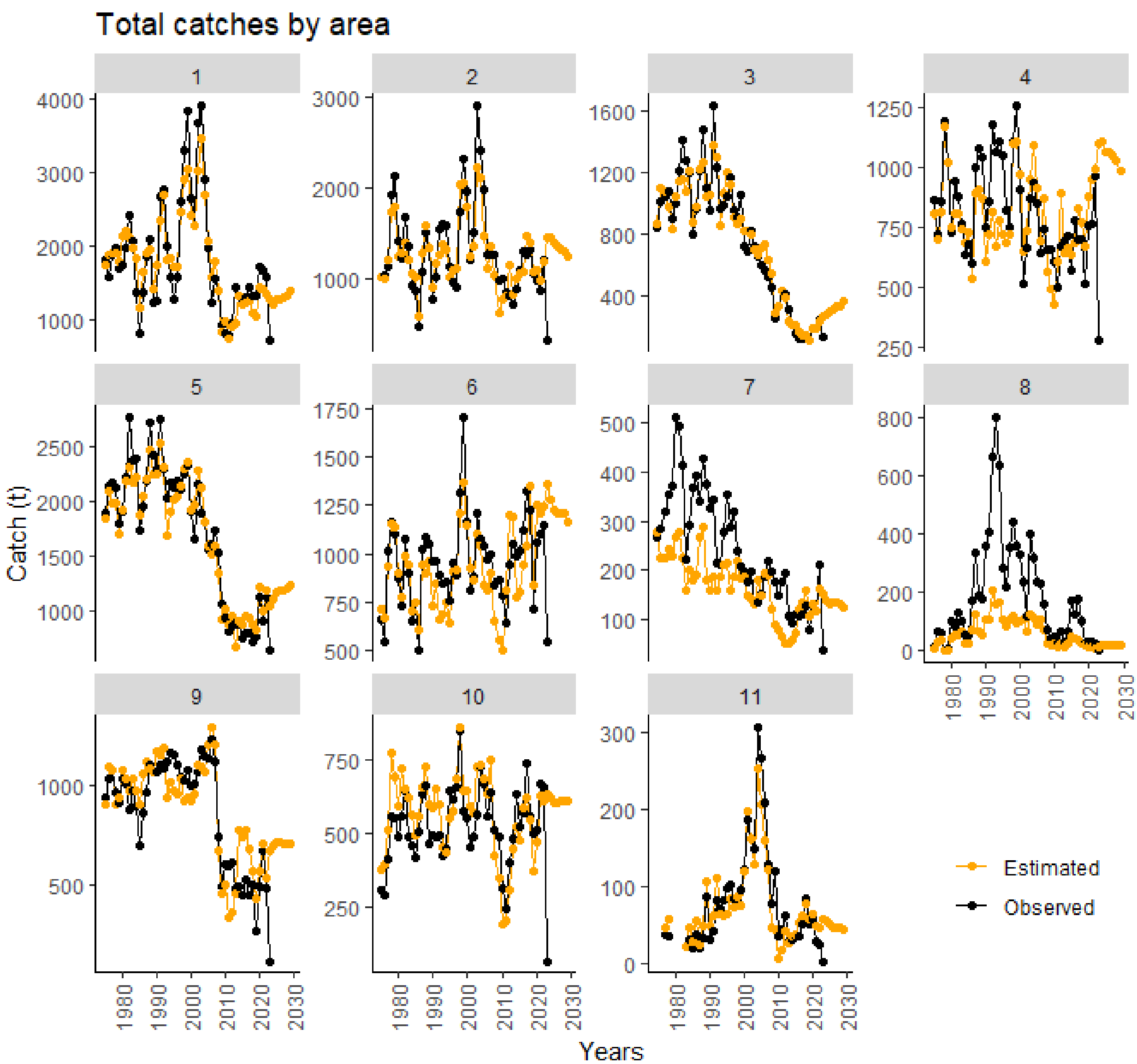
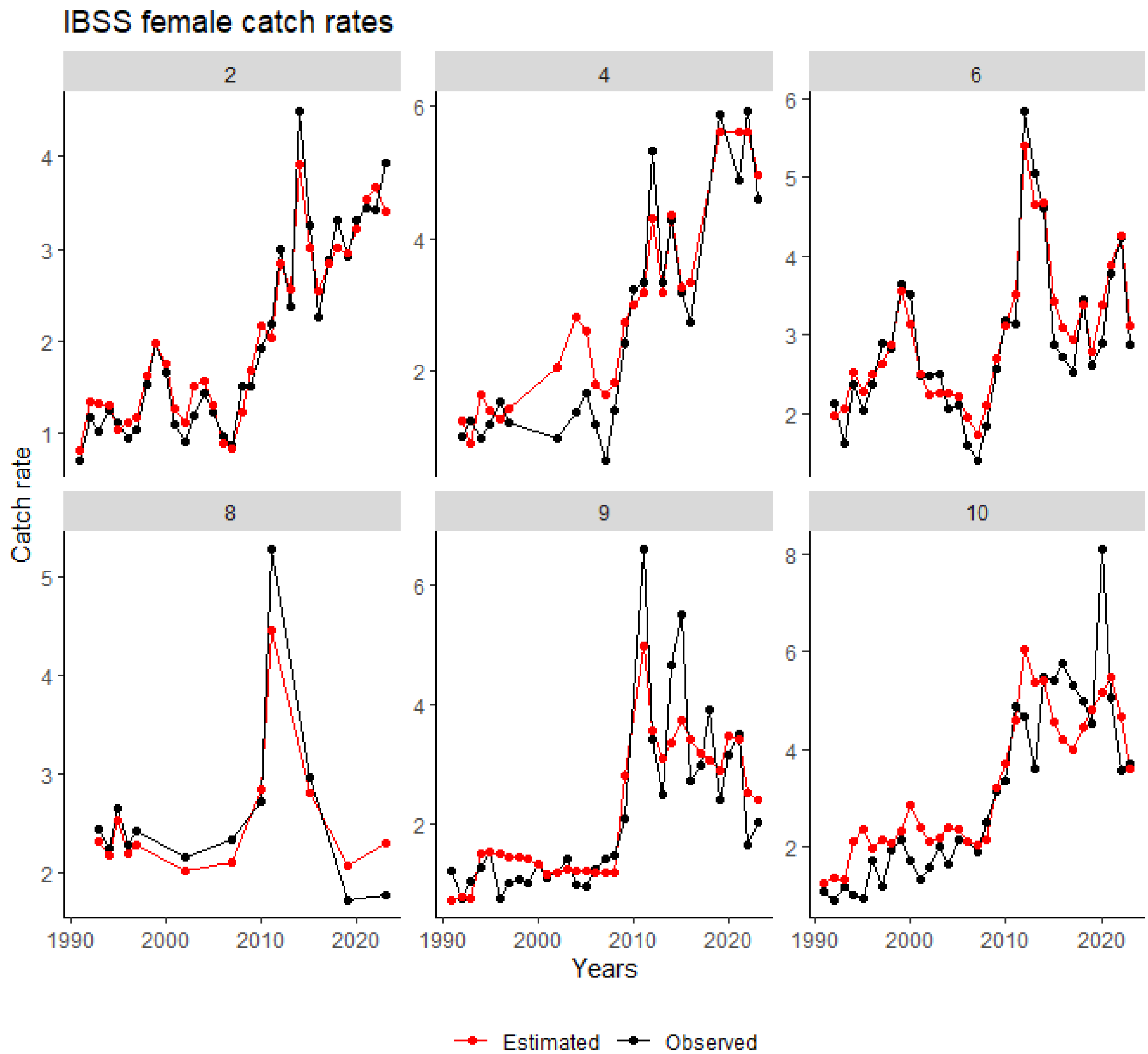
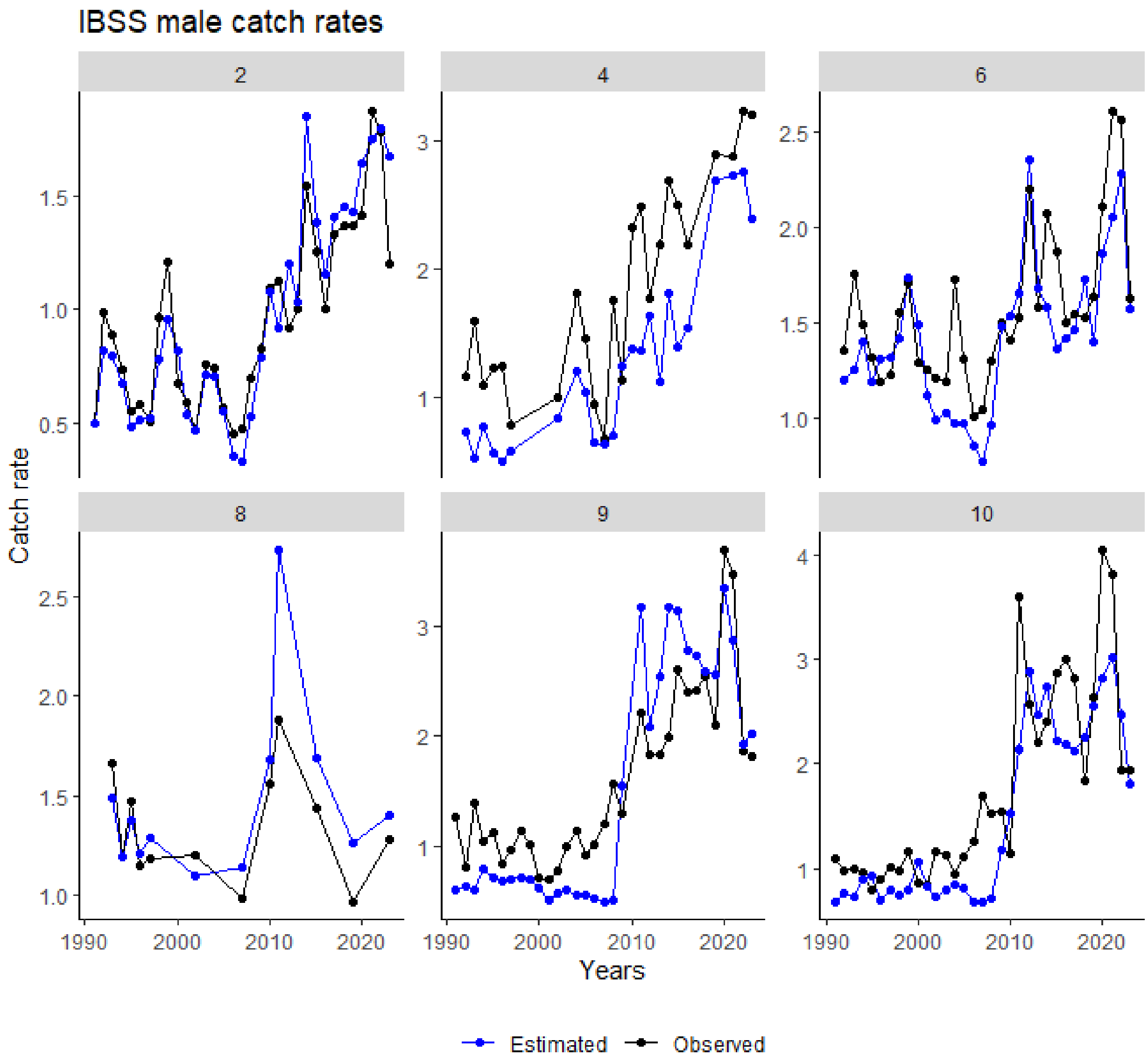


