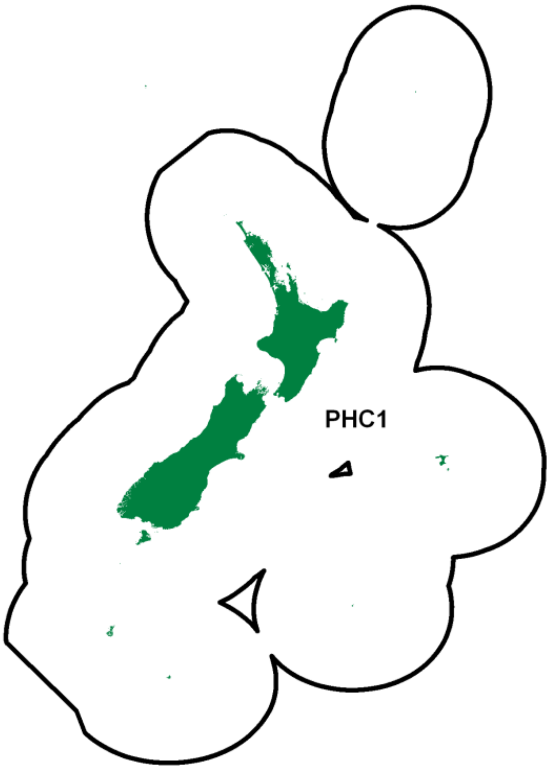
PACKHORSE ROCK LOBSTER (PHC)

(*Sagmariasus verreauxi*)
Green crayfish, Pawharu



1. FISHERY SUMMARY

Two species of rock lobster are taken in New Zealand coastal waters: the red rock lobster (*Jasus edwardsii*), which supports nearly all the landings and is caught all around the North Island and South Island, Stewart Island, and the Chatham Islands; and the packhorse rock lobster (*Sagmariasus verreauxi*), which is taken mainly in the north of the North Island, including the Bay of Plenty. Packhorse lobsters grow to a much larger size than red rock lobsters and have a different shell colouration and shape. A summary of a new stock assessment for this species is presented in this chapter.

The packhorse rock lobster fishery was brought into the Quota Management System (QMS) on 1 April 1990. The fishery is currently managed as a single Quota Management Area (QMA) labelled 'PHC 1'. Before entering the QMS, the packhorse rock lobster fishery was managed using input controls, including: minimum legal size (MLS) tail length (TL) regulations; a prohibition on the take of berried females and soft shell lobsters; making it illegal to commercially dive for or spear lobsters; requiring specific modification to pots to allow small lobsters to escape; requiring that lobsters are landed ashore alive; and some local area closures. Up until April 1 2024 all these input controls were still used with a set MLS of 216 mm TL for both sexes, however from 1 April 2024, the MLS changed from being a TL measure (216 mm for both sexes), to an MLS using a tail width (TW) measure (90 mm for females and 84 mm for males). Both historical and current MLS applies to catch by both commercial and recreational fishers.

The Total Allowable Commercial Catch (TACC) was set for the first time in 1990–91 for PHC 1. Non-commercial allowances have not been set, but recreational fisheries are subject to other regulations such as size and bag limits. Figure 1 shows the historical commercial landings and TACC tonnages for PHC 1.

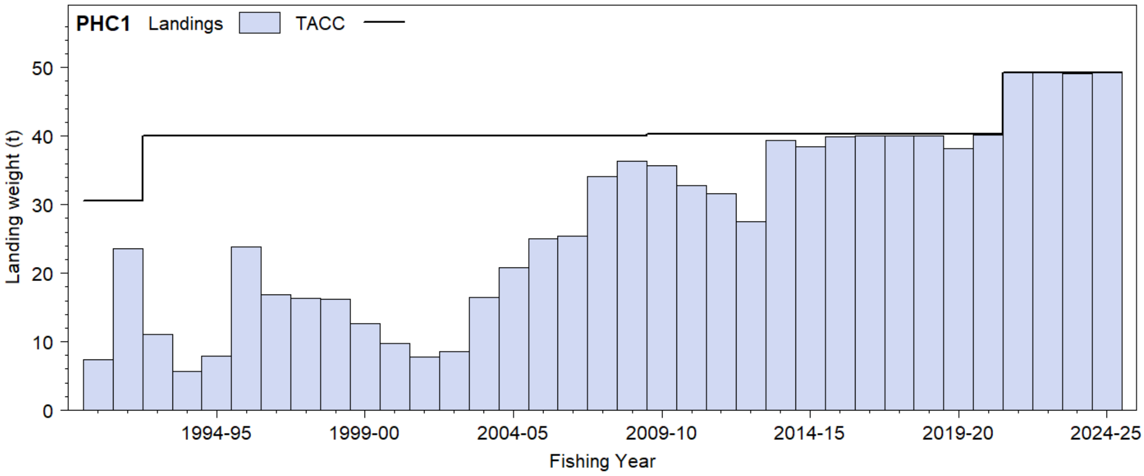


Figure 1: Historical landings and TACC (tonnes) from 1990 to present for the packhorse rock lobster (*Sagmariasus verreauxi*) fishery (PHC 1).

1.1 Commercial fisheries

The New Zealand packhorse rock lobster fishery is small compared with the red rock lobster fishery. Catches of this species are almost entirely taken along the north and east coasts of the North Island, overlapping with the red rock lobster fishery in CRA 1 and CRA 2 (Webber 2013). A few fishers actively target packhorse rock lobster at their main New Zealand breeding grounds, centred at North Cape, in the Far North. Nearly all the packhorse target catches are taken in statistical areas 901 and 902. Approximately half of the total reported catch since 1990–91 was taken as bycatch by a much larger fleet targeting red rock lobsters. The red rock lobster target catch of packhorse rock lobster extends from Northland (area 901) to the Eastern Bay of Plenty (area 908) but is mainly concentrated between areas 901 and 906 (Figure 2).

When the packhorse rock lobster fishery was brought into the QMS on 1 April 1990, the TACC was set at 27 tonnes. This was raised in the same year to 30.5 tonnes due to quota appeals. The TACC remained at 30.5 tonnes for just two years and was increased to 40.3 tonnes during the 1992–93 fishing year, where it remained until 2021–22 when it was increased to 49.3 tonnes (Table 1). Since the introduction of the QMS, packhorse rock lobster catches have been relatively low, although they have been close to the TACC since 2013–14 (Table 1). Historical landings have been estimated to be much higher (Kensler & Skrzynski 1970, Booth 2011), although these catch estimates are likely to be much less precise than those available since 1990–91 from Quota Management Reports (QMRs) or their replacement Monthly Harvest Reports (MHRs).

Table 1 provides a summary of the reported commercial catches and TACCs for PHC 1 by fishing year since 1990–91. The QMR/MHR data (since 1 October 2001) provide the most accurate information on landings. The QMS-reported landings of the packhorse rock lobster stock more than halved between 1998–99 and 2001–02 and were below 30 t y^{-1} up to 2007–08. Landings have since exceeded 30 t y^{-1}, except for 2012–13, when 27.5 t was reported. Subsequent landings have been close to the TACC.

