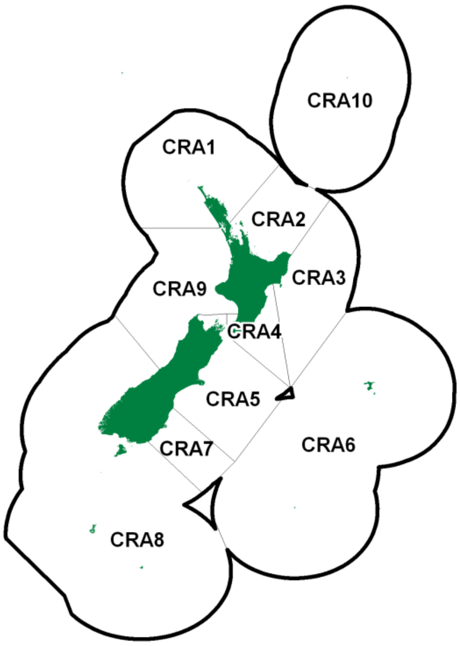
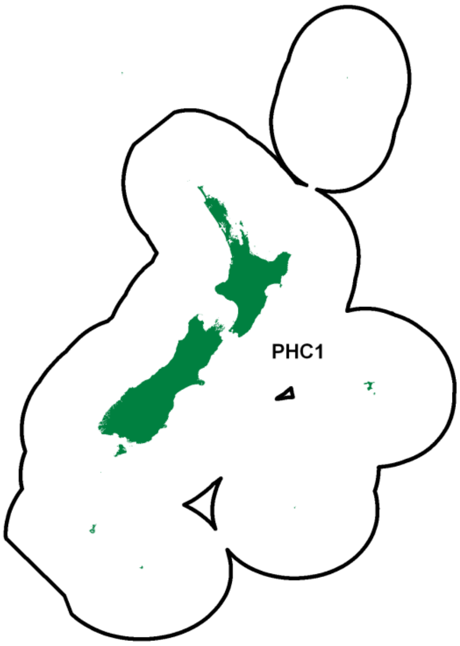
ROCK LOBSTER (CRA and PHC)

(*Jasus edwardsii*, *Sagmariasus verreauxi*)
Crayfish, Koura papatea, Pawharu





1. FISHERY SUMMARY

Two species of rock lobsters are taken in New Zealand coastal waters. The red rock lobster (*Jasus edwardsii*) supports nearly all the landings and is caught all around the North and South Islands, Stewart Island and the Chatham Islands. The packhorse rock lobster (*Sagmariasus verreauxi*) is taken mainly in the north of the North Island, including the Bay of Plenty. Packhorse lobsters (PHC) grow to a much larger size than red rock lobsters (CRA) and have different shell colouration and shape.

The rock lobster fisheries were brought into the Quota Management System (QMS) on 1 April 1990, when Total Allowable Commercial Catches (TACCs) were set for each Quota Management Area (QMA) shown above. Before this, rock lobster fishing was managed by input controls, including limited entry, minimum legal size (MLS) regulations, a prohibition on the taking of berried females and soft-shelled lobsters, and some local area closures. Most of these input controls have been retained, but the limited entry provisions were removed and allocation of individual transferable quota (ITQ) was made to the previous licence holders based on catch history.

Historically, three rock lobster stocks were recognised for stock assessment purposes:

- NSI – the North and South Island (including Stewart Island) red rock lobster stock
- CHI – the Chatham Islands red rock lobster stock
- PHC – the New Zealand packhorse rock lobster stock

In 1994, the Rock Lobster Fishery Assessment Working Group (RLFAWG) agreed to divide the historical NSI stock into three substocks based on groupings of the existing QMAs (without assigning CRA 9):

- NSN – the northern stocks CRA 1 and 2
- NSC – the central stocks CRA 3, 4 and 5
- NSS – the southern stocks CRA 7 and 8

Since 2001, assessments have been carried out at the QMA level. Exploratory assessments at the statistical area level began in 2016. The fishing year runs from 1 April to 31 March.

For seven of the nine rock lobster QMAs, management involves the operation of management procedures (MPs), which include a ‘harvest control rule’ to convert observed abundance (standardised CPUE) into a TACC for the following year. These rules have been evaluated through extensive computer simulation and found to meet the requirements of the Fisheries Act. All QMAs use MPs except CRA 6 and CRA 9 (see Section 4 for a detailed discussion of each rule). CRA 6 has never had a formal stock assessment. The TACC for CRA 10 is nominal because it is not fished commercially. The TACC for PHC 1 increased from 30 t in 1990 to its current value of 40.3 t at the beginning of the 1992–93 fishing year, following quota appeals.