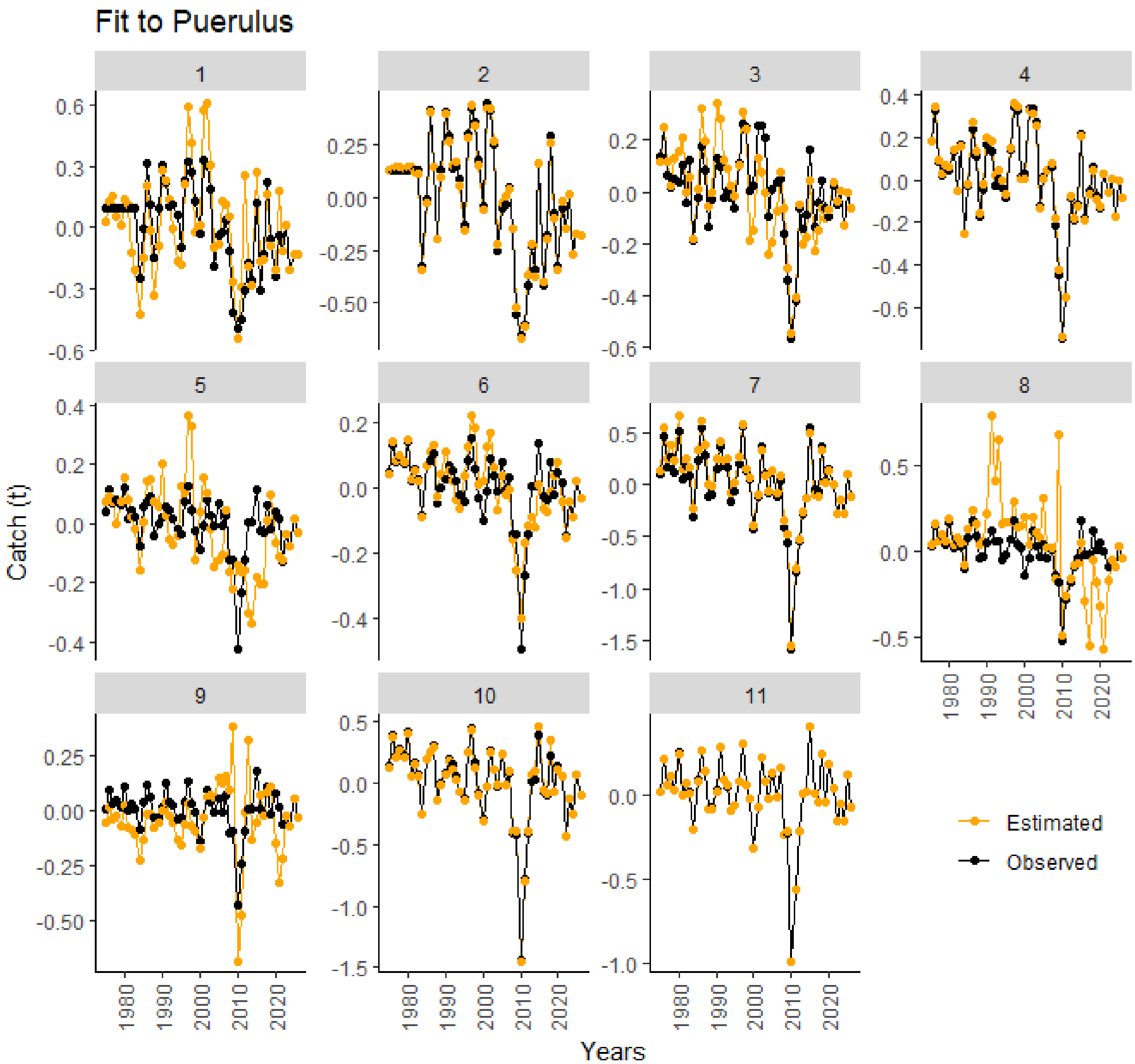
Figure A3.1. Model map showing the 11 areas used in the model and their association with the three management zones. The 40 m and 200 m isobaths are shown as light grey lines.


Total catches
All
A
B
C
Catch (t)
Years
15000
10000
5000
2000
1500
1000
500
4000
3000
2000
8000
6000
4000
2000
1980
1990
2000
2010
2020
2030
Estimated
Observed

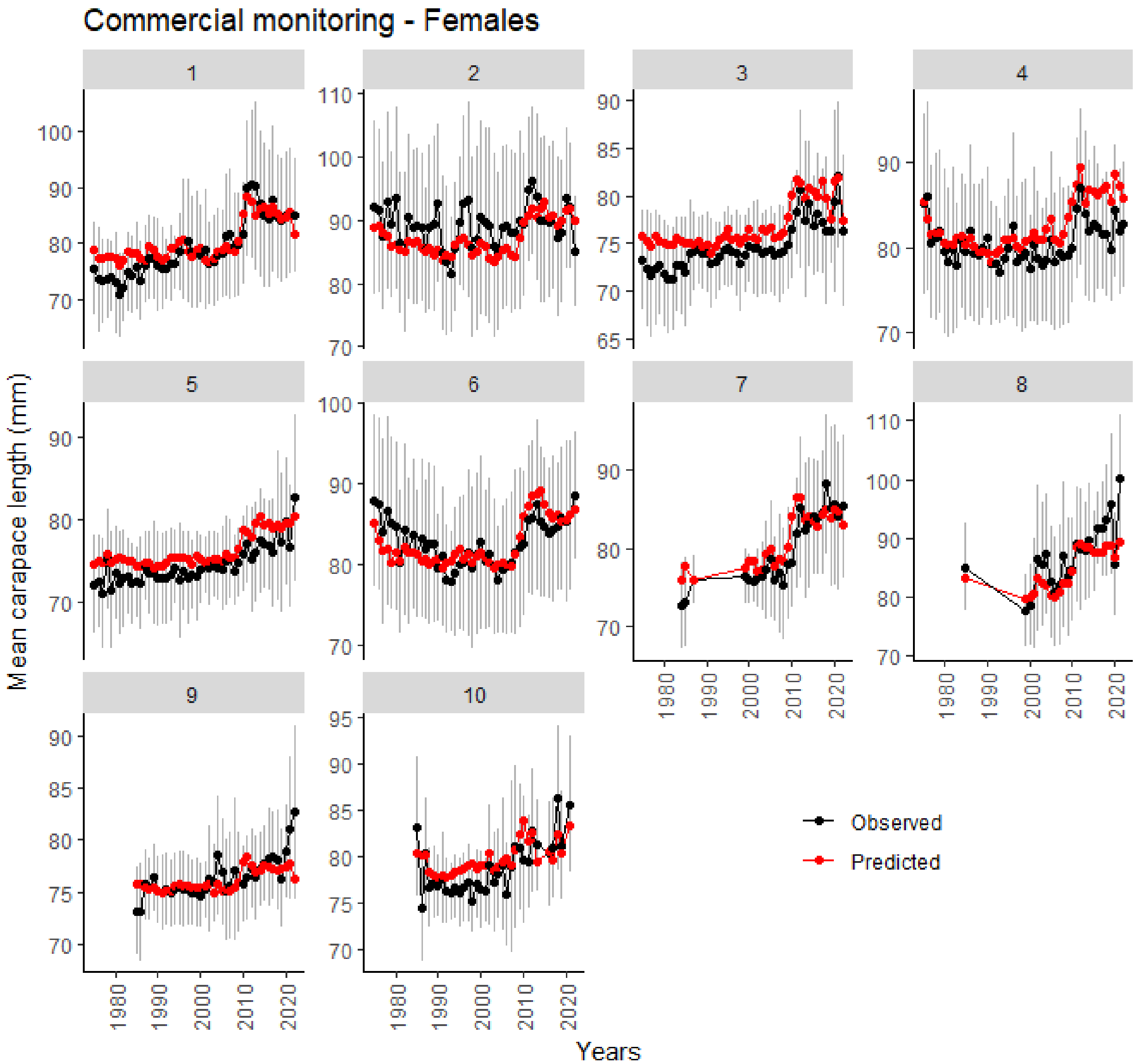

Total catches by area
1
2
3
4
5
6
7
8
9
10
11
Catch (t)
Years
Estimated
Observed
1980
1990
2000
2010
2020
2030

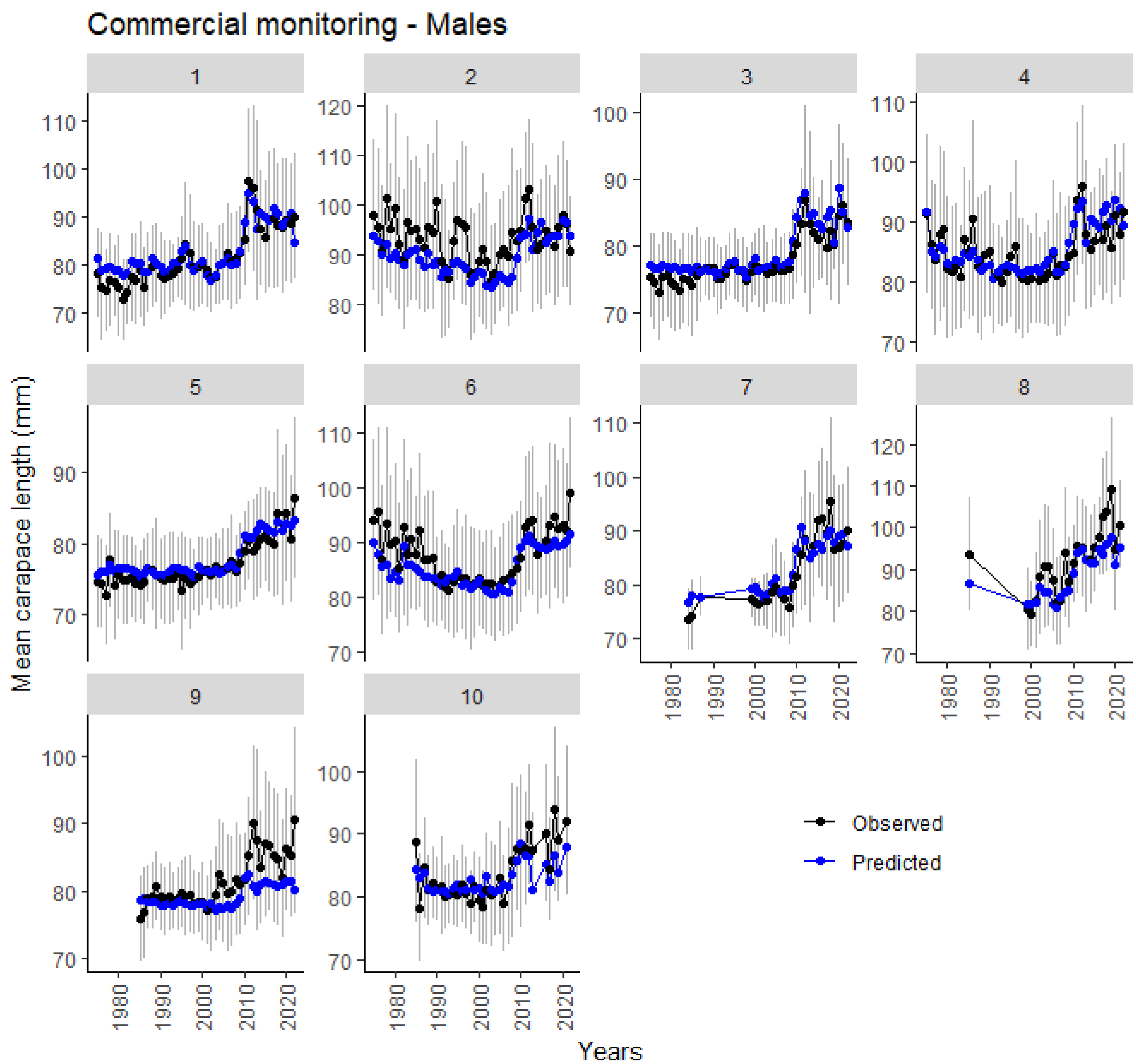

IBSS female catch rates
2
4
6
8
9
10
Catch rate
Years
1990
2000
2010
2020
Estimated
Observed

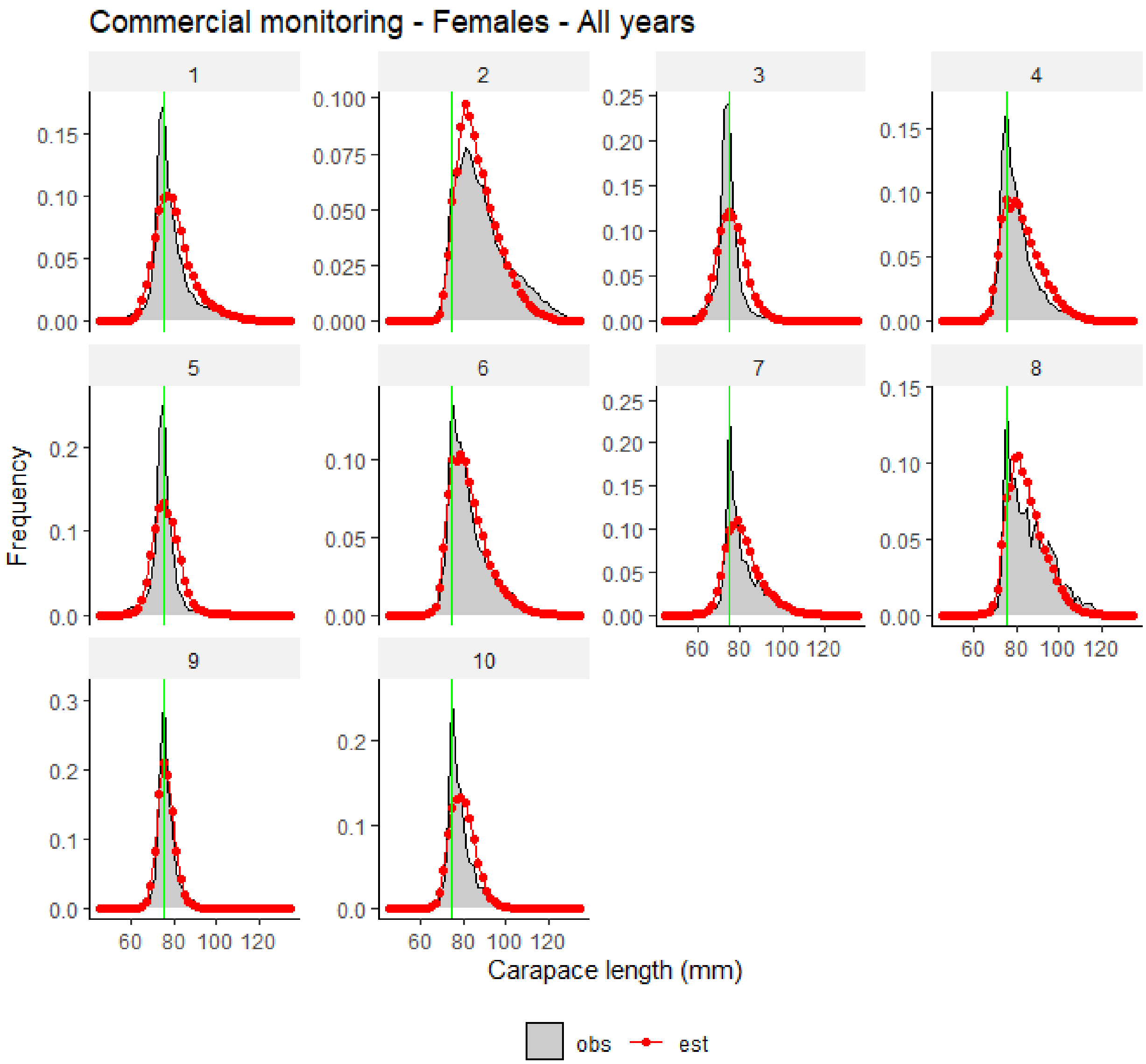

IBSS male catch rates
2
4
6
8
9
10
Catch rate
Years
1990
2000
2010
2020
Estimated
Observed