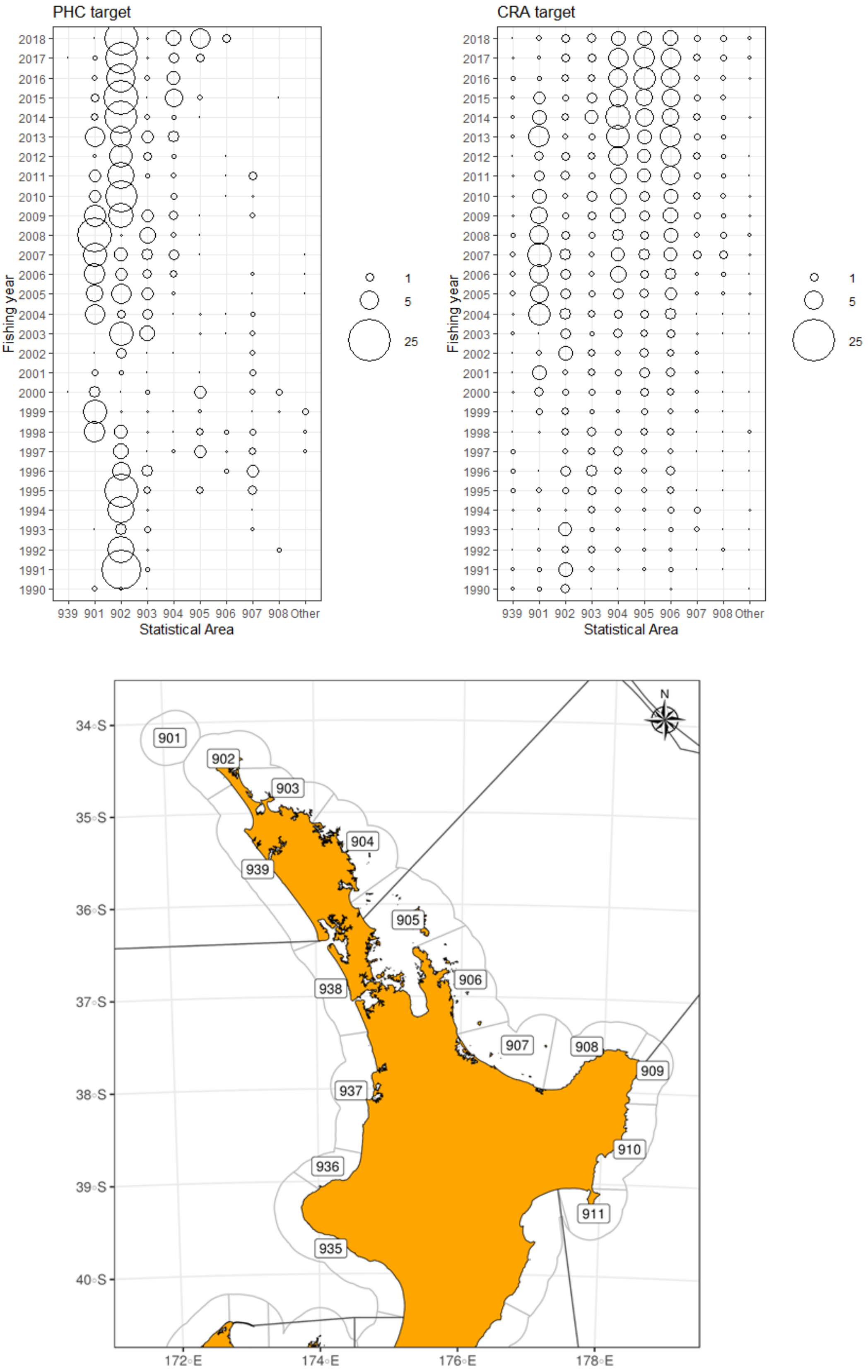


Figure 2: Distribution of packhorse rock lobster (*Sagmariasus verreauxi*) catch by statistical area and fishing year for fishing events targeting packhorse rock lobster (PHC) (top-left) and red rock lobster (CRA) (top-right) (circle areas are proportional to the catch in tonnes, and the same size scale is used for all plots) (source: estimated catch from CELR); and the location of relevant statistical areas (bottom).

Table 1: Reported commercial catch (t) from QMRs or MHRs (after 1 October 2001) and TACC (t) for packhorse rock lobster (*Sagmariasus verreauxi*) (PHC 1) for each fishing year since the species was included in the QMS on 1 April 1990.

Fishing year	Catch	TACC	Fishing year	Catch	TACC
1990–91	7.4	30.5[1]	2008–09	36.4	40.3
1991–92	23.6	30.5	2009–10	35.7	40.3
1992–93	15.3	40.3	2010–11	32.8	40.3
1993–94	5.7	40.3	2011–12	31.6	40.3
1994–95	7.9	40.3	2012–13	27.5	40.3
1995–96	23.8	40.3	2013–14	39.4	40.3
1996–97	16.9	40.3	2014–15	38.5	40.3
1997–98	16.2	40.3	2015–16	39.9	40.3
1998–99	16.2	40.3	2016–17	40.0	40.3
1999–00	12.6	40.3	2017–18	40.1	40.3
2000–01	9.8	40.3	2018–19	40.1	40.3
2001–02	7.8	40.3	2019–20	38.2	40.3
2002–03	8.6	40.3	2020–21	40.1	40.3
2003–04	16.4	40.3	2021–22	49.3	49.3
2004–05	20.8	40.3	2022–23	49.2	49.3
2005–06	25.0	40.3	2023–24	49.1	49.3
2006–07	25.4	40.3	2024–24	49.2	49.3
2007–08	34.0	40.3			

[1] Entered QMS at 27 t in 1990–91 but raised immediately to 30.5 t in first year of operation due to quota appeals.

1.2 Recreational fisheries

Recreational fishers may gather packhorse rock lobster by pot or hand (freediving or scuba), although recreational fishers are subject to all of the other input controls in place for commercial fishers. Recreational fishers may not take soft shell individuals or berried females, and it is illegal to spear them. Additionally, a daily bag limit of six rock lobsters (combined across both species) applies to recreational fishers. Four estimates of recreational packhorse lobster catch are available: three national panel surveys (2011–12, 2017–18 and 2022–23); and an East Northland survey conducted by John Holdsworth in 2013 (Table 2). Recreational fishing catch in the stock assessment was assumed to increase from 2 t to 10 t from 1953 to 1979 and to remain at 10 t thereafter.

Table 2: Information used to estimate recreational catch of packhorse rock lobster (*Sagmariasus verreauxi*). The mean weight estimates are from Holdsworth (2014) for 2017–18, and Johnson et al. (2024) for 2022–23. The three national panel surveys attempt to estimate PHC catch for all New Zealand while the Holdsworth survey applies to Northland.

Category	Numbers	Mean weight	Weight (kg)	CV
2011–12 (NPS: Wynne-Jones et al. 2014)	3 233	–	–	0.34
2013 (Holdsworth 2014)	–	–	5 000	–
2017–18 (NPS: Wynne-Jones et al. 2019)	11 750	2.412	28 662	0.79
2022–23 (NPS: Heinemann & Gray 2024)	4 143	2.142	8 874	0.46

1.3 Customary non-commercial fisheries

The total customary catches for packhorse rock lobster are not known but are thought to be low.

1.4 Illegal catch

The total illegal catches for packhorse rock lobster are not known but are thought to be low.

1.5 Other sources of mortality

Other sources of mortality include handling mortality caused by high-grading or the return of under-sized and berried female lobsters to the water. Moreover, predation in pots by octopus and other predators is known to occur. Octopus predation could be quantified from observer catch sampling data, but estimates were not used for the stock assessment.

2. BIOLOGY

Although New Zealand packhorse rock lobsters have not been aged, they are thought to be relatively long-lived. The dominant early-life stage of rock lobster species is the phyllosoma larva, which, in the case of packhorse rock lobsters, are thought to survive for up to one year post-spawning before metamorphosing into pueruli that then settle on the seafloor (Kittaka et al. 1997). There is no monitoring of New Zealand packhorse lobster puerulus settlement to inform recruitment, as there is for red rock lobsters (Foreman et al. 2020).

Pueruli moult into first instar juveniles after 3–4 weeks (Kittaka et al. 1997). Along the coast of New South Wales, Australia, juveniles tend to be more abundant than mature lobsters shallower than 10 m (New South Wales Department of Primary Industries 2017). Around New Zealand, juveniles are predominantly found along the north and east coasts of the North Island, down current of the Northland spawning grounds (Booth 2011).

A recent characterisation by Roberts & Webber (2021) estimated that female sexual maturity is reached between 80 and 110 mm tail width (TW). This is consistent with an earlier estimate of 160–184 mm carapace length (Booth 1984). The size at which 50% of females have setae (~85 mm TW) is near the bottom end of this range, indicating that the presence of berries (rather than setae) should be used to determine individual maturity stages of packhorse lobsters (Roberts & Webber 2021), consistent with the earlier findings of Booth (1984).