Summary of management actions by QMA since 1990 for rock lobster:

QMA	Type of management	Frequency of review	Year first MP implemented	Year of TACC/TAC changes since 1990
CRA 1 (Northland)	MP	5 years	2015	1991, 1992, 1993, 1996, 1999, 2015
CRA 2 (Bay of Plenty)	MP	5 years	2014[5]	1991, 1992, 1993, 1997, 2014
CRA 3 (Gisborne)	MP	5 years	2005	1991, 1992, 1993, 1996, 1997, 1998, 2005, 2009, 2012, 2013, 2014, 2017
CRA 4 (Wairarapa)	MP	5 years	2007[3]	1991, 1992, 1993, 1999, 2009, 2010, 2011 , 2013, 2014, 2016, 2017
CRA 5 (Marlborough/Kaikoura)	MP	5 years	2009[1]	1991, 1992, 1993, 1996, 1999, 2016[4]
CRA 6 (Chatham Islands)	Not assessed	Unspecified	Not applicable	1991, 1993, 1997, 1998
CRA 7 (Otago)	MP	5 years	1996[2]	1991, 1992, 1993, 1996, 1999, 2001, 2004, 2006, 2008, 2009, 2010, 2011, 2012, 2013, 2014, 2015, 2017
CRA 8 (Stewart Island/Fiordland)	MP	5 years	1996[2]	1991, 1992, 1993, 1999, 2001, 2004, 2006, 2008, 2009, 2011
CRA 9 (Westland, Taranaki)	Not assessed	Suspended (2015)	2014	1991, 1992, 1993, 2014
CRA 10 (Kermadec Island)	Not assessed	Unspecified	Not applicable	–
PHC 1 (all NZ)	Not assessed	Unspecified	Not applicable	1991, 1992

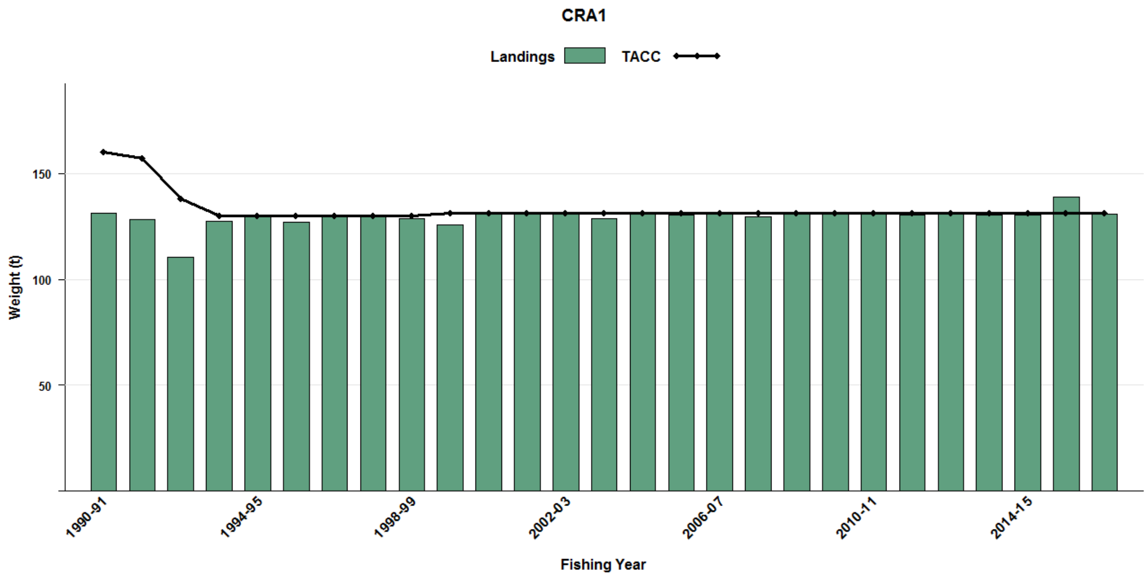
1 The CRA 5 MP was implemented by MPI in 2012 but industry had operated a voluntary rule since 2009.
2 In 2016 a new MP was implemented for CRA 5, and a new MP was implemented for CRA to use CPUE based on the retained lobsters only. For CRA 7, following a new stock assessment and re-evaluation of the MP in 2015, the old MP was retained.
3 Voluntary TACC reductions based on an MP were made by the CRA 4 industry in 2007 and 2008. The MP was implemented by MPI in 2009 and a revised MP was adopted in 2017.
4 Only increase in recreational allowance from 40 t to 87 t.
5 CRA 2 was assessed in 2017 and a new MP may be implemented for use in April 2018.

TACs (Total Allowable Catch: includes TACC plus all non-commercial allowances) were set for the first time in 1997–98 for three CRA QMAs (Table 1). Setting TACs is a requirement under the Fisheries Act 1996 and TACs have been set since 1997–98 whenever adjustments have been made to the TACCs or non-commercial allowances. Figure 1 shows historical commercial landings and TACC values for all CRA stocks.

The MLS in the commercial fishery for red rock lobster is based on tail width (TW), except in the Otago (CRA 7) fishery, where the MLS for commercial fishing is a tail length (TL) of 127 mm for both sexes. The female MLS in all other rock lobster QMAs except Southern (CRA 8) has been 60 mm TW since mid-1992. For CRA 8 the female MLS has been 57 mm TW since 1990. The male MLS has been 54 mm TW for all QMAs since 1988, except in Otago (see above) and Gisborne (CRA 3), where since 1993 it has been 52 mm TW for the June–August period, a measure that changed the commercial CRA 3 fishery to a mainly winter fishery for males from 1993–2002.

A closed season applies in CRA 6 from 01 March to 30 April in each year.