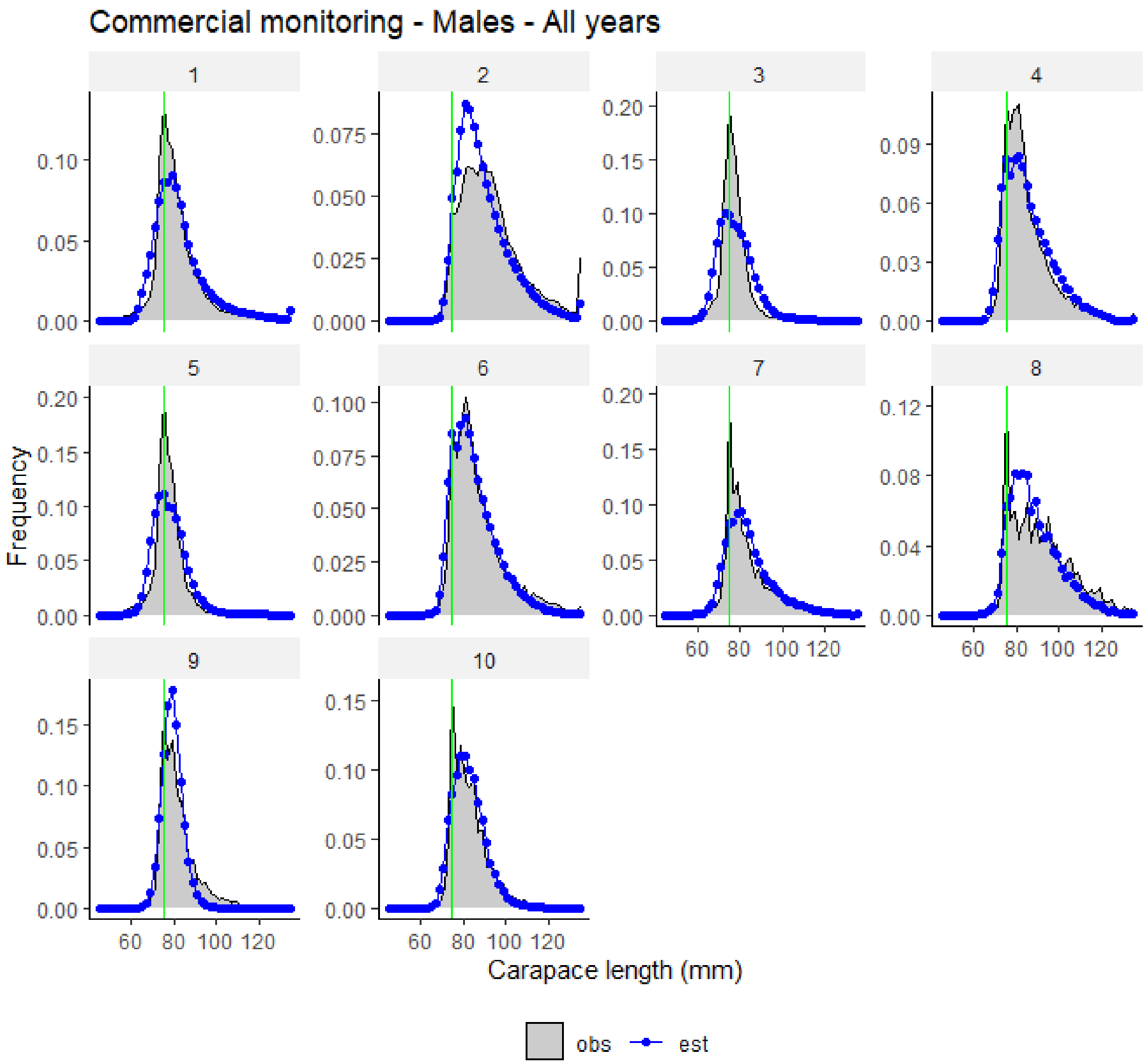


Fit to Puerulus
1
2
3
4
5
6
7
8
9
10
11
Catch (t)
Years
Estimated
Observed
1980
1990
2000
2010
2020

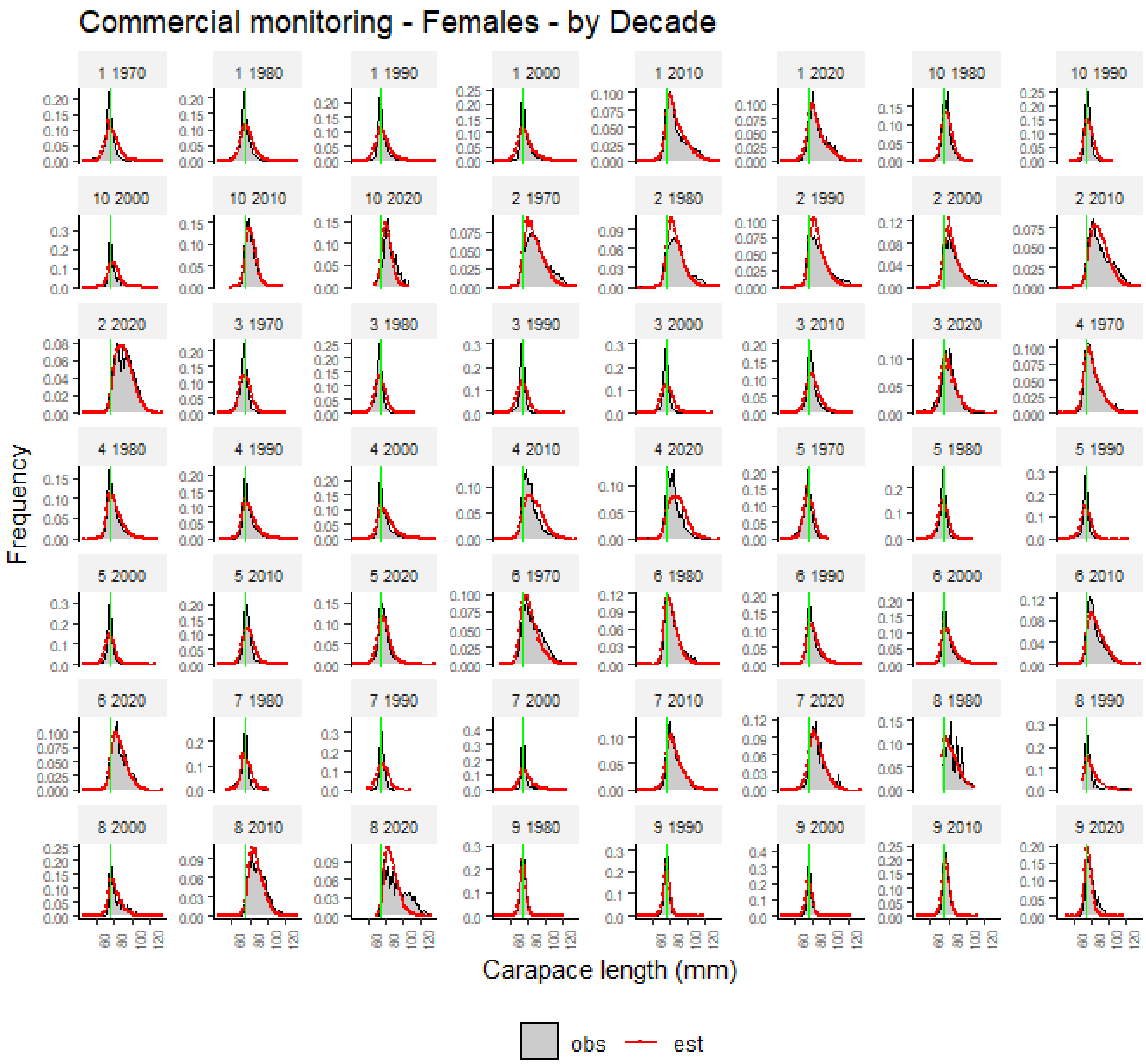

Commercial monitoring - Females
1
2
3
4
5
6
7
8
9
10
Mean carapace length (mm)
Years
Observed
Predicted

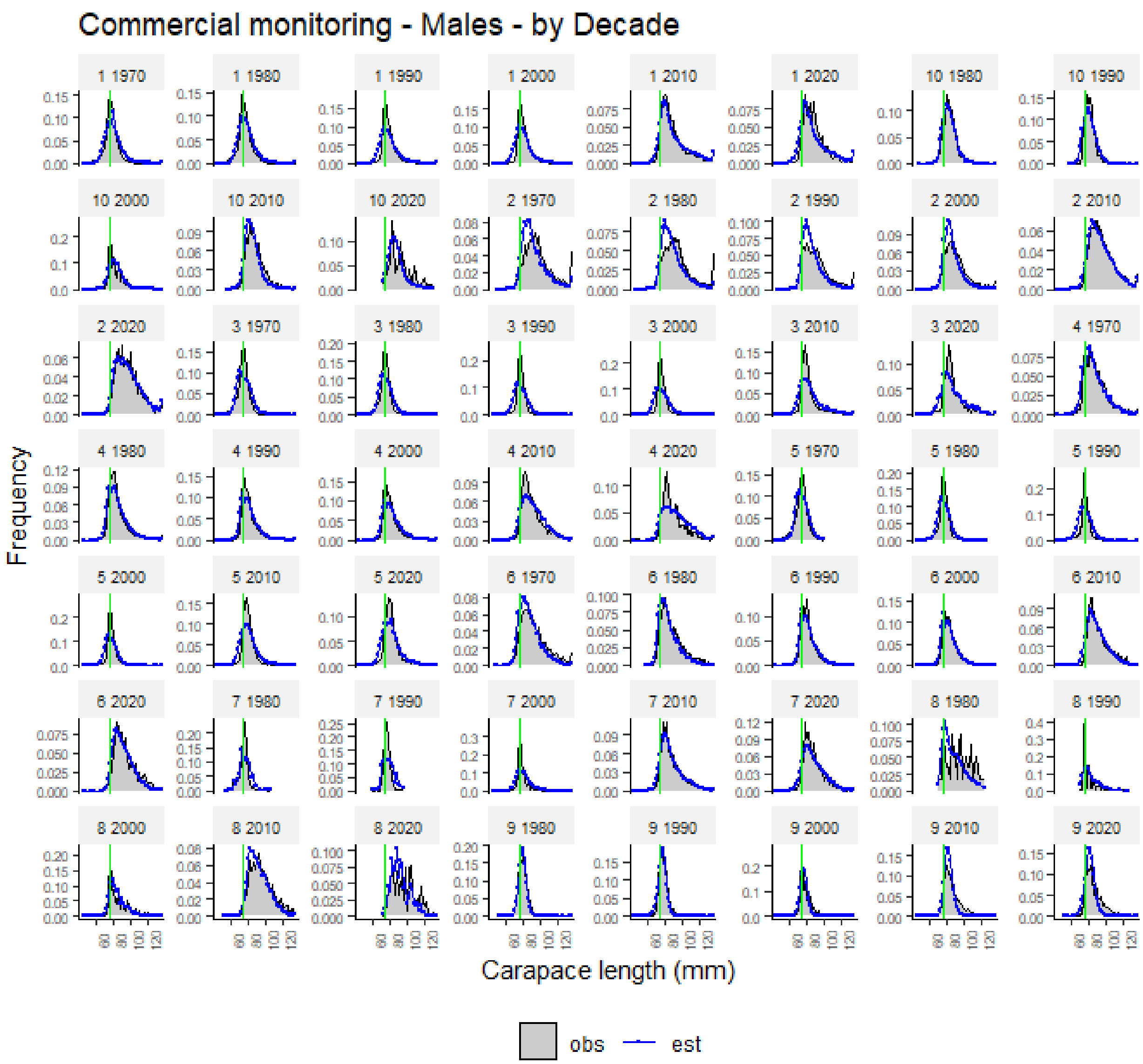

Commercial monitoring - Males
1
2
3
4
5
6
7
8
9
10
Mean carapace length (mm)
Years
1980
1990
2000
2010
2020
Observed
Predicted