As they approach maturity, individuals appear to migrate counter-current up the east coast of the North Island, eventually returning to the main spawning grounds around the Far North of New Zealand (Booth 1984, Booth 2011), although this conclusion is based on a relatively small number of tags and other supporting information. Then, as with other rock lobster species, individuals of both sexes move seasonally inshore and offshore as they moult and then reproduce. Large individuals accumulate over shallow seafloor (< 60m depth) by October. Berried females are first found in late September, and most are berried by December (Kensler 1967). Packhorse lobsters are considered the most fecund of all rock lobster species, with very large females producing up to two million eggs (Kensler 1967). In December and January, the lobsters then move into deeper waters (up to at least 100 m depth) where eggs hatch and the larvae are dispersed by strong currents (Booth 2011). Their movements after this are poorly understood, although the evidence suggests they remain on the deep seafloor (up to 200 m) until the next inward migration for moulting and breeding (Booth 2011).

The fishery characterisation by Webber (2013) identified the need for basic biological information to inform a stock assessment. Subsequent morphometric work has obtained relationships between tail length, tail width, and weight (Roberts & Webber 2021) (summarised below). A characterisation of the limited tag recapture information (fewer than 100 recaptures to date) found that these recaptures have potential to inform sex-specific growth at size (which is likely to be much faster than that of red rock lobster) and to increase understanding of the movement patterns of vulnerable lobsters (Roberts & Webber 2021).

Relationship between tail length and tail width

The relationship between tail length (TL) and tail width (TW) was modelled with measurement error in both TL and TW as

$$\log(TW_i) = \log(\alpha) + \beta \log\left(\mu_i^{TL}\right) + \varepsilon_i$$

where μ_i^{TL} is the expected TL (mm) from the measurement error component of the model

$$\log\left(\mu_i^{TL}\right) \sim N(\log(TL_i),\ 0.02^2)$$

and

$$\varepsilon_s \sim \text{student}(0,\ \sigma^2)$$

or any other suitable distribution (e.g., the normal distribution). The student-t distribution was used to minimise the impacts of outliers, so records where the wrong sex may have been recorded were not removed because this would have been a subjective decision. A log-log relationship was used to better model the variance such that variance is higher at larger sizes, a pattern that seems apparent in the data (Figure 3). The choice of 0.02 as the standard deviation for the measurement error model was somewhat subjective but equates to a standard deviation of approximately 5 mm about the tail length in natural space. Bayesian inference was conducted using the R package *brms* (Table 3, Figure 3).

The current MLS for packhorse lobster is 90 mm TW for females and 84 mm TW for males. The model predicted that the previous TL based MLS equates to a median estimate of 89.1 mm TW for females and 83.5 mm TW for males (Figure 4). In practice, any tail width MLS close to these values would be suitable (e.g., 90 mm for females and 84 mm for males which gives the same difference between the sexes as the 60 mm and 54 mm tail width MLS for red rock lobsters).

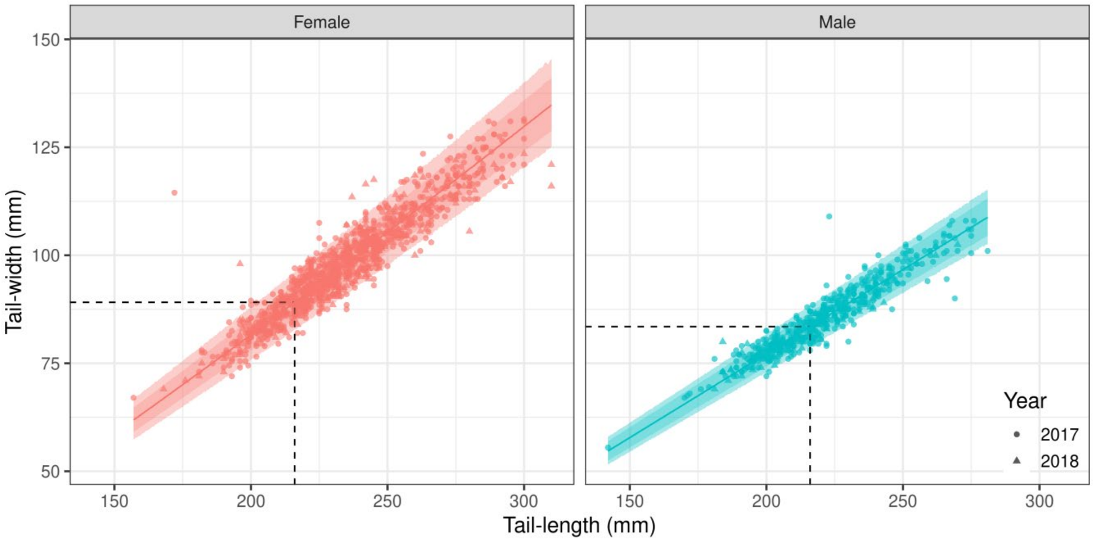


Figure 3: Relationship between tail length and tail width for packhorse rock lobster (*Sagmariasus verreauxi*) showing the data (points), the posterior mean (solid line), posterior distribution (inner shaded region), and posterior predictive distribution (outer shaded region) by sex. The dashed vertical line is the historical MLS of 216 mm tail length and the dashed horizontal lines are the equivalent predictions of MLS in tail width.

Table 3: Parameter summary for the packhorse rock lobster (*Sagmariasus verreauxi*) tail length (TL) to tail width (TW) model. The parameter α is the intercept, β is the slope, σ is the standard deviation, and ν is the degrees of freedom of the student-t distribution.

Parameter	Sex	Mean	SD	2.5%	Median	97.5%
$\log(\alpha)$	Female	-1.560	0.066	-1.690	-1.560	-1.428
$\log(\alpha)$ offset	Male	0.622	0.102	0.420	0.622	0.821
β	Female	1.126	0.012	1.102	1.126	1.150
β offset	Male	-0.128	0.019	-0.165	-0.128	-0.091
σ	Female	-3.407	0.030	-3.467	-3.407	-3.348
σ offset	Male	-0.360	0.061	-0.379	-0.359	-0.242
ν	–	4.285	0.631	3.243	4.212	5.682

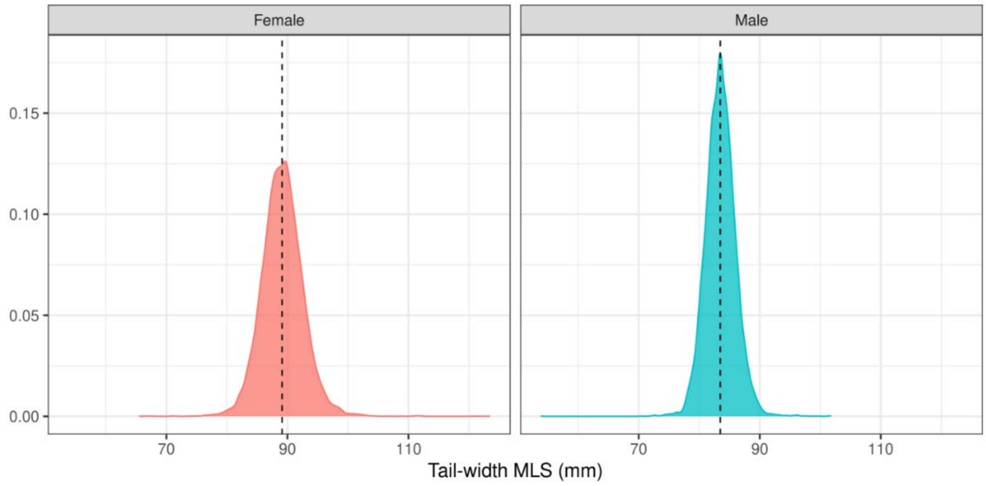


Figure 4: Prediction of the tail width minimum landing size (MLS) for packhorse rock lobster (*Sagmariasus verreauxi*) showing the variability about this prediction.