Beginning with the 1993–94 fishing year, the CRA 3 fishery was closed, by regulation, to all users from September to the end of November. The commercial fishery was additionally shut for all of December up to 15 January. The month of May was also closed to commercial fishing. These regulatory closures ended after 2001–02, except for the May closure, which was retained until the end of the 2013–14 fishing year. After the regulatory closures disappeared in 2001–02, the fishing industry instituted a voluntary closure from 15 December to 15 January, beginning with the 2002–03 fishing year. From the 2008–09 fishing year, the voluntary closure was extended to start in September, but only in Statistical Areas 909 and 910. Area 911 (Mahia) opted at that time to remain open in the spring–summer (SS) season, but chose to impose a 54 mm MLS on all male lobster taken.



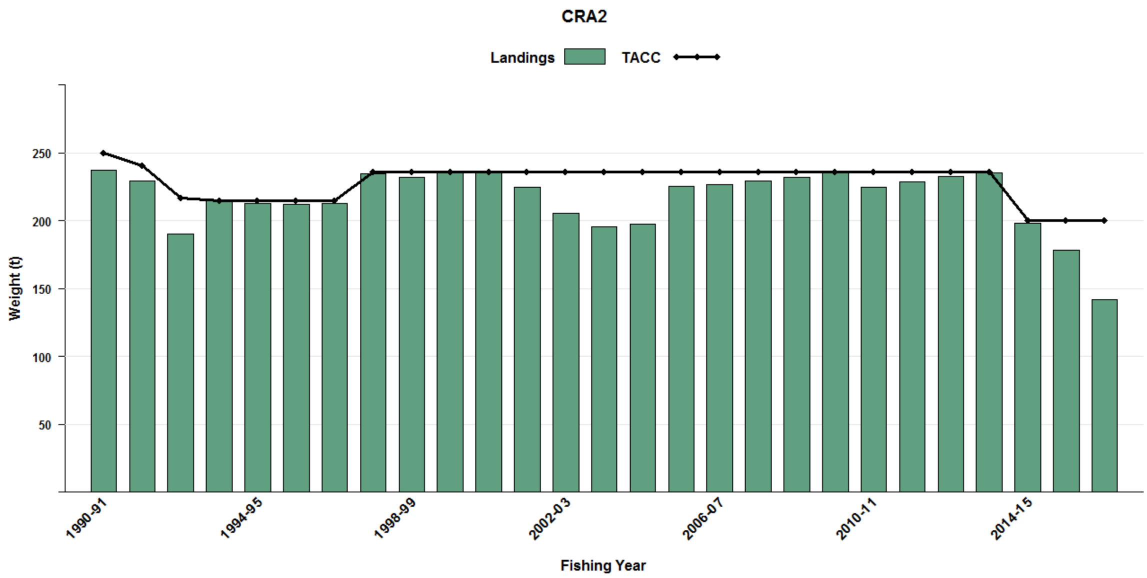
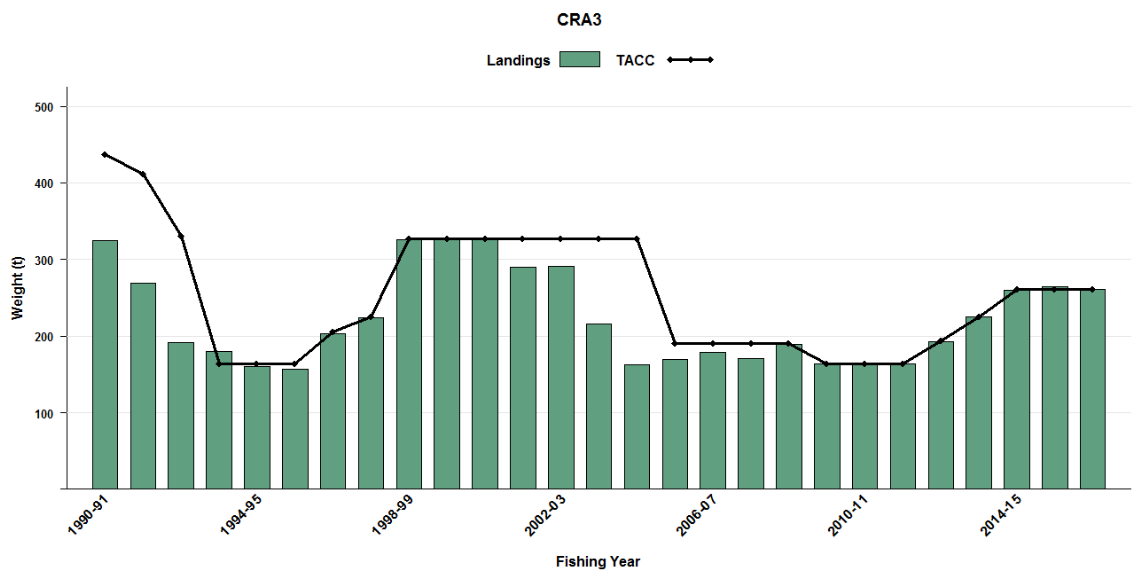
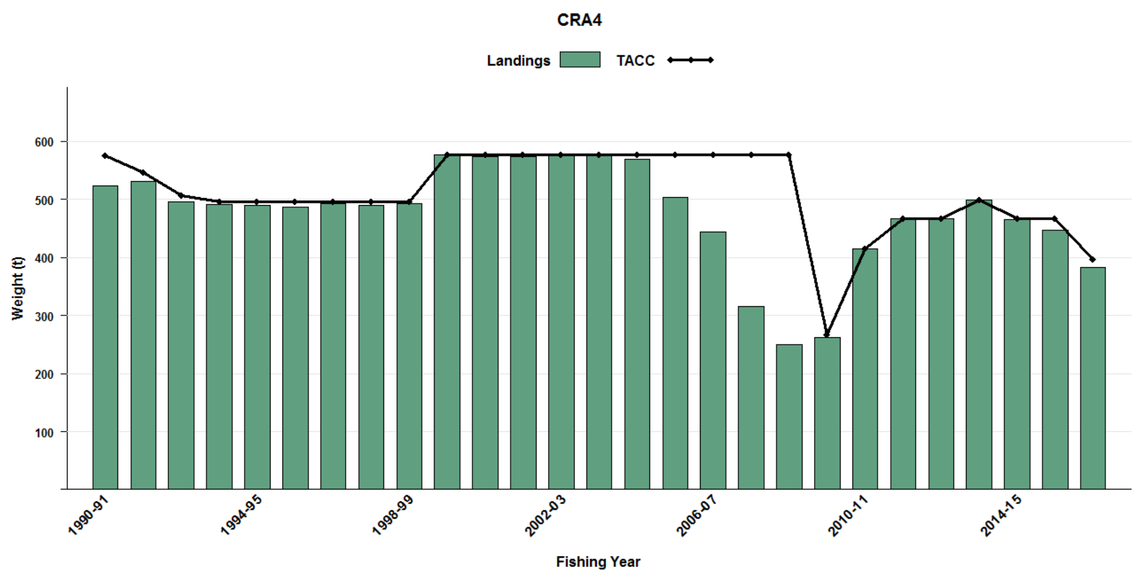