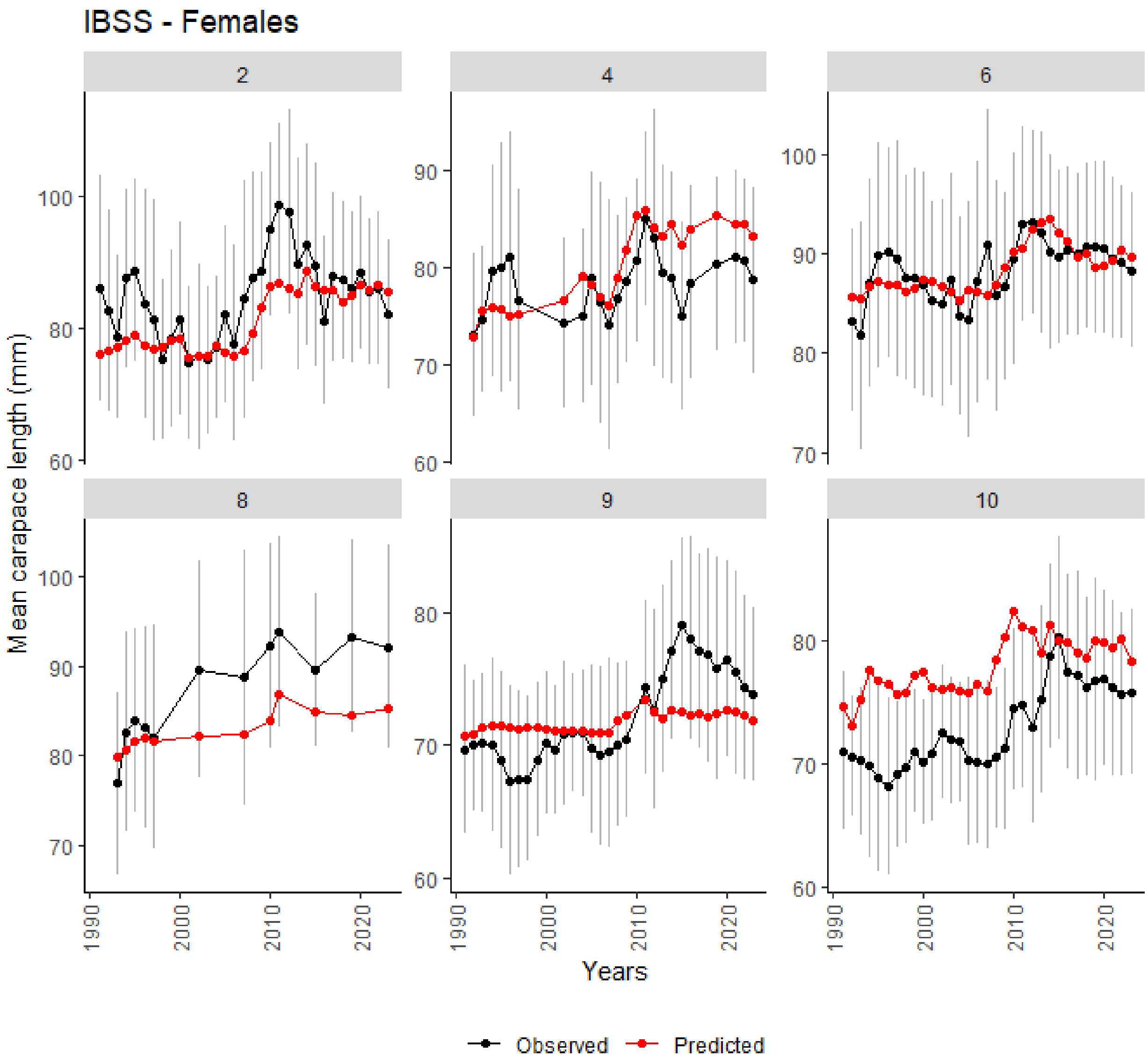

Commercial monitoring - Females - All years
1
2
3
4
5
6
7
8
9
10
Frequency
Carapace length (mm)
60
80
100
120
obs
est

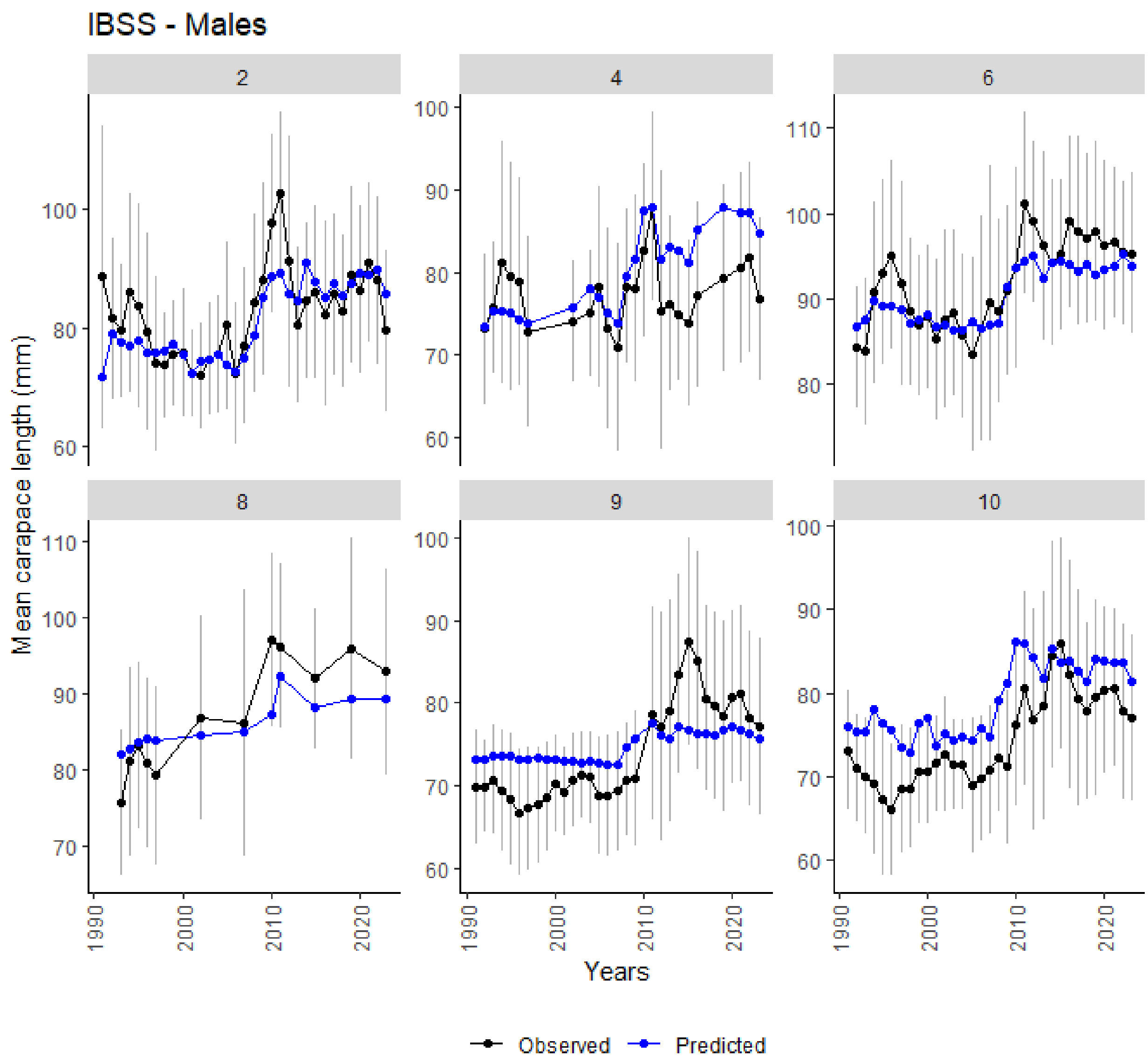


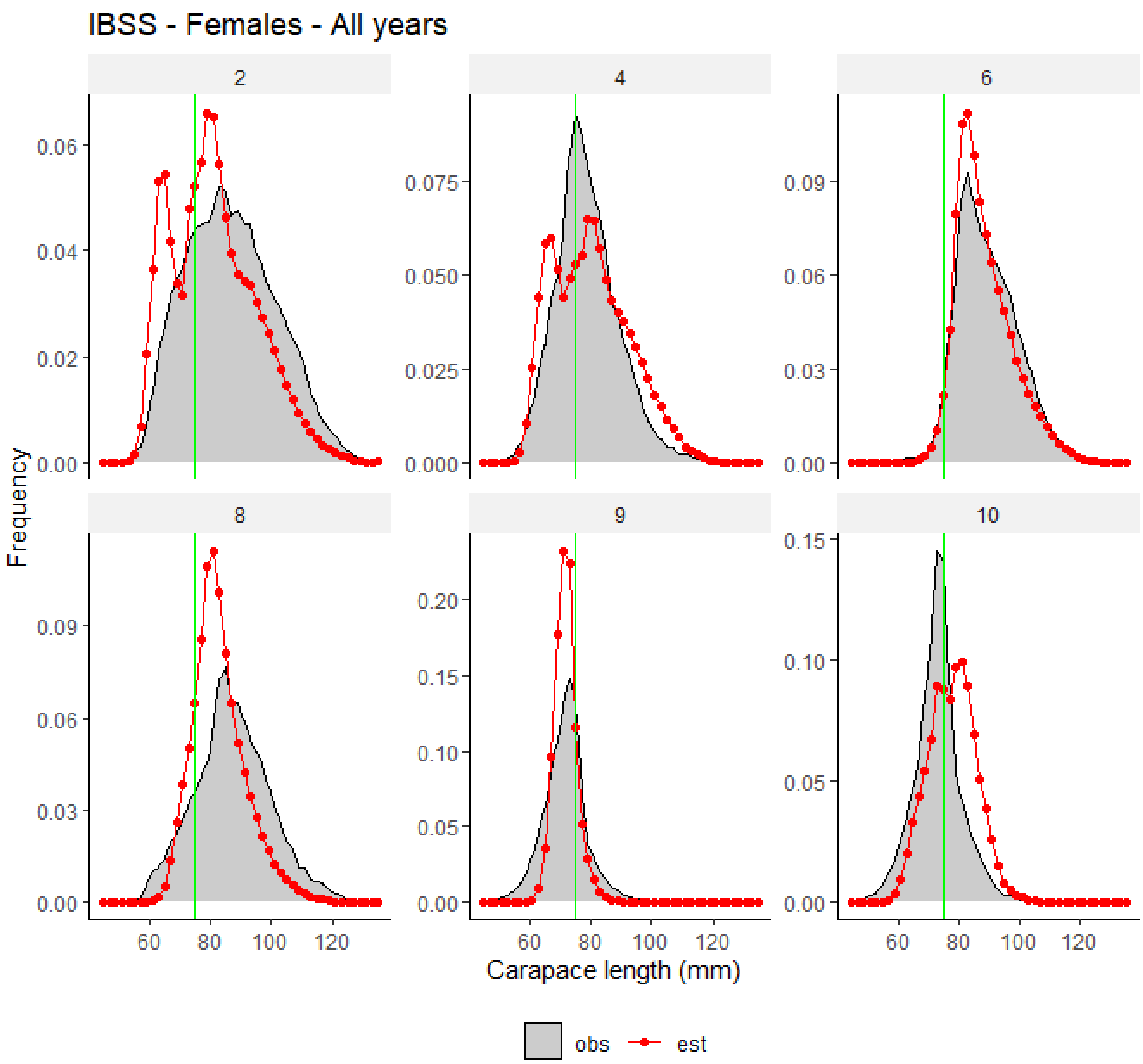
Commercial monitoring - Males - All years
1
2
3
4
5
6
7
8
9
10
Frequency
0.00
0.05
0.10
0.000
0.025
0.050
0.075
0.100
0.15
0.20
0.03
0.06
0.09
0.04
0.08
0.12
60
80
100
120
Carapace length (mm)
obs
est