Relationship between tail width and weight

The relationship between length (L), or in this case TW, and weight (W) is commonly modelled using the simple length-weight relationship, usually written as

$$W_i = \alpha L_i^{\beta}$$

or in log-space

$$\log(W_i) = \log(\alpha) + \beta \log(L_i).$$

Here, the relationship between TW and weight is modelled with measurement error as

$$\log(W_i) = \log(\alpha) + \beta \log\left(\mu_i^L\right) + \varepsilon_i$$

where

$$\log\left(\mu_i^L\right) \sim N(\log(L_i),\ 0.02^2)$$

and

$$\varepsilon_i \sim \text{student}(0,\ \sigma^2)$$

or any other suitable distribution (e.g., the normal distribution). Because the student-t distribution is used to minimise the impacts of outliers, records where the wrong sex may have been recorded were not removed because this would have been a subjective decision. Bayesian inference was conducted using the R package *brms*. The estimated parameter values are given in Table 4. The posterior relationships between tail width and weight are shown in Figure 5.

Table 4: Parameter summary for the length-weight model for packhorse rock lobster (*Sagmariasus verreauxi*). The parameter α is the intercept, β is the slope, σ is the standard deviation, and ν is the degrees of freedom of the student-t distribution.

Parameter	Sex	Mean	SD	2.5%	Median	97.5%
α	Female	0.03933	0.0039	0.03235	0.03912	0.04741
α	Male	0.00023	0.0005	0.00015	0.00023	0.00034
β	Female	2.340	0.0213	2.298	2.340	2.382
β	Male	3.577	0.0460	3.487	3.577	3.667
σ	Female	0.0520	0.0028	0.0466	0.0520	0.0575
σ	Male	0.0491	0.0046	0.0403	0.0491	0.0583
ν	–	3.175	0.337	2.572	3.151	3.893

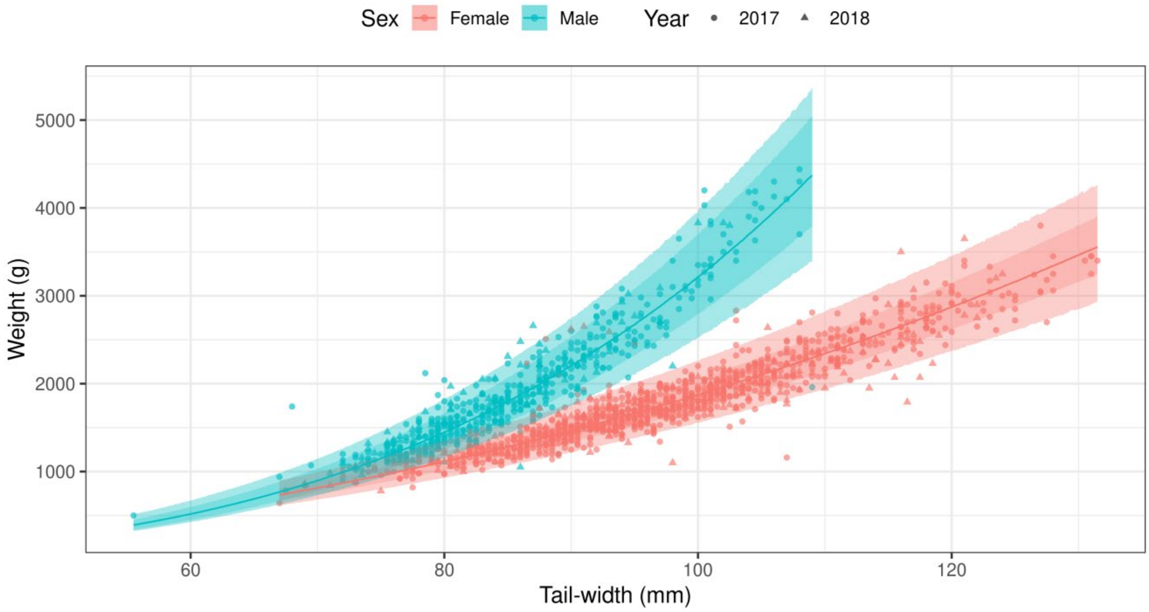


Figure 5: Relationship between tail width (mm) and weight (g) for packhorse rock lobster (*Sagmariasus verreauxi*), showing the data by sex and survey year (points), the posterior mean (solid line), posterior distribution (inner shaded region), and posterior predictive distribution (outer shaded region).

3. STOCKS AND AREAS

The spatial extent of the current packhorse lobster fishery (PHC 1) spans two of the red rock lobster QMAs (CRA 1 and CRA 2). It is known from research on the New Zealand and Australian populations that this species is highly migratory, and it is likely that the relative vulnerability of different life stages (and potentially demographic groups) will vary spatially. Tag recapture data may have potential for estimating movement rates between regions of the north coast of the North Island of New Zealand, though the data are too sparse to inform analyses at present.

The stock structure of packhorse rock lobsters is informed by genetic studies and simulations of the dispersal of phyllosomae by oceanographic currents. A recent genetic analysis based on single nucleotide polymorphisms (SNPs) concluded that the New Zealand and Australian populations are genetically homogenous at neutral loci despite physical separation by the Tasman Sea (Woodings et al. 2018). This contradicted an earlier genetic analysis based on a comparatively small sample size (Brasher et al. 1992). Woodings et al. (2018) speculated on the role of oceanographic currents in advecting pelagic phyllosomae across the Tasman Sea from New South Wales to New Zealand. An earlier study using satellite-derived surface currents concluded that around 2% of packhorse rock lobster larvae survive the crossing, mostly arriving at the northern tip of the North Island (Chiswell et al. 2003). There are other strong parallels comparing the New Zealand and Australian stocks; for example, with respect to increasing catch rates since the early 1990s, and their life cycles and movement patterns (Booth 2011, New South Wales Department of Primary Industries 2017).

4. STOCK ASSESSMENT

This section reports the first stock assessment for packhorse rock lobster (PHC 1) completed in 2020. After examining the available data, it was decided that a length-structured stock assessment using the lobster stock dynamics (LSD) model would not be possible due to lack of adequate length-frequency and tag-recapture data. A delay-difference model was also considered and tested, but reasonable fits to the CPUE series could not be obtained. Instead, a simple biomass dynamics model was used.

Catch history

The catch history used in this stock assessment is provided in Figure 6. The stock assessment added commercial catch and recreational catch (discussed in Section 2) but ignored customary and illegal catches. The commercial catch from 1953–54 to 1978–79 was set to 65% of the catch presented by Booth (2011) because it was thought that these catch estimates were too high to be credible. For instance, catch estimates presented by Kensler & Skrzynski (1970) for 1962–1966 were on average 30% of the Booth (2011) catches for the same period, and the catch estimates presented by Annala & King (1983) for 1967–1973 were on average 10% of the Booth (2011) catches. However, the Kensler & Skrzynski (1970) and Annala & King (1983) catches probably represent a lower bound on the catch because anecdotal evidence (Booth 2011) suggests a considerable amount of catch went unreported.