Figure 1: Historical commercial landings and TACC for the nine main CRA stocks and PHC 1. [Continued on next page]





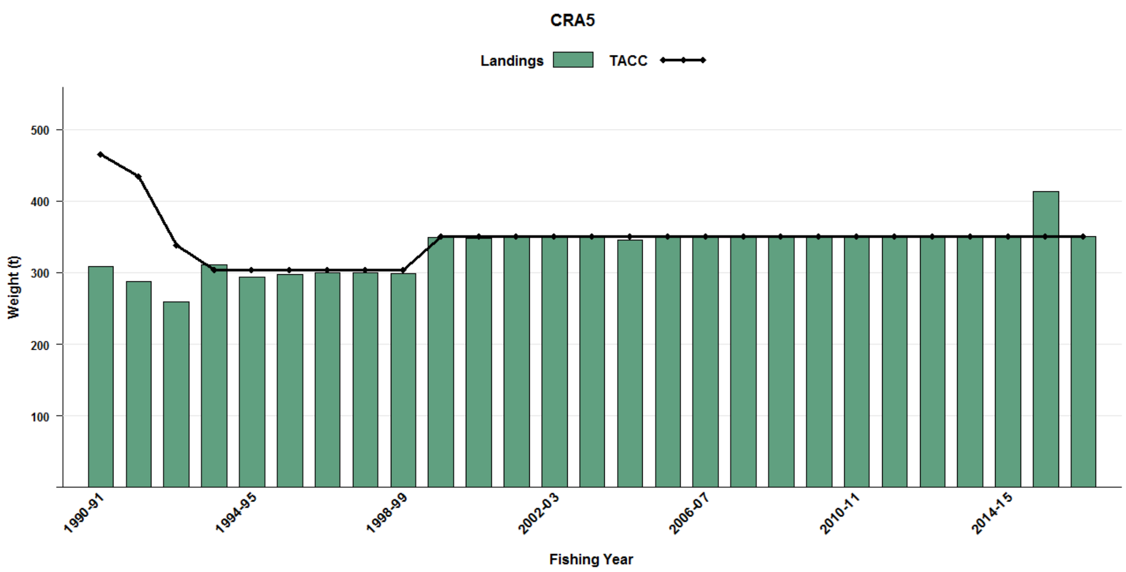
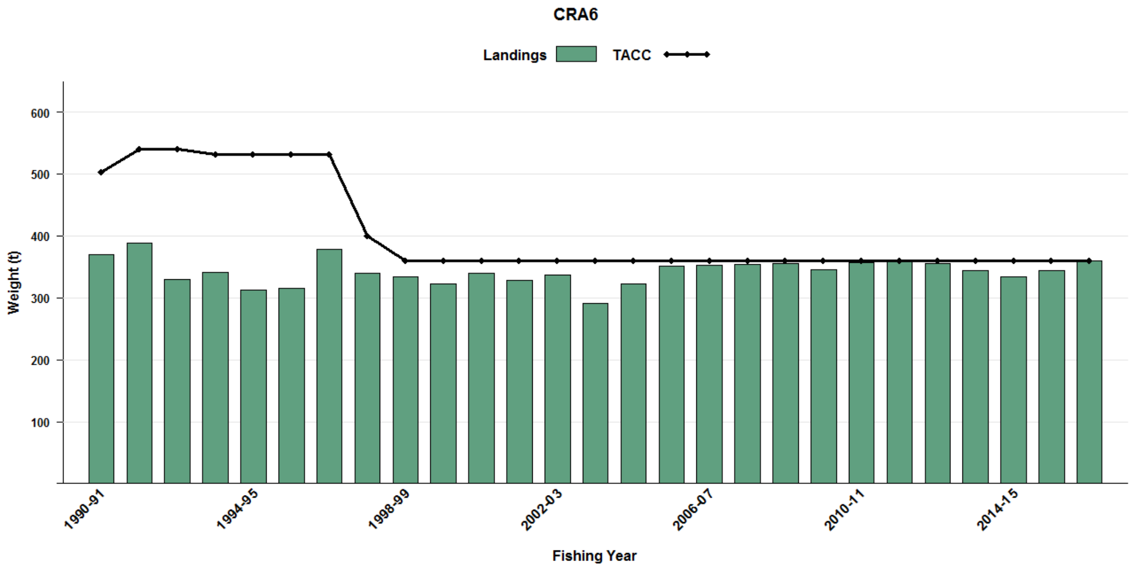
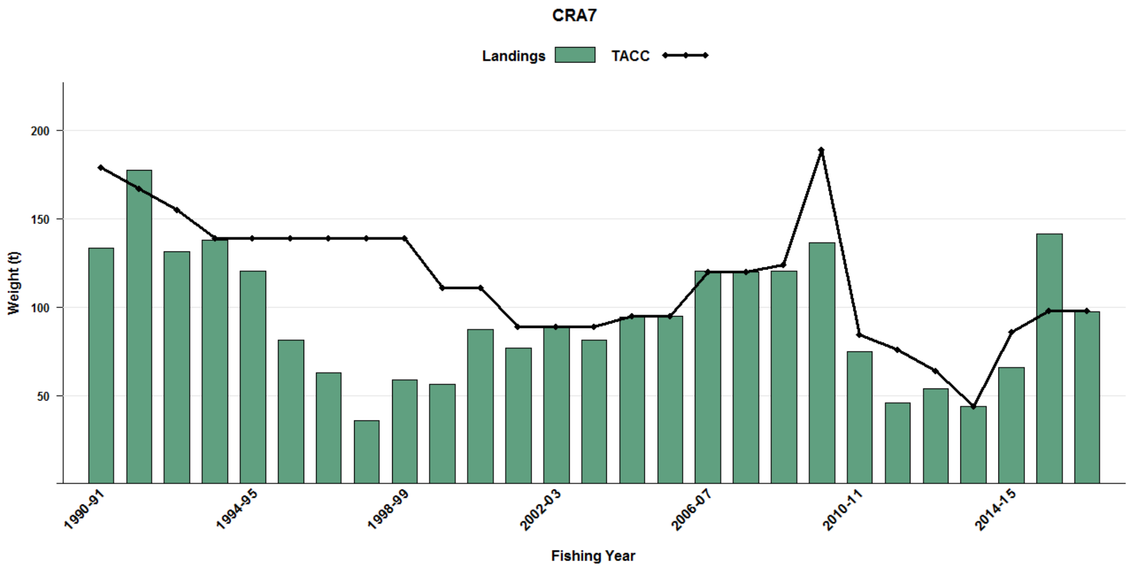


Figure 1 [Continued]: Historical landings and TACC for the nine main CRA stocks and PHC 1.