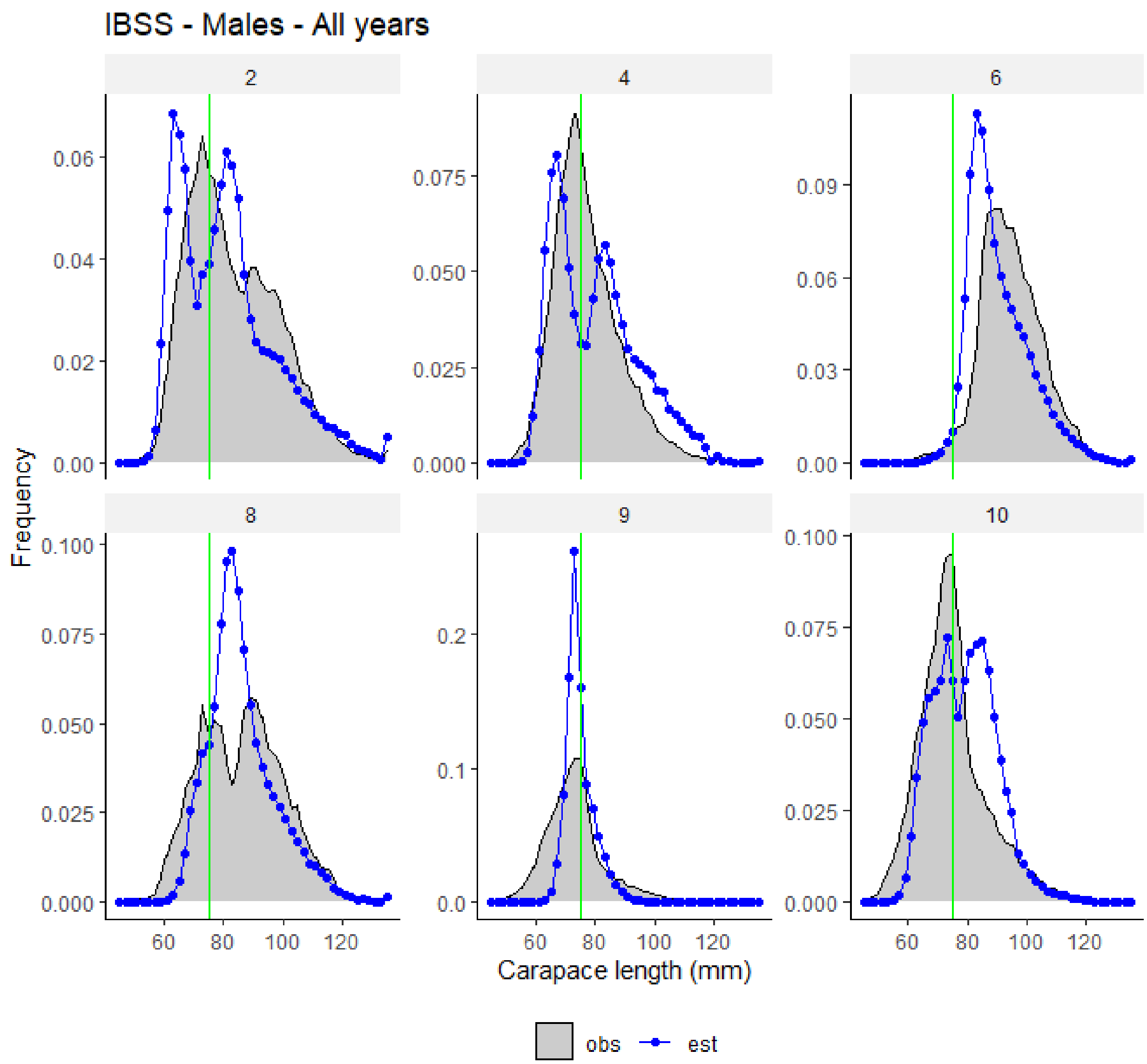

Commercial monitoring - Females - by Decade
Frequency
Carapace length (mm)
obs
est

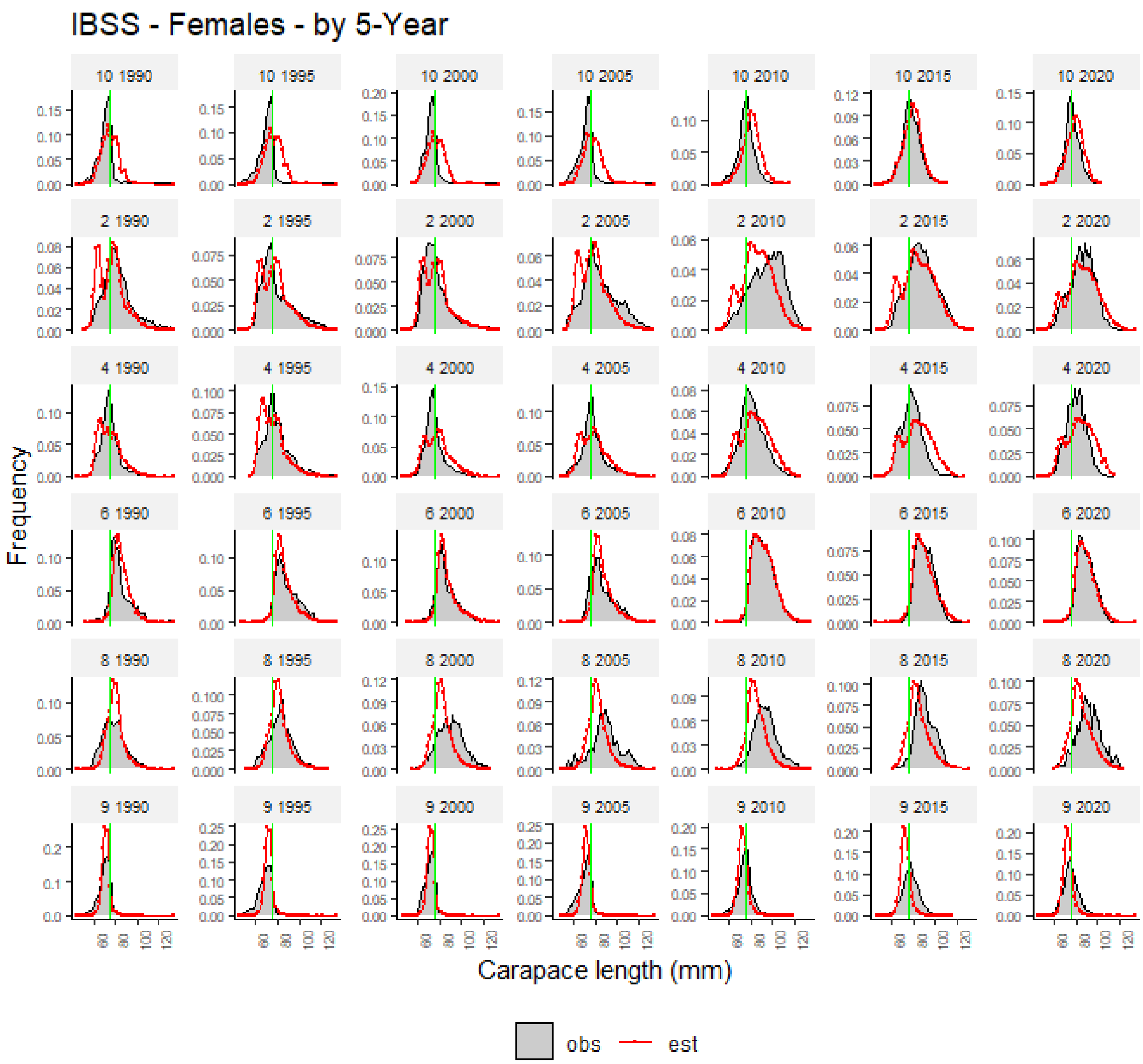

Commercial monitoring - Males - by Decade
1 1970
1 1980
1 1990
1 2000
1 2010
1 2020
10 1980
10 1990
10 2000
10 2010
10 2020
2 1970
2 1980
2 1990
2 2000
2 2010
2 2020
3 1970
3 1980
3 1990
3 2000
3 2010
3 2020
4 1970
4 1980
4 1990
4 2000
4 2010
4 2020
5 1970
5 1980
5 1990
5 2000
5 2010
5 2020
6 1970
6 1980
6 1990
6 2000
6 2010
6 2020
7 1980
7 1990
7 2000
7 2010
7 2020
8 1980
8 1990
8 2000
8 2010
8 2020
9 1980
9 1990
9 2000
9 2010
9 2020
Frequency
Carapace length (mm)
obs
est

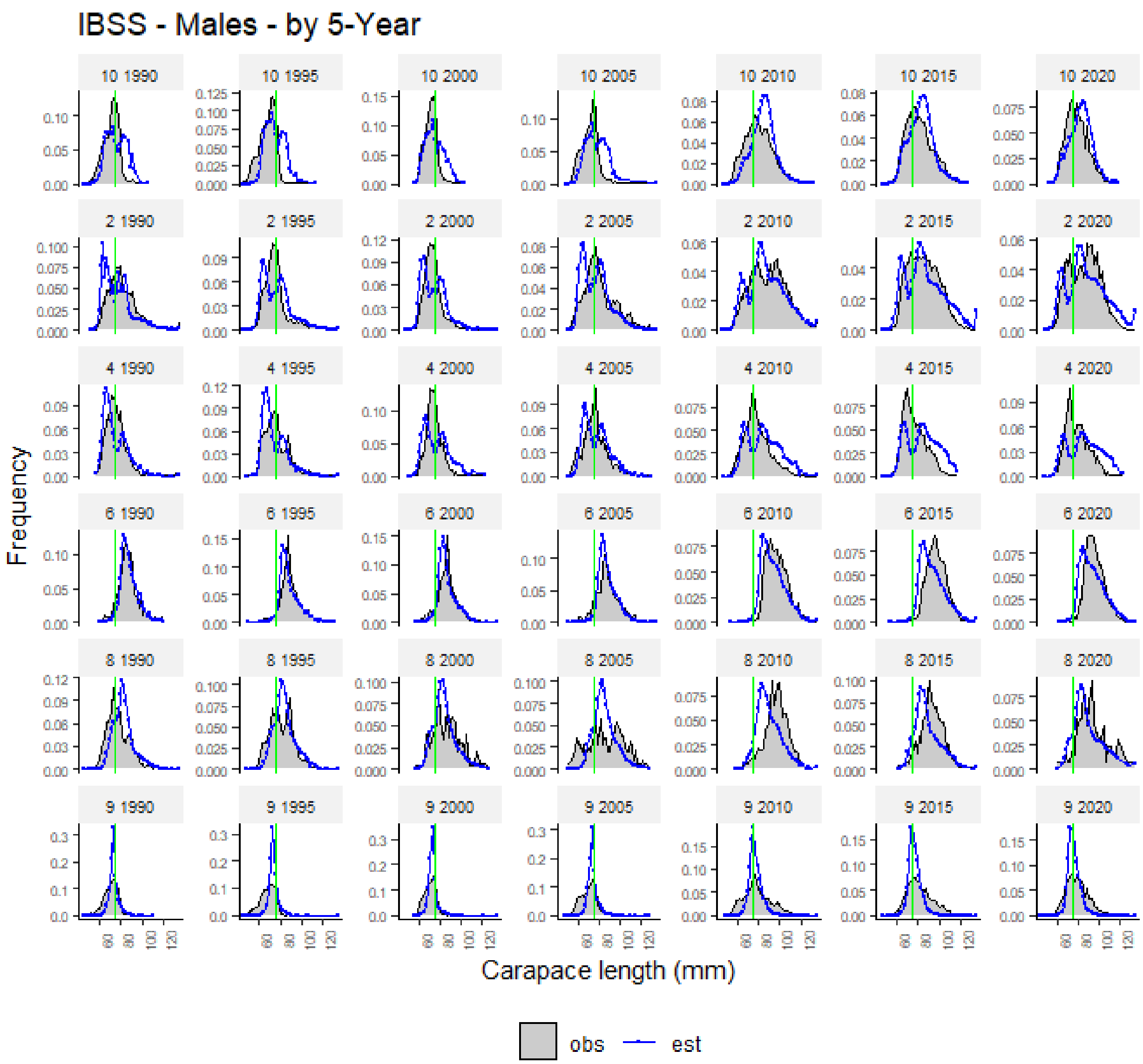

IBSS - Females
2
4
6
8
9
10
Mean carapace length (mm)
Years
1990
2000
2010
2020
Observed
Predicted

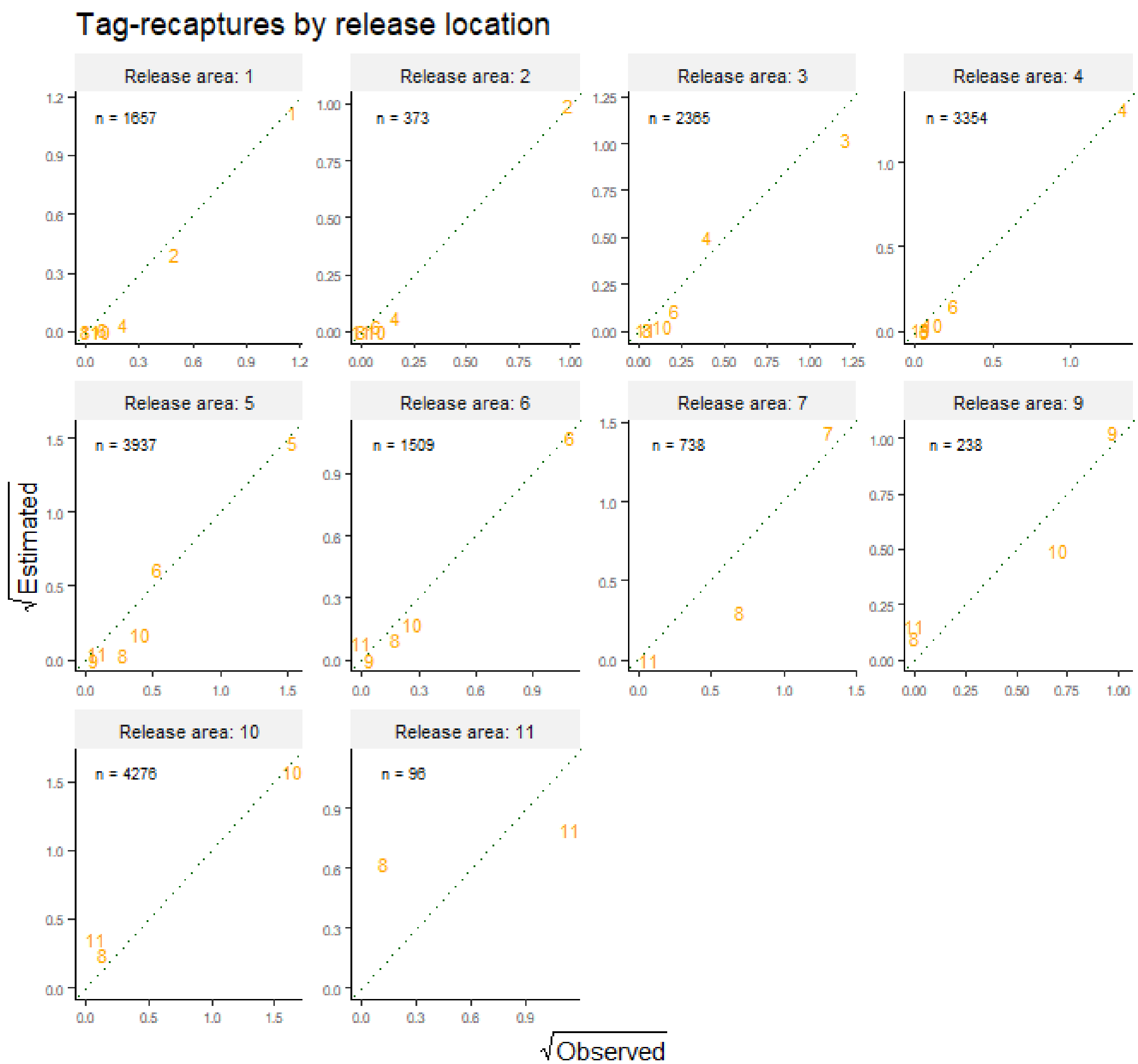

IBSS - Males
2
4
6
8
9
10
Mean carapace length (mm)
Years
1990
2000
2010
2020
Observed
Predicted