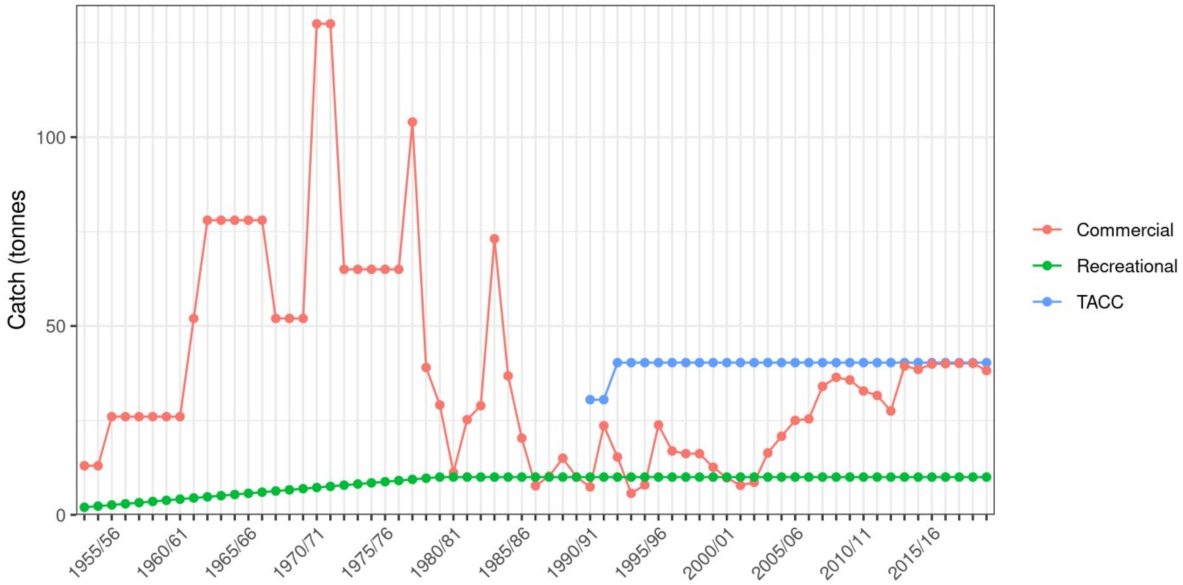


Figure 6: Total allowable commercial catch (TACC) from 1990–91 to 2018–19, and the commercial and recreational catch of packhorse rock lobster (*Sagmariasus verreauxi*) (PHC 1) from 1953–54 to 2018–19 used in this stock assessment. Commercial catch from 1953–54 to 1978–79 is 65% of the catches reported by Booth (2011), from 1979–80 to 1989–90 is FSU, and from 1990–91 onwards is QMR/MHR.

Catch per unit effort (CPUE)

Webber (2013) developed a standardised catch per unit effort (CPUE) time series for the New Zealand packhorse rock lobster fishery, which was subsequently updated by Roberts & Webber 2021). Following the advice of the Rock Lobster Working Group (RLWG), the updated CPUE analysis only included fishing events targeting red rock lobster, which included approximately half the reported catch of packhorse rock lobster since its introduction into the QMS (Figure 2). This was decided because the targeted packhorse rock lobster fishery is operated by a very small number of vessels relative to the number of vessels targeting red rock lobsters which regularly report packhorse rock lobster catches. Those vessels that target packhorse lobster tend to focus on spawning aggregations and their catch rates are likely to exhibit hyperstability. The catch data used for the standardised CPUE estimates were subjected to error screening (Bentley et al. 2005), and the estimated catches were scaled using the F2 LFX algorithm (Starr 2020).

A Bayesian generalised linear model (GLM) was used to estimate the CPUE series using the R package *brms*. Compared with standardisations that used maximum likelihood, Bayesian GLMs better represent parameter uncertainty. The chosen CPUE model assumed a hurdle-lognormal distribution and included fishing year, month, and vessel coefficients for both the hurdle and lognormal components.

The updated CPUE standardisation estimated an increasing trend in catch rate for PHC 1 from 1991–92 to 2018–19 (Table 5, Figure 7). The recent rate of increase in CPUE is comparable in scale with that observed in the New South Wales fishery for the same species (where it is called ‘Eastern rock lobster’) (New South Wales Department of Primary Industries 2017), although the timing of the increase seems to differ.

Table 5: Unstandardised (geometric mean) CPUE and standardised CPUE (kg/potlift) (Roberts & Webber 2021) for packhorse rock lobster (*Sagmariasus verreauxi*) (PHC 1) from 1991–92 to 2018–19. CELR data held by Fisheries New Zealand were used in this analysis, using the ‘F2’ algorithm corrected for ‘LFX’ destination code landings (see text for definition), constrained to vessels with at least five years in the fishery and events targeting CRA only (i.e., events targeting PHC were excluded). This series was estimated using a vessel explanatory variable.

Fishing year	Unstandardised	Standardised	SE
1991–92	0.0130	0.0029	0.0015
1992–93	0.0086	0.0050	0.0022
1993–94	0.0074	0.0039	0.0017
1994–95	0.0156	0.0071	0.0026
1995–96	0.0264	0.0107	0.0035
1996–97	0.0432	0.0217	0.0073
1997–98	0.0160	0.0161	0.0057
1998–99	0.0287	0.0223	0.0066
1999–00	0.0144	0.0188	0.0060
2000–01	0.0230	0.0276	0.0073
2001–02	0.0229	0.0304	0.0080
2002–03	0.0193	0.0192	0.0055
2003–04	0.0164	0.0199	0.0053
2004–05	0.0371	0.0337	0.0082
2005–06	0.0265	0.0255	0.0062
2006–07	0.0275	0.0303	0.0073
2007–08	0.0336	0.0367	0.0088
2008–09	0.0200	0.0251	0.0062
2009–10	0.0284	0.0267	0.0065
2010–11	0.0255	0.0440	0.0101
2011–12	0.0269	0.0359	0.0080
2012–13	0.0176	0.0342	0.0082
2013–14	0.0237	0.0427	0.0095
2014–15	0.0211	0.0383	0.0089
2015–16	0.0227	0.0316	0.0080
2016–17	0.0234	0.0330	0.0088
2017–18	0.0316	0.0511	0.0123
2018–19	0.0410	0.0559	0.0155

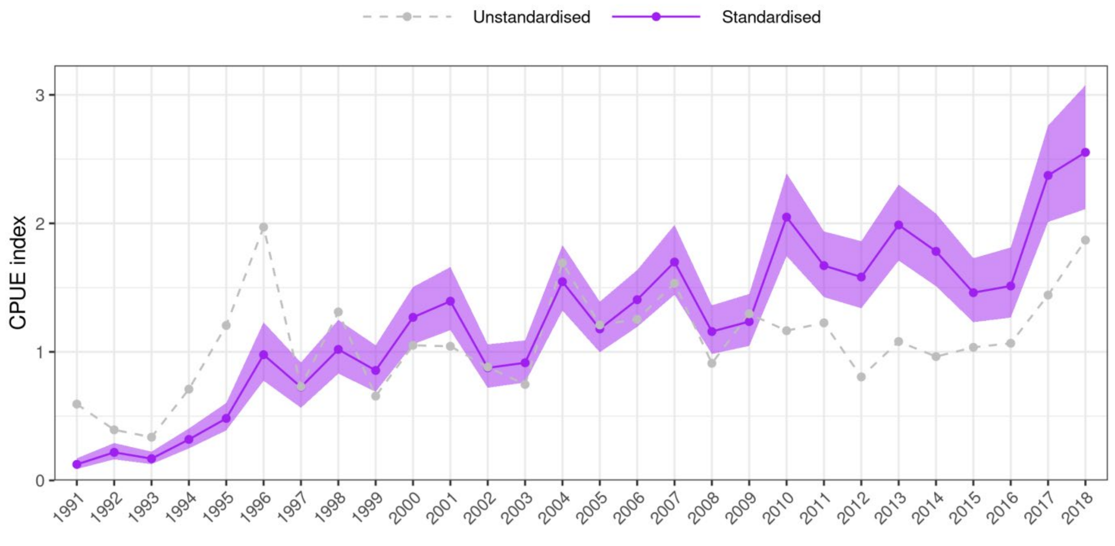


Figure 7: Unstandardised (geometric mean) CPUE and standardised CPUE (kg/potlift) of packhorse rock lobster (*Sagmariasus verreauxi*) (PHC 1) from 1991–92 to 2018–19. Note that the CPUE values in this plot have been rescaled to have a mean value of 1, and so are on a different scale to those presented in Table 5.