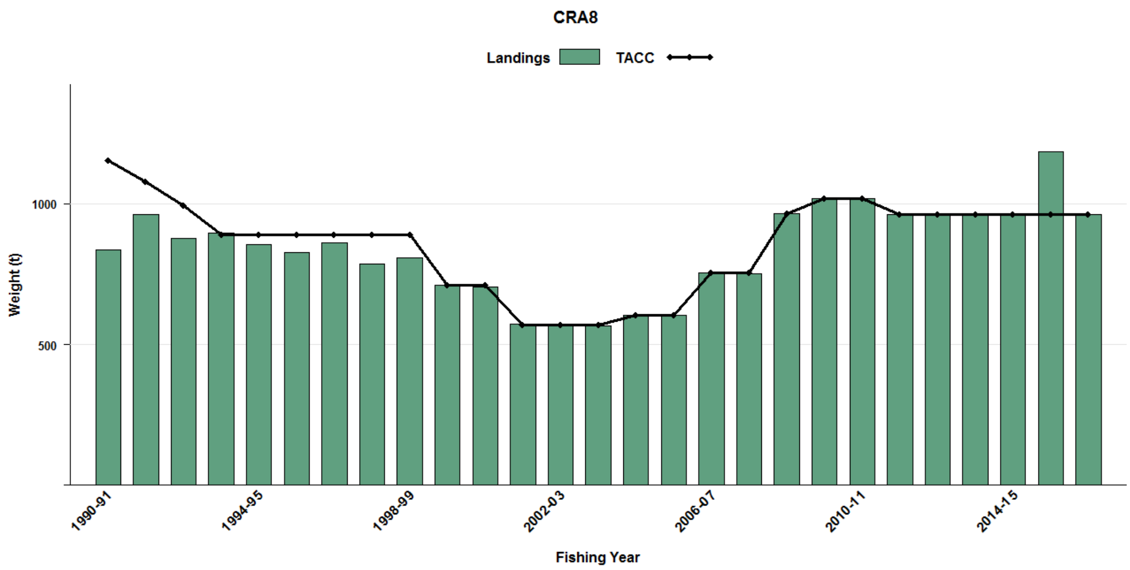
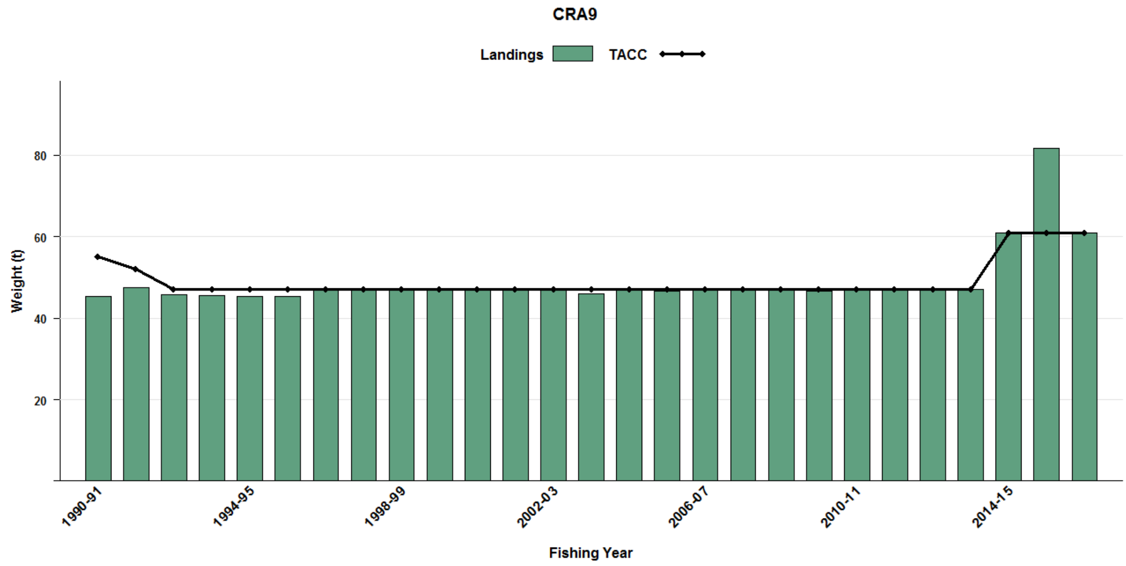


Figure 1 [Continued]: Historical landings and TACC for the nine main CRA stocks and PHC 1.



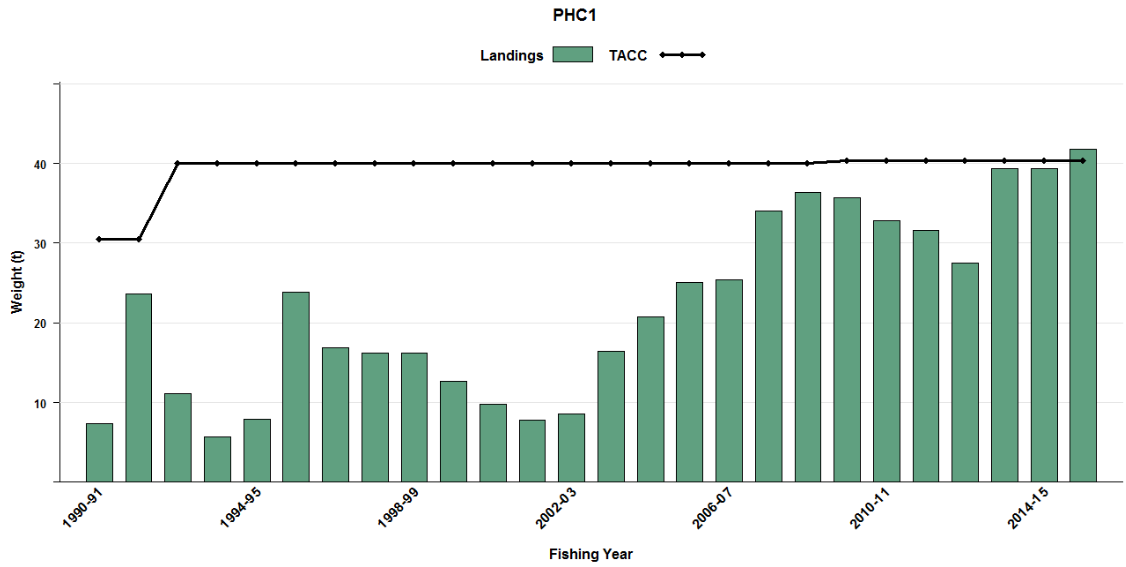


Figure 1 [Continued]: Historical landings and TACC for the nine main CRA stocks and PHC 1.

For recreational fishers, the red rock lobster MLS has been 54 mm TW for males since 1990 and 60 mm TW for females since 1992 in all areas. The commercial and recreational MLS for packhorse rock lobster is 216 mm TL for both sexes.