IBSS - Females - All years
2
4
6
8
9
10
Frequency
Carapace length (mm)
obs
est
0.00
0.02
0.04
0.06
0.000
0.025
0.050
0.075
0.03
0.06
0.09
0.05
0.10
0.15
0.20
60
80
100
120

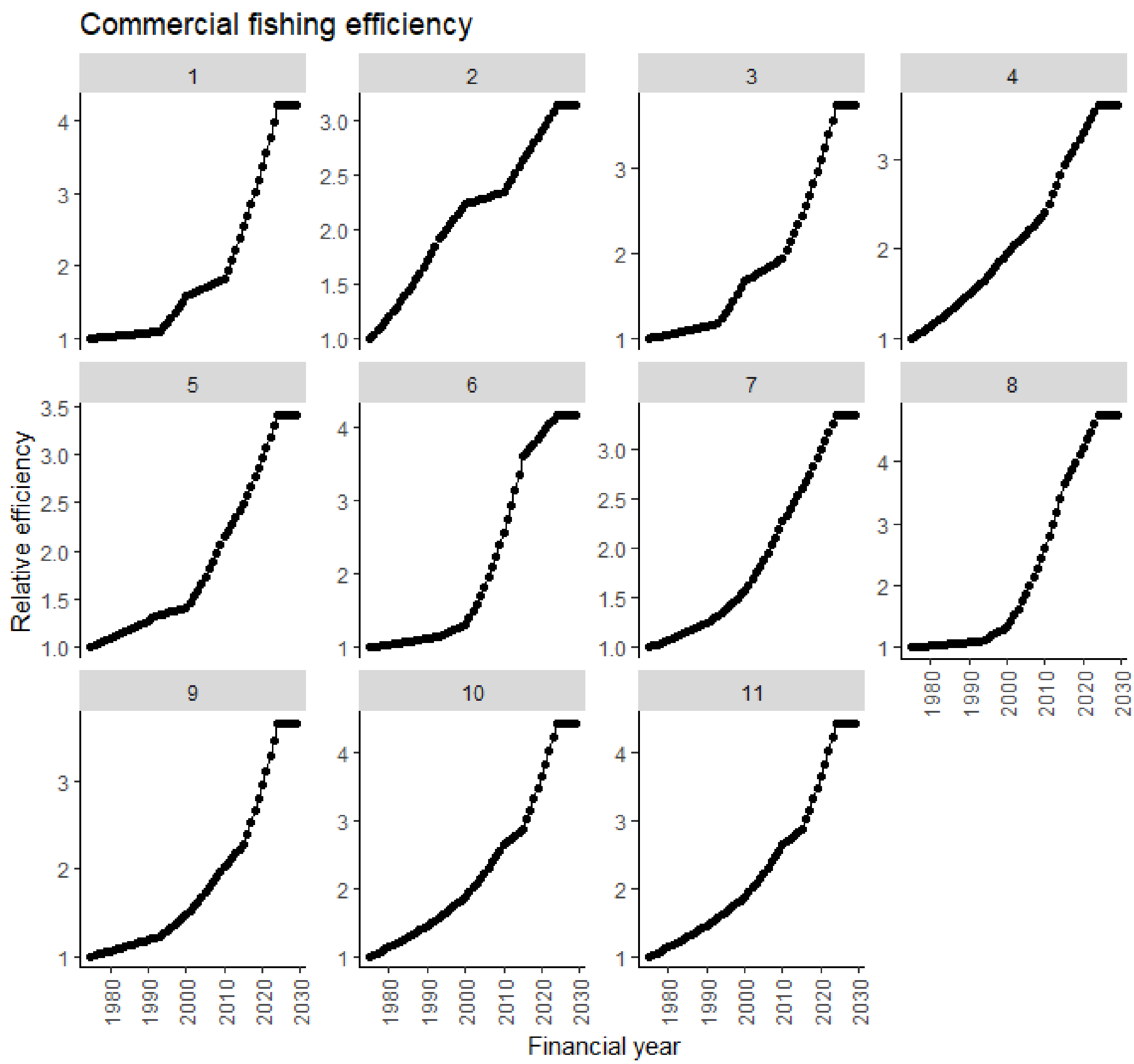

IBSS - Males - All years
2
4
6
8
9
10
Frequency
Carapace length (mm)
obs
est


IBSS - Females - by 5-Year
Frequency
Carapace length (mm)
obs
est
10 1990
10 1995
10 2000
10 2005
10 2010
10 2015
10 2020
2 1990
2 1995
2 2000
2 2005
2 2010
2 2015
2 2020
4 1990
4 1995
4 2000
4 2005
4 2010
4 2015
4 2020
6 1990
6 1995
6 2000
6 2005
6 2010
6 2015
6 2020
8 1990
8 1995
8 2000
8 2005
8 2010
8 2015
8 2020
9 1990
9 1995
9 2000
9 2005
9 2010
9 2015
9 2020


IBSS - Males - by 5-Year
Frequency
Carapace length (mm)
obs
est



Tag-recaptures by release location
Release area: 1
n = 1657
Release area: 2
n = 373
Release area: 3
n = 2365
Release area: 4
n = 3354
Release area: 5
n = 3937
Release area: 6
n = 1509
Release area: 7
n = 738
Release area: 9
n = 238
Release area: 10
n = 4276
Release area: 11
n = 96
√Estimated
√Observed

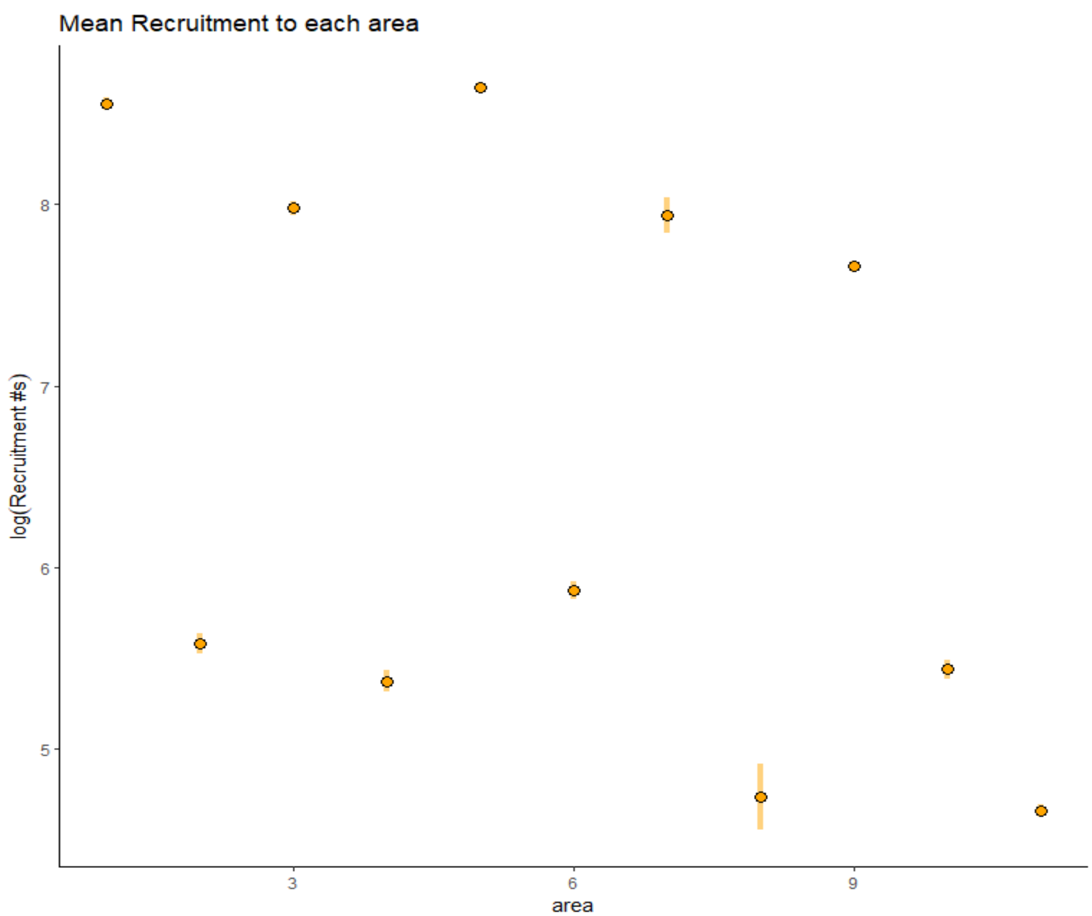


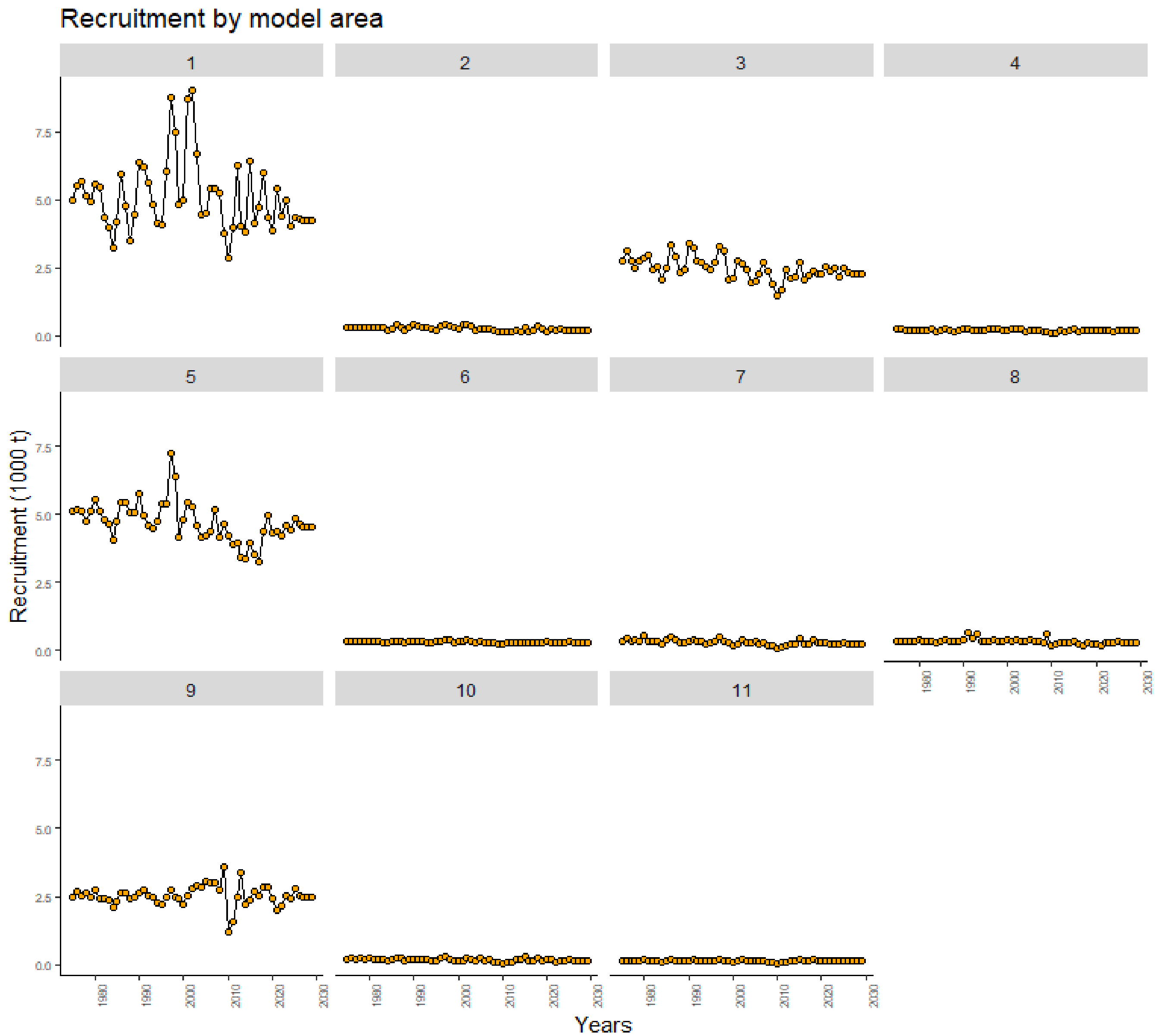
Appendix 5. Integrated parameter estimates