Model structure

The stock assessment assumes Pella-Tomlinson (1969) production (P_t) each fishing year (t)

$$P_t = \frac{r}{z} B_t \left(1 - \left(\frac{B_t}{K}\right)^z\right)$$

where r is the intrinsic rate of population increase, z is the Pella-Tomlinson shape parameter, K is the carrying capacity, and B_t is the biomass (tonnes) each year (Pella & Tomlinson 1969). The shape parameter defines a Schaefer (1954) model if $z = 1$, and as z tends towards zero it becomes the modified Fox (1970) model. The initial biomass is assumed to be at the carrying capacity

$$B_{t=1} = K e^{\varepsilon_{t=1}^p}.$$

Otherwise the biomass is defined as

$$B_t = (B_{t-1} + P_{t-1} - C_{t-1}) e^{\varepsilon_t^p}$$

where C_t is the catch (tonnes) which includes commercial and recreational catch added together each fishing year. The process error each fishing year is

$$\varepsilon_t^p \sim N\left(0, \sigma_p^2\right)$$

where σ_p is the process error standard deviation. The CPUE series is assumed to be directly proportional to biomass such that

$$I_t = q B_t e^{\varepsilon_t^o}$$

where q is the catchability coefficient. The observation error (ε_t^o) is defined as

$$\varepsilon_t^o \sim N(0, \sigma_t^2)$$

and

$$\sigma_t = \frac{1}{\tau} \sqrt{\left(\sigma_t^{\mathrm{GLM}}\right)^2 + \left(\sigma_t^{\mathrm{add}}\right)^2}$$

where σ_t^{GLM} is the SD from the GLM, σ_t^{add} is additive process error, and τ is the CPUE data set weight.

A prior was used for the parameter z which has an expected value of 1 (i.e., a Schaefer model)

$$z \sim \mathrm{lognormal}(\log(1) + 0.5^2, 0.5^2).$$

The prior was also used for the parameter σ_p that resulted in a sensible level of process error

$$\sigma_p \sim \mathrm{lognormal}(\log(0.05), 0.01^2).$$

The derived quantities B_{MSY} and MSY were calculated as

$$B_{\mathrm{MSY}} = K \left(\frac{1}{z+1}\right)^{\frac{1}{z}}$$

and

$$MSY = \frac{r}{z} B_{MSY} \left(1 - \left(\frac{B_{MSY}}{K}\right)^z\right).$$

This model was coded in *Stan*, specifically for the packhorse lobster (PHC 1) stock assessment. A full list of prior specifications and parameter bounds are provided in Table 6. Alternative models trialled an initial depletion parameter and a CPUE power parameter (to allow for hyperstability/hyperdepletion), but these were both dropped as their parameter estimates were close to 1 and they did not change the model fits/outcomes in a meaningful way.

Table 6: Specifications for estimated parameters in the packhorse rock lobster (*Sagmariasus verreauxi*) (PHC 1) stock assessment models including the upper and lower bounds, prior type, and prior parameters.

Parameter	Lower bound	Upper bound	Prior type	par 1	par 2
r	0	3	uniform	–	–
z	0.001	5	lognormal	$\log(1) + 0.5^2 = 0.25$	0.5
K	1	1e5	uniform	–	–
q	0	1	uniform	–	–
σ_p	0	–	lognormal	$\log(0.05) = -3$	0.01
B_t	0	–	lognormal	–	σ_p

Model inference

The assessment model was fitted to standardised CPUE assuming a lognormal distribution. Additive process error was used and set to 0.1 from 1991 to 2016, and 0.05 in 2017 and 2018, to improve the fit of the last two years. The CPUE data set weight was set to 0.3 so that the standard deviation of normalised residuals was 1.

Bayesian inference was conducted using Stan's Hamiltonian Monte Carlo (HMC) Markov chain Monte Carlo (MCMC) algorithm. Four chains, each with a burn-in period of 4000 samples and length of 4000 samples, were run retaining every second sample, for a total of 2000 samples in the posterior distribution.

Performance indicators and results

Biomass in the assessment model is the annual biomass vulnerable to the fishery because it is scaled to the CPUE, which is based on the vulnerable population. Figure 8 shows the posterior distribution of the estimated packhorse rock lobster biomass by fishing year for the base case stock assessment.

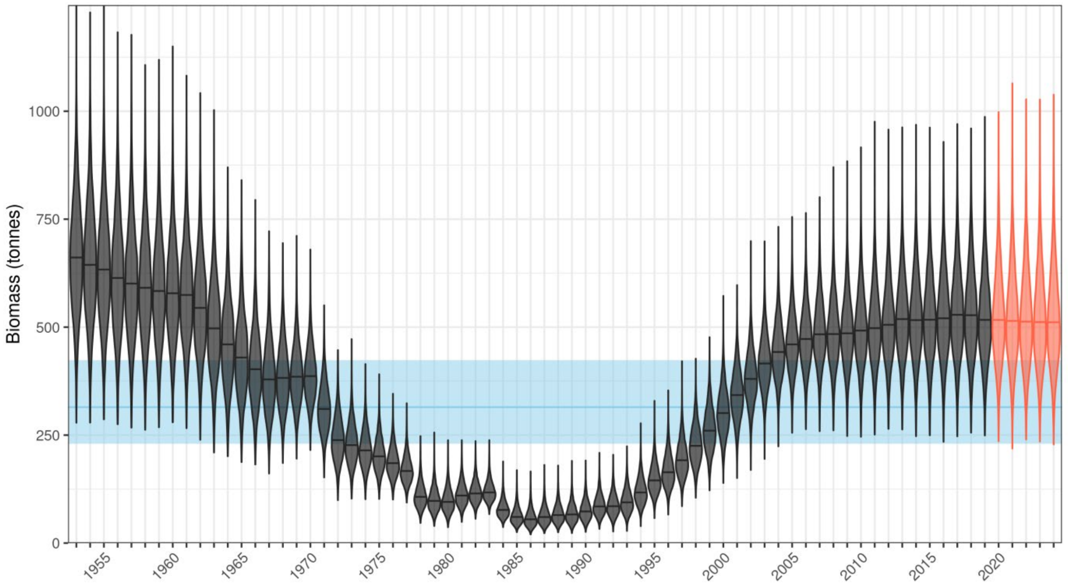


Figure 8: Posterior distribution of the packhorse rock lobster (*Sagmariasus verreauxi*) (PHC 1) biomass (tonnes) for the base case stock assessment model by fishing year. The horizontal line within each violin represents the median, the red violins represent projection years 2020–21 to 2024–25, the horizontal blue line represents the median of B_{MSY}, and the blue shaded region represents the 90% credible interval of B_{MSY}.

Sensitivity runs

Two MCMC sensitivity runs were run:

1. Changing the informative prior on the Pella-Tomlinson shape parameter to $z \sim \text{lognormal}(\log(1) + 0.5^2, 0.5^2)$ (**flat_z**); and
2. Project forward with process error mean of 0 and SD of σ_p (**proj_low**); otherwise this model run is the same as the **base** run.

Results from the base case and the two sensitivity trials are compared in Table 7. Neither sensitivity differed much from the **base** run. The **flat_z** run produced a lower estimate of the population increase parameter (r) and the shape parameter (z) and a higher carrying capacity (K); however, this alternative combination of parameters produced a very similar fit to the CPUE series and a very similar stock status to the **base** model run. As expected, the **proj_low** model run produced a slightly lower projected biomass (B_{2024}) compared with the **base** model run; however, this difference is minimal. This inverse correlation of the two key model parameters is typical of simple production models, resulting from a trade-off between stock size and productivity. Because the only data provided to the model are catch and a biomass trend, in the absence of biological data specific to the stock, the model cannot reconcile these two hypotheses.