1.1 Commercial fisheries

Table 1 provides a summary by fishing year of the reported commercial catches, TACCs and TACs by Fishstock (CRA). The Quota Management Reports (QMRs) and their replacement Monthly Harvest Reports (MHRs; since 1 October 2001) provide the most accurate information on landings. Other sources of annual catch estimates include the Licensed Fish Receiver Returns (LFRRs) and the Catch, Effort, and Landing Returns (CELRs).

Table 1: Reported commercial catch (t) from QMRs or MHRs (after 1 October 2001), commercial TACC (t) and total TAC (t) (where this quantity has been set) for *Jasus edwardsii* by rock lobster QMA for each fishing year since the species was included in the QMS on 1 April 1990. –, TAC not set for QMA or catch not available (current fishing year). [Continued on next page]

	CRA 1			CRA 2			CRA 3			CRA 4		
Fishing year	Catch	TACC	TAC	Catch	TACC	TAC	Catch	TACC	TAC	Catch	TACC	TAC
1990–91	131.1	160.1	–	237.6	249.5	–	324.1	437.1	–	523.2	576.3	–
1991–92	128.3	157.0	–	229.7	241.3	–	268.8	411.9	–	530.5	545.7	–
1992–93	110.5	138.0	–	190.3	216.6	–	191.5	330.9	–	495.7	506.7	–
1993–94	127.4	130.5	–	214.9	214.6	–	179.5	163.9	–	492.0	495.7	–
1994–95	130.0	130.5	–	212.8	214.6	–	160.7	163.9	–	490.4	495.7	–
1995–96	126.7	130.5	–	212.5	214.6	–	156.9	163.9	–	487.2	495.7	–
1996–97	129.4	130.5	–	213.2	214.6	–	203.5	204.9	–	493.6	495.7	–
1997–98	129.3	130.5	–	234.4	236.1	452.6	223.4	224.9	379.4	490.4	495.7	–
1998–99	128.7	130.5	–	232.3	236.1	452.6	325.7	327.0	453.0	493.3	495.7	–
1999–00	125.7	131.1	–	235.1	236.1	452.6	326.1	327.0	453.0	576.5	577.0	771.0
2000–01	130.9	131.1	–	235.4	236.1	452.6	328.1	327.0	453.0	573.8	577.0	771.0
2001–02	130.6	131.1	–	225.0	236.1	452.6	289.9	327.0	453.0	574.1	577.0	771.0
2002–03	130.8	131.1	–	205.7	236.1	452.6	291.3	327.0	453.0	575.7	577.0	771.0
2003–04	128.7	131.1	–	196.0	236.1	452.6	215.9	327.0	453.0	575.7	577.0	771.0
2004–05	130.8	131.1	–	197.3	236.1	452.6	162.0	327.0	453.0	569.9	577.0	771.0
2005–06	130.5	131.1	–	225.2	236.1	452.6	170.1	190.0	319.0	504.1	577.0	771.0
2006–07	130.8	131.1	–	226.5	236.1	452.6	178.7	190.0	319.0	444.6	577.0	771.0
2007–08	129.8	131.1	–	229.7	236.1	452.6	172.4	190.0	319.0	315.2	577.0	771.0
2008–09	131.0	131.1	–	232.3	236.1	452.6	189.8	190.0	319.0	249.4	577.0	771.0
2009–10	130.9	131.1	–	235.2	236.1	452.6	164.0	164.0	293.0	262.2	266.0	461.0
2010–11	130.8	131.1	–	224.8	236.1	452.6	163.7	164.0	293.0	414.8	415.6	610.6
2011–12	130.4	131.1	–	229.0	236.1	452.6	163.9	164.0	293.0	466.2	466.9	661.9
2012–13	130.9	131.1	–	234.3	236.1	452.6	193.3	193.3	322.3	466.3	466.9	661.9
2013–14	130.3	131.1	–	235.7	236.1	452.6	225.5	225.5	354.5	499.4	499.7	694.7
2014–15	130.2	131.1	–	198.6	200.0	416.5	260.4	261.0	390.0	465.5	467.0	662.0
2015–16	129.4	131.1	273.1	174.7	200.0	416.5	260.8	261.0	390.0	438.1	467.0	662.0
2016–17	130.6	131.1	273.1	142.3	200.0	416.5	260.9	261.0	390.0	382.8	397.0	592.0
2017–18	–	131.1	273.1	–	200.0	416.5	–	237.9	366.9	–	289.0	484.0