Table A5. List of parameters used in the integrated model

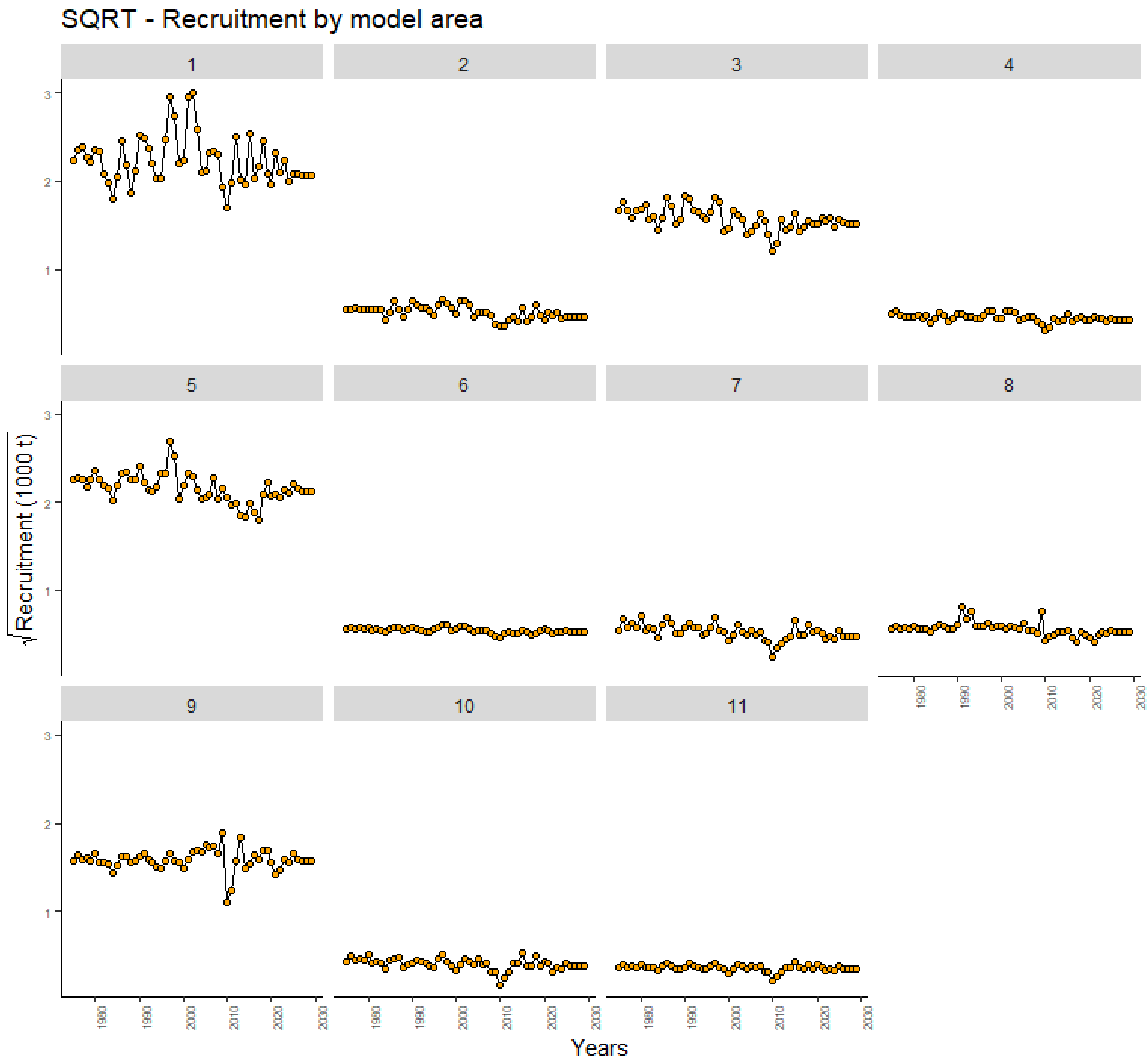
Parameter	Number	Estimated (Y/N)
Fishing efficiency 1 (area, 10=11)	10	Y
Fishing efficiency 2 (area, 10=11)	10	Y
Fishing efficiency 3 (area, 10=11)	10	Y
Fishing efficiency 4 (area, 10=11)	10	Y
Puerulus power (area)	11	Y
Migration (area, no migration out of 8)	10	Y
Migration north (year)	54	Y

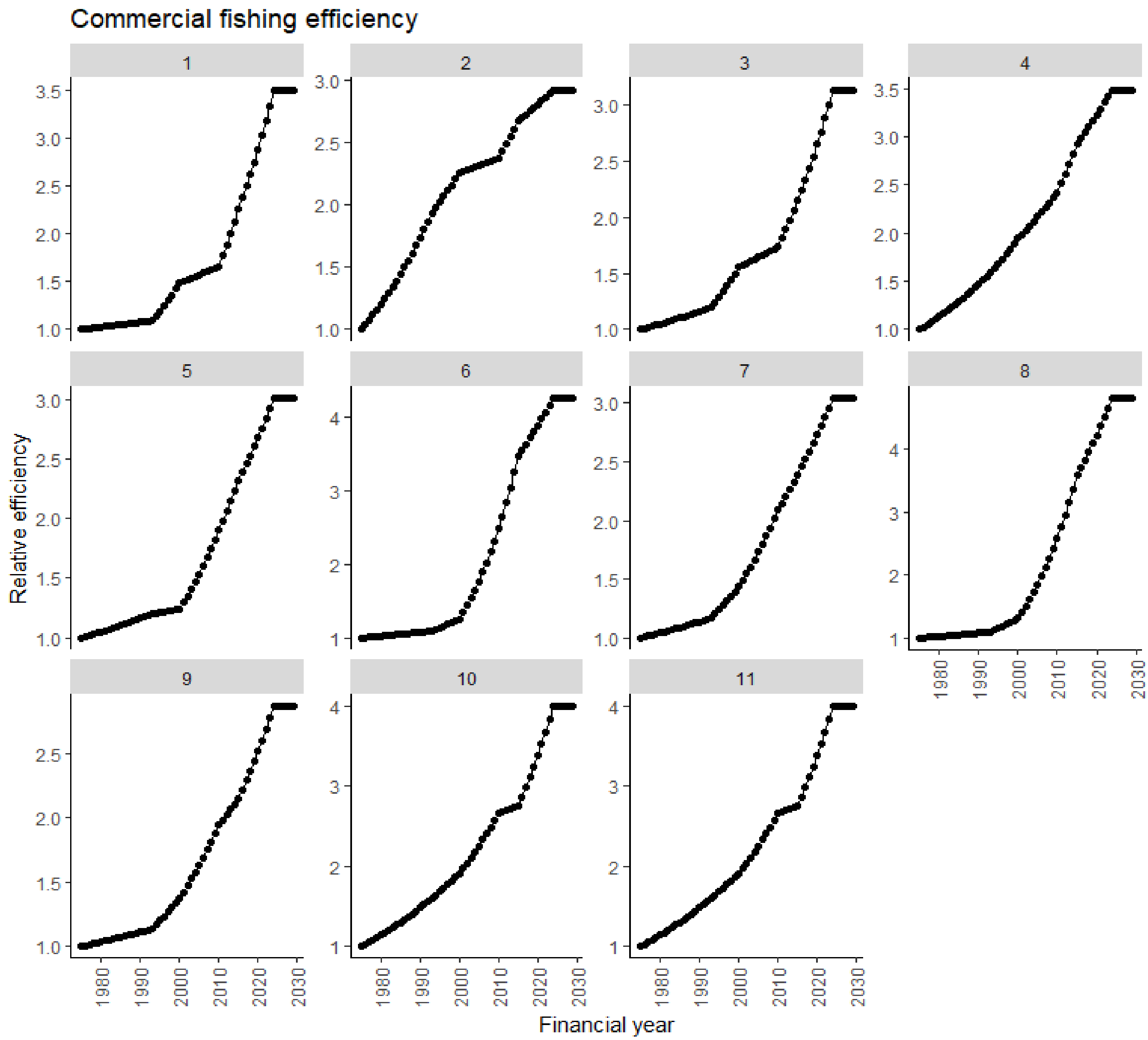
Mean CL of white lobster (area, 10=11)	10	Y
SD of white lobster CL (common between areas)	1	Y
Mean recruitment (area)	11	Y
No escape gap select. logistic inflection (area)	11	Y
54 mm escape gap select. logistic inflection (area)	11	Y
55 mm escape gap select. logistic inflection (area)	11	Y
Escape gap selectivity logistic slope	1	Y
Average commercial catchability (area)	11	Y
IBSS catchability (area)	6	Y
IBSS catchability sex scaler	1	Y
Catchability white lobster	1	Y
Recruitment deviations (year x area)	594	Y
Historic recruitment deviations	220	Y
Catchability deviations (year x area)	594	N
Natural mortality (area)	11	N
Natural mortality whites	1	N
Initial fishing mortality (area)	11	N
Temperature catchability relationship	11	N