Table 7: Packhorse rock lobster (*Sagmariasus verreauxi*) stock (PHC 1) base case and sensitivity stock assessment model runs, reporting the 5th, 50th (median), and 95th quantiles of the posterior distributions. [Continued on next page]

	base			**proj_low**			**flat_z**		
	5%	**50%**	**95%**	**5%**	**50%**	**95%**	**5%**	**50%**	**95%**
SDNR	0.875	0.997	1.139	0.877	0.998	1.140	0.815	0.942	1.105
proj_mu	-0.012	0.012	0.037	–	–	–	-0.012	0.012	0.037
proj_sd	0.031	0.048	0.068	–	–	–	0.030	0.048	0.069
proj_rho	-0.002	0.000	0.001	–	–	–	-0.002	0.000	0.001
K	449.1	650.9	868.4	483.2	662.9	879.7	524.1	711.7	921.2
r	0.252	0.391	0.719	0.250	0.381	0.650	0.189	0.282	0.558
z	0.376	0.776	1.646	0.377	0.771	1.556	0.024	0.270	1.321
σ_p	0.049	0.050	0.051	0.049	0.050	0.051	0.049	0.050	0.051
B_0	444.8	648.9	875.9	475.4	661.3	887.5	517.0	710.3	933.2
B_{min}	31.7	53.8	91.2	33.2	55.5	91.6	26.2	43.8	79.0
B_{2019}	359.9	510.1	693.3	381.8	520.7	695.8	395.3	520.0	683.5
B_{MSY}	221.8	309.6	418.7	233.8	315.9	423.0	230.2	298.4	395.6
MSY	60.3	68.4	77.5	60.1	68.0	76.5	57.2	64.9	74.3
B_{2019} / B_0	0.660	0.793	0.928	0.660	0.792	0.926	0.592	0.743	0.894
P($B_{2019} > B_{min}$)		1.000			1.000			1.000	
P($B_{2019} > B_{MSY}$)		1.000			1.000			1.000	
P($B_{2019} > B_0$)		0.007			0.006			0.003	
B_{2024} - 0 t	430.0	610.2	825.8	448.2	603.7	791.4	478.3	634.3	845.4
B_{2024} - 40.3 t	351.4	502.9	703.2	361.5	494.4	668.1	375.4	514.5	714.3
B_{2024} - 47 t	335.4	483.5	682.2	344.5	475.0	647.5	357.6	493.5	691.9
B_{2024} - 53 t	320.4	465.9	662.6	328.8	457.1	628.8	340.8	474.9	671.5
B_{2024} - 67 t	282.8	423.3	617.1	290.0	413.7	583.5	299.2	429.4	624.1
B_{2024} - 80 t	243.9	381.7	573.7	250.2	371.8	541.7	256.9	385.6	577.6
B_{2024} - phased	266.0	406.9	600.7	273.1	397.5	568.6	283.6	413.8	608.6
B_{2024} / B_0 - 0 t	0.792	0.950	1.106	0.779	0.917	1.061	0.723	0.910	1.087
B_{2024} / B_0 - 40.3 t	0.634	0.788	0.941	0.625	0.754	0.890	0.564	0.741	0.916
B_{2024} / B_0 - 47 t	0.606	0.758	0.912	0.597	0.725	0.860	0.537	0.711	0.886
B_{2024} / B_0 - 53 t	0.579	0.731	0.886	0.570	0.698	0.832	0.511	0.684	0.858
B_{2024} / B_0 - 67 t	0.513	0.663	0.821	0.508	0.632	0.766	0.450	0.618	0.794
B_{2024} / B_0 - 80 t	0.448	0.597	0.758	0.444	0.567	0.703	0.390	0.554	0.731
B_{2024} / B_0 - phased	0.491	0.636	0.792	0.486	0.607	0.740	0.431	0.595	0.767
B_{2024} / B_{2019} - 0 t	1.051	1.198	1.362	0.991	1.161	1.353	1.060	1.222	1.406
B_{2024} / B_{2019} - 40.3 t	0.865	0.994	1.132	0.809	0.956	1.117	0.855	0.994	1.152
B_{2024} / B_{2019} - 47 t	0.828	0.956	1.094	0.775	0.918	1.075	0.817	0.955	1.111
B_{2024} / B_{2019} - 53 t	0.794	0.922	1.059	0.742	0.884	1.039	0.781	0.918	1.073
B_{2024} / B_{2019} - 67 t	0.707	0.837	0.974	0.666	0.800	0.949	0.691	0.829	0.987
B_{2024} / B_{2019} - 80 t	0.617	0.753	0.898	0.583	0.718	0.865	0.599	0.745	0.906
B_{2024} / B_{2019} - phased	0.674	0.803	0.943	0.634	0.767	0.917	0.660	0.798	0.956
B_{2024} / B_{MSY} - 0 t	1.649	1.964	2.324	1.639	1.909	2.203	1.690	2.132	2.610
B_{2024} / B_{MSY} - 40.3 t	1.347	1.628	1.949	1.332	1.570	1.823	1.365	1.728	2.159
B_{2024} / B_{MSY} - 47 t	1.289	1.567	1.883	1.275	1.509	1.760	1.299	1.658	2.083
B_{2024} / B_{MSY} - 53 t	1.233	1.510	1.823	1.222	1.452	1.701	1.240	1.593	2.017

Table 7: [Continued]

	base			proj_low			flat_z		
	5%	**50%**	**95%**	**5%**	**50%**	**95%**	**5%**	**50%**	**95%**
B_{2024} / B_{MSY} - 67 t	1.095	1.374	1.683	1.088	1.315	1.563	1.099	1.441	1.856
B_{2024} / B_{MSY} - 80 t	0.952	1.237	1.556	0.950	1.181	1.430	0.951	1.294	1.707
B_{2024} / B_{MSY} - phased	1.043	1.316	1.629	1.039	1.262	1.509	1.050	1.387	1.803
P($B_{2024} > B_{2019}$) - 0 t		0.986			0.941			0.989	
P($B_{2024} > B_{2019}$) - 40.3 t		0.467			0.319			0.475	
P($B_{2024} > B_{2019}$) - 47 t		0.285			0.185			0.293	
P($B_{2024} > B_{2019}$) - 53 t		0.162			0.106			0.173	
P($B_{2024} > B_{2019}$) - 67 t		0.030			0.014			0.038	
P($B_{2024} > B_{2019}$) - 80 t		0.005			0.001			0.007	
P($B_{2024} < B_{2019}$) - phased		0.014			0.006			0.024	
P($B_{2024} <$ 20% B_0) - 0 t		0.000			0.000			0.000	
P($B_{2024} <$ 20% B_0) - 40.3 t		0.000			0.000			0.000	
P($B_{2024} <$ 20% B_0) - 47 t		0.000			0.000			0.000	
P($B_{2024} <$ 20% B_0) - 53 t		0.000			0.000			0.000	
P($B_{2024} <$ 20% B_0) - 67 t		0.000			0.000			0.000	
P($B_{2024} <$ 20% B_0) - 80 t		0.000			0.000			0.000	
P($B_{2024} <$ 20% B_0) - phased		0.000			0.000			0.000	
P($B_{2024} > B_{MSY}$) - 0 t		1.000			1.000			1.000	
P($B_{2024} > B_{MSY}$) - 40.3 t		1.000			1.000			0.999	
P($B_{2024} > B_{MSY}$) - 47 t		0.999			1.000			0.999	
P($B_{2024} > B_{MSY}$) - 53 t		0.999			1.000			0.998	
P($B_{2024} > B_{MSY}$) - 67 t		0.985			0.990			0.981	
P($B_{2024} > B_{MSY}$) - 80 t		0.912			0.898			0.923	
P($B_{2024} < B_{MSY}$) - phased		0.971			0.975			0.970	

Projections

Projections were completed using the current commercial catch (40.3 t) or a range of alternative catch levels, specified in Table 8. In all projection years, the recreational catch of 10 t was added to the commercial catch. Projections ran for 20 years, from 2020–21 to 2039–40, but results were reported for the 5th projection year only (2024–25) (Table 7).

Table 8: Commercial catch (t) of the packhorse rock lobster (*Sagmariasus verreauxi*) specified for each projected fishing year (2020–21 to 2039–40).

		Commercial catch						
Fishing year	**Recreational catch**	**0**	**40.3**	**47**	**53**	**67**	**80**	**Phased**
2020–21	10	0	40.3	47	53	67	80	53
2021–22	10	0	40.3	47	53	67	80	67
2022–23	10	0	40.3	47	53	67	80	80
2024–25	10	0	40.3	47	53	67	80	80
2025–26 onwards	10	0	40.3	47	53	67	80	80

5. ENVIRONMENTAL AND ECOSYSTEM CONSIDERATIONS

A summary of environmental and ecosystem considerations is given in the red rock lobster (CRA) chapter, which will also be relevant to the packhorse rock lobster target fishery, although note there are some differences in pot configuration and fishing operations. The summary given in the red rock lobster introduction is from the perspective of the rock lobster fisheries, and a more detailed summary from an issue-by-issue perspective is available in the Aquatic Environment and Biodiversity Annual Review 2021 (Fisheries New Zealand 2021). The environmental effects of rock lobster fisheries have also been covered more extensively by Breen (2005).

6. FUTURE RESEARCH CONSIDERATIONS

Future research considerations include:

- ramp up the recreational catch estimates in recent years by assuming they are proportional to the recent increase in CPUE;
- investigate other means of improving estimates of non-commercial catch;
- collect more length-frequency and tag-recapture data so that a length-structured assessment model can be attempted in the future;
- investigate the development of approaches for the direct ageing of lobsters (e.g., Gnanalingam et al. 2019) to inform the estimation of growth rate;
- include area × year or month × year interactions in standardised CPUE analysis;
- investigate annual data for evidence of avoidance behaviour by, for example, comparing data in each half of the quota year to determine whether there is evidence of the TAC constraining CPUE and areas fished in recent years;
- investigate the potential for using PHC data from Australia (e.g., tag-recapture data for growth);
- investigate the impact of alternative catch series on stock assessment conclusions;
- upgrade estimates of maturity to properly define *SSB*; and
- look for evidence of non-stationarity in carrying capacity; consider how to accommodate a potentially increasing carrying capacity.

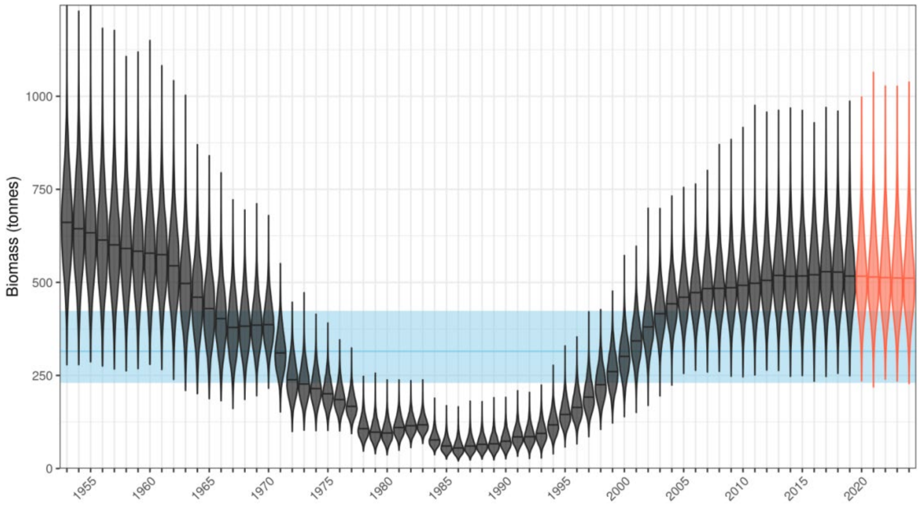
7. STATUS OF THE STOCKS

Stock structure assumptions

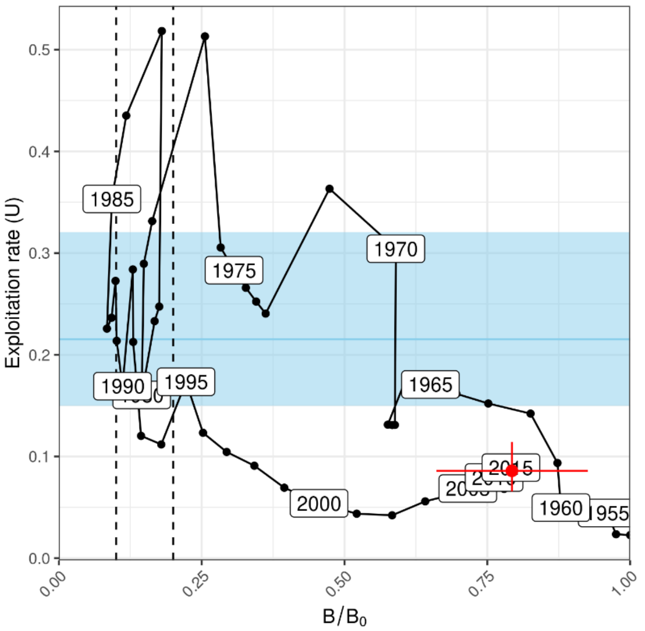
A single New Zealand-wide stock is assumed for packhorse lobster.

Stock Status		
Most Recent Assessment Plenary Publication Year	2020	
Intrinsic productivity level		
Catch in most recent year of assessment	Year: 2018–19 April fishing year	Catch: 41.1 t
Assessment Runs Presented	2020 assessment: MCMC base case	
Reference Point	Interim Target: B_{MSY} Soft limit: 20% B_0 (default) Hard limit: 10% B_0 (default) Overfishing threshold: U_{MSY}	
Status in relation to Target	Likely (> 60%) to be at or above the target	
Status in relation to Limits	Very Unlikely (< 10%) to be below the soft and hard limits	
Status in relation to Overfishing	Overfishing is Unlikely (< 40%) to be occurring	

Historical Stock Status Trajectory and Current Status



Posterior distribution of the packhorse rock lobster (*Sagmariasus verreauxi*) (PHC 1) biomass (tonnes) for the base case stock assessment model by fishing year. The horizontal line within each violin represents the median, the red violins represent projection years 2020–21 to 2024–25, the horizontal blue line represents the median of B_{MSY}, and the blue shaded region represents the 90% credible interval of B_{MSY}.



Snail trail of the packhorse rock lobster (*Sagmariasus verreauxi*) (PHC 1) base case model. The line tracks the median of the posterior for each axis and the red point with error bars represents the 90% credible interval for the final model year (2019). The dashed vertical lines are 20% B_0 (soft limit) and 10% B_0 (hard limit), the horizontal blue line represents the median of U_{MSY}, and the blue shaded region represents the 90% credible interval of U_{MSY}.

Fishery and Stock Trends

Recent Trend in Biomass or Proxy	Vulnerable biomass has been increasing steadily since the early 1990s, although it has levelled out over the last decade.
Recent Trend in Fishing Intensity or Proxy	The exploitation rate has been increasing since 2001 but is well below U_{MSY}.
Other Abundance Indices	-
Trends in Other Relevant Indicators or Variables	-

Projections and Prognosis	
Stock Projections or Prognosis	Biomass is projected to decrease slightly and then stabilise over the next five years at the level of the TACC and 2019 recreational catches.
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Very Unlikely (< 10%) to go below the soft and hard limits
Probability of Current Catch or TACC causing Overfishing to continue or commence	Very Unlikely (< 10%)

Assessment Methodology		
Assessment Type	Level 1 – Full Quantitative Stock Assessment	
Assessment Method	Bayesian biomass dynamics model	
Assessment Dates	Latest assessment Plenary publication year: 2020	Next assessment: 2024
Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	CPUE	2 – Medium or Mixed Quality: possible high level of false zeros and CPUE temporarily ending in 2018
Data not used (rank)	- length frequency, tagging data - logbooks	3 – Low Quality: too sparse to be of use in a model 2 – Medium or Mixed Quality: no lengths/counts by potlift
Changes to Model Structure and Assumptions	-	
Major Sources of Uncertainty	- level of historical catches, including non-commercial - level of current non-commercial catches, including recreational and illegal catches - very little information on growth (<100 tag recoveries) - very limited biological sampling of the fishery - reliance on bycatch CPUE - CPUE series suspended after 2018 - only moderate understanding of population dynamics - limited understanding of migration extent, both in terms of distance and quantity - likely change in fishing behaviour over time - fish may become unavailable to the fishery above a certain size (e.g., too big to pot or move to offshore regions) - unknown size at maturity	

Qualifying Comments
The biomass dynamics model used in this assessment is a simple model that is unable to incorporate the detailed biological characteristics of the stock. Instead, growth and mortality are subsumed into a single parameter, the entire modelled population is assumed to be vulnerable to the fishery, and the only data used are historical catches and a CPUE time series. Although these simplifying assumptions may reduce confidence in the model, it has nevertheless been accepted as a reasonable representation of the current status of the stock.

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