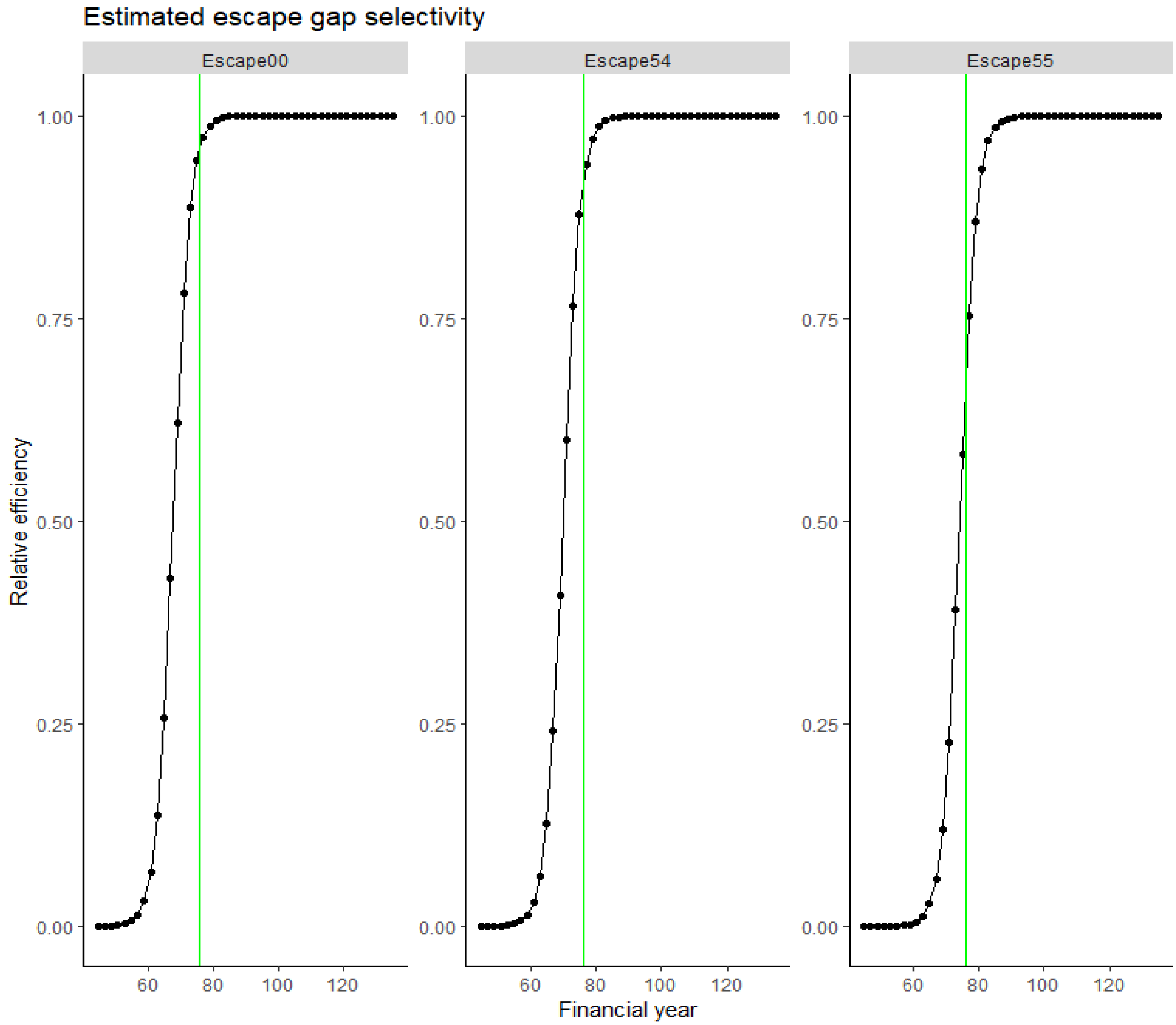




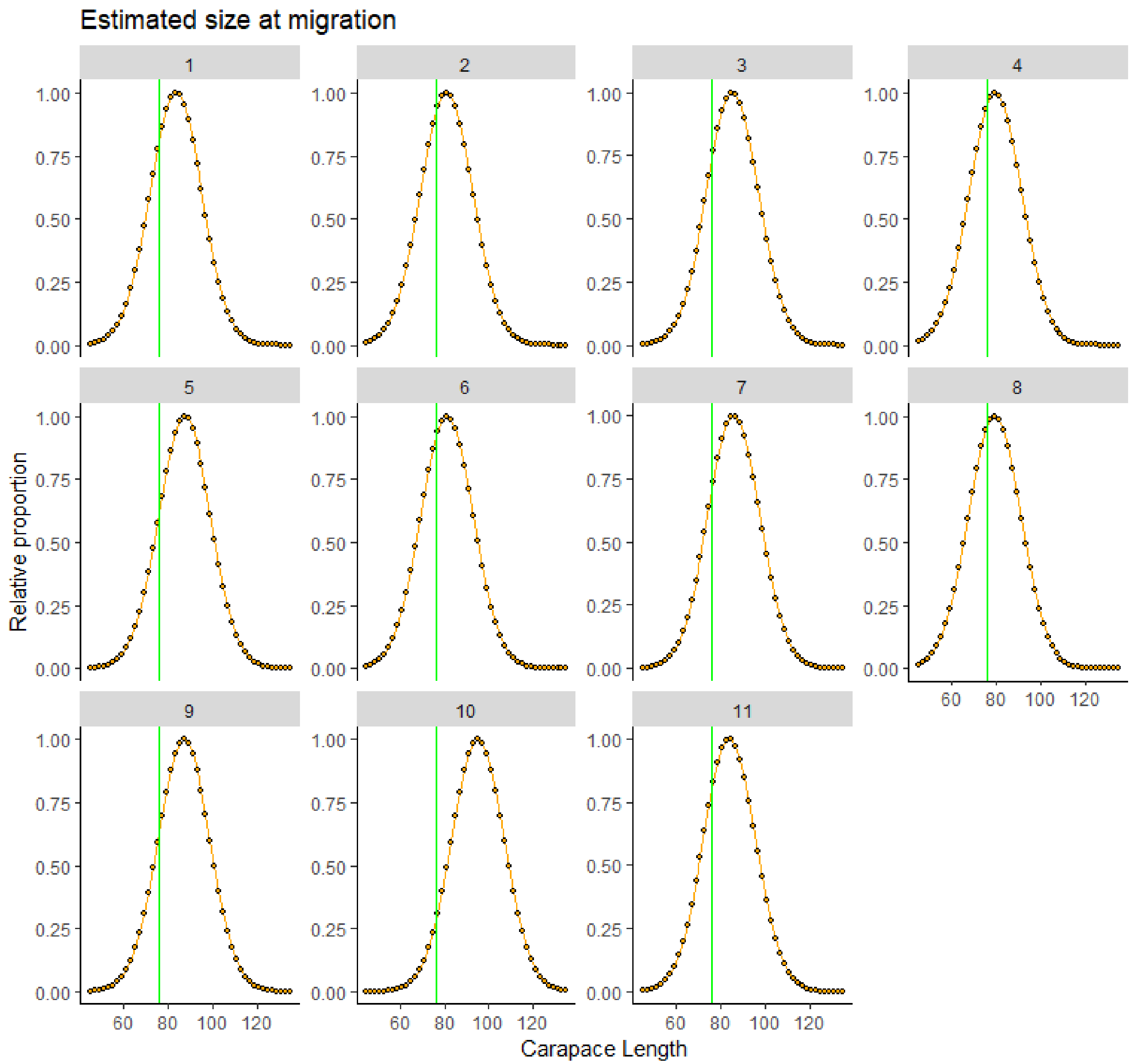
Recruitment by model area
1
2
3
4
5
6
7
8
9
10
11
Recruitment (1000 t)
Years
0.0
2.5
5.0
7.5
1980
1990
2000
2010
2020
2030


SQRT - Recruitment by model area
1
2
3
4
5
6
7
8
9
10
11
√Recruitment (1000 t)
Years
1980
1990
2000
2010
2020
2030
1
2
3

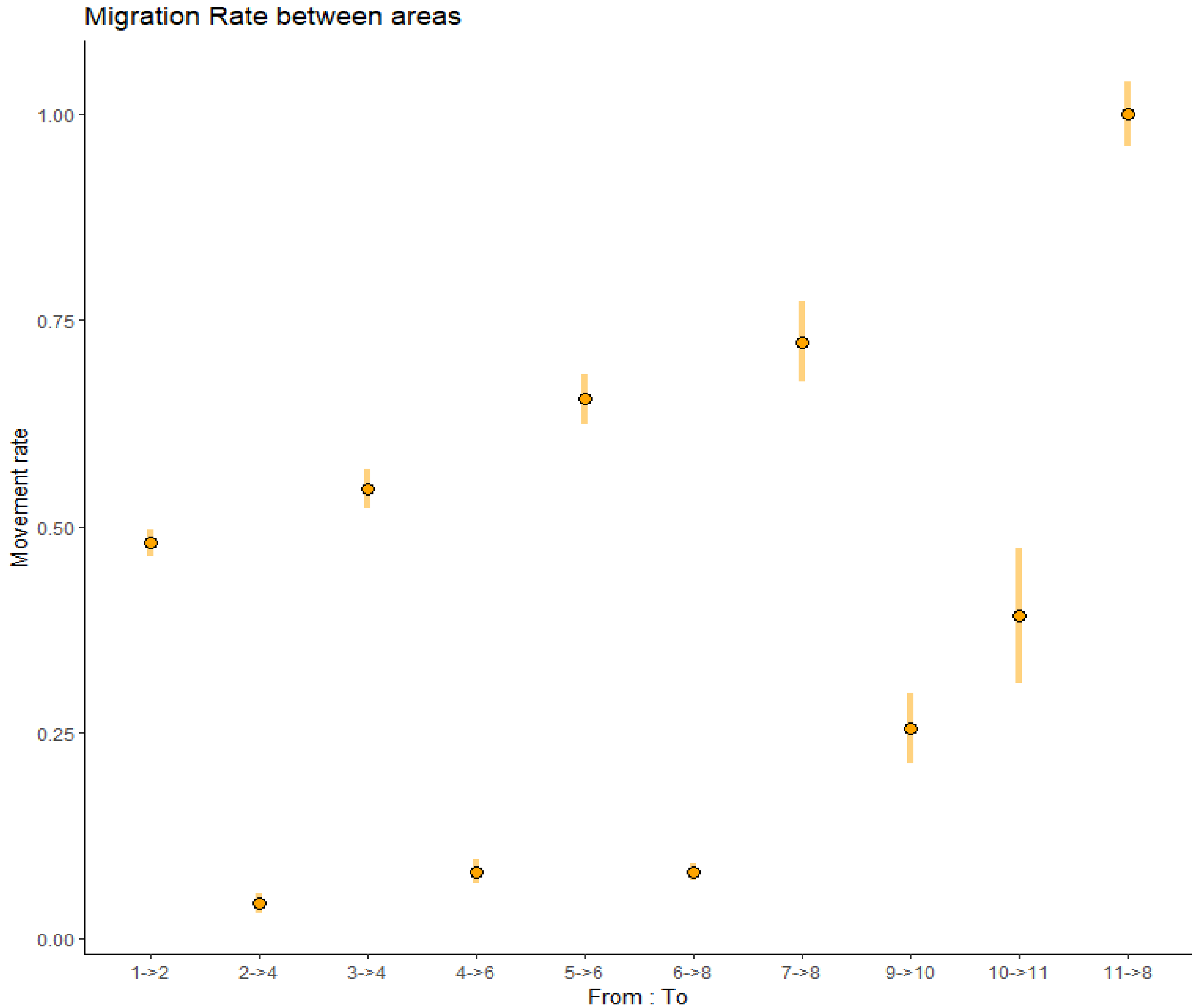

Commercial fishing efficiency
1
2
3
4
5
6
7
8
9
10
11
Relative efficiency
Financial year
1980
1990
2000
2010
2020
2030

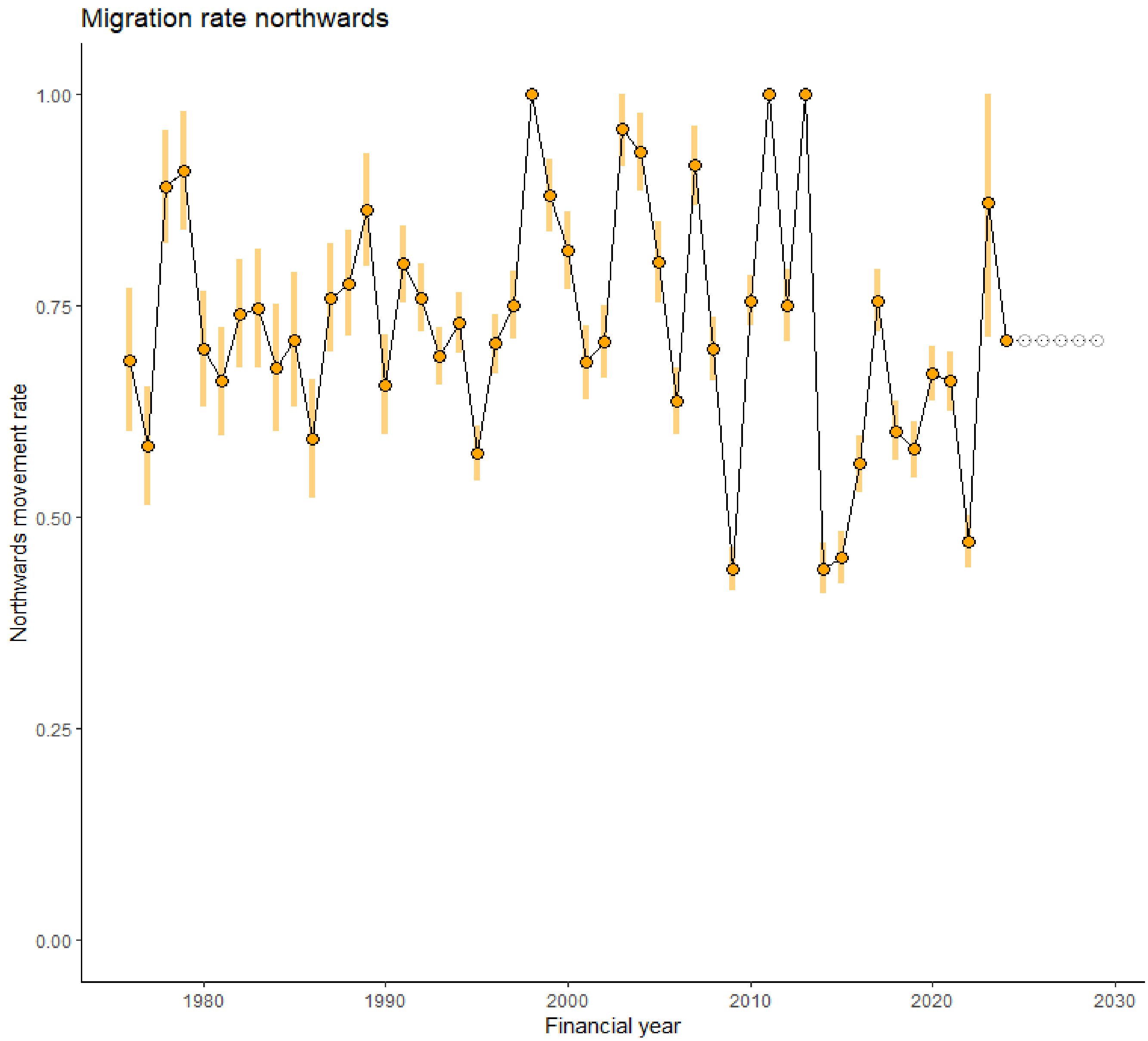


Estimated escape gap selectivity
Escape00
Escape54
Escape55
Relative efficiency
Financial year
0.00
0.25
0.50
0.75
1.00
60
80
100
120



Estimated size at migration
1
2
3
4
5
6
7
8
9
10
11
1.00
0.75
0.50
0.25
0.00
60
80
100
120
Relative proportion
Carapace Length


Migration Rate between areas
Movement rate
1.00
0.75
0.50
0.25
0.00
1->2
2->4
3->4
4->6
5->6
6->8
7->8
9->10
10->11
11->8
From : To


Migration rate northwards
Northwards movement rate
1.00
0.75
0.50
0.25
0.00
1980
1990
2000
2010
2020
2030
Financial year