	CRA 5			CRA 6			CRA 7			CRA 8		
Fishing year	Catch	TACC	TAC	Catch	TACC	TAC	Catch	TACC	TAC	Catch	TACC	TAC
1990–91	308.6	465.2	–	369.7	503.0	–	133.4	179.4	–	834.5	1 152.4	–
1991–92	287.4	433.7	–	388.3	539.6	–	177.7	166.8	–	962.7	1 077.0	–
1992–93	258.8	337.7	–	329.4	539.6	–	131.6	154.5	–	876.5	993.7	–
1993–94	311.0	303.7	–	341.8	530.6	–	138.1	138.9	–	896.1	888.1	–
1994–95	293.9	303.7	–	312.5	530.6	–	120.3	138.9	–	855.6	888.1	–
1995–96	297.6	303.7	–	315.3	530.6	–	81.3	138.9	–	825.6	888.1	–
1996–97	300.3	303.2	–	378.3	530.6	–	62.9	138.7	–	862.4	888.1	–
1997–98	299.6	303.2	–	338.7	400.0	480.0	36.0	138.7	–	785.6	888.1	–
1998–99	298.2	303.2	–	334.2	360.0	370.0	58.6	138.7	–	808.1	888.1	–
1999–00	349.5	350.0	467.0	322.4	360.0	370.0	56.5	111.0	131.0	709.8	711.0	798.0
2000–01	347.4	350.0	467.0	342.7	360.0	370.0	87.2	111.0	131.0	703.4	711.0	798.0
2001–02	349.1	350.0	467.0	328.7	360.0	370.0	76.9	89.0	109.0	572.1	568.0	655.0
2002–03	348.7	350.0	467.0	336.3	360.0	370.0	88.6	89.0	109.0	567.1	568.0	655.0
2003–04	349.9	350.0	467.0	290.4	360.0	370.0	81.4	89.0	109.0	567.6	568.0	655.0
2004–05	345.1	350.0	467.0	323.0	360.0	370.0	94.2	94.9	114.9	603.0	603.4	690.4
2005–06	349.5	350.0	467.0	351.7	360.0	370.0	95.0	94.9	114.9	603.2	603.4	690.4
2006–07	349.8	350.0	467.0	352.1	360.0	370.0	120.2	120.2	140.2	754.9	755.2	842.2
2007–08	349.8	350.0	467.0	356.0	360.0	370.0	120.1	120.2	140.2	752.4	755.2	842.2
2008–09	349.7	350.0	467.0	355.3	360.0	370.0	120.3	123.9	143.9	966.0	966.0	1 053.0
2009–10	349.9	350.0	467.0	345.2	360.0	370.0	136.5	189.0	209.0	1 018.3	1 019.0	1 110.0
2010–11	350.0	350.0	467.0	357.4	360.0	370.0	74.8	84.5	104.5	1 018.3	1 019.0	1 110.0
2011–12	350.0	350.0	467.0	359.7	360.0	370.0	45.7	75.7	95.7	961.2	962.0	1 053.0
2012–13	350.0	350.0	467.0	355.9	360.0	370.0	53.8	63.9	83.9	960.8	962.0	1 053.0
2013–14	350.0	350.0	467.0	343.6	360.0	370.0	44.0	44.0	64.0	964.6	962.0	1 053.0
2014–15	349.2	350.0	467.0	334.5	360.0	370.0	66.0	66.0	86.0	962.0	962.0	1 053.0
2015–16	350.1	350.0	467.0	353.3	360.0	370.0	97.6	97.7	117.7	961.8	962.0	1 053.0
2016–17	350.0	350.0	514.0	359.5	360.0	370.0	97.6	97.7	117.7	962.1	962.0	1 053.0
2017–18	–	350.0	514.0	–	360.0	370.0	–	112.5	132.5	–	962.0	1 053.0

Table 1 [Continued]:

	CRA 9			Total		
Fishing year	Catch	TACC	TAC	Catch[1]	TACC[1]	TAC[1]
1990–91	45.3	54.7	–	2 907.4	3 777.8	–
1991–92	47.5	51.5	–	3 020.9	3 624.5	–
1992–93	45.7	47.1	–	2 629.9	3 264.9	–
1993–94	45.5	47.0	–	2 746.2	2 913.0	–
1994–95	45.2	47.0	–	2 621.5	2 913.0	–
1995–96	45.4	47.0	–	2 548.6	2 913.0	–
1996–97	46.9	47.0	–	2 690.5	2 953.3	–
1997–98	46.7	47.0	–	2 584.2	2 864.1	1 312.0
1998–99	46.9	47.0	–	2 726.0	2 926.2	1 275.6
1999–00	47.0	47.0	–	2 748.5	2 850.2	3 442.6
2000–01	47.0	47.0	–	2 795.9	2 850.2	3 442.6
2001-02	46.8	47.0	–	2 593.0	2 685.2	3 277.6
2002–03	47.0	47.0	–	2 591.1	2 685.2	3 277.6
2003–04	45.9	47.0	–	2 451.5	2 685.2	3 277.6
2004–05	47.0	47.0	–	2 472.3	2 726.4	3 318.8
2005–06	46.6	47.0	–	2 475.8	2 589.4	3 184.8
2006–07	47.0	47.0	–	2 604.6	2 766.6	3 362.0
2007–08	47.0	47.0	–	2 472.5	2 766.6	3 362.0
2008–09	47.0	47.0	–	2 640.7	2 981.0	3 576.5
2009–10	46.6	47.0	–	2 688.8	2 762.2	3 362.6
2010–11	47.0	47.0	–	2 781.7	2 807.3	3 407.7
2011–12	47.0	47.0	–	2 753.0	2 792.8	3 393.2
2012–13	47.0	47.0	–	2 792.2	2 810.3	3 410.7
2013–14	47.1	47.0	–	2 840.1	2 855.4	3 455.8
2014–15	60.8	60.8	115.8	2 827.2	2 857.8	3 560.3
2015–16	60.6	60.8	115.8	2 826.5	2 889.5	3 865.0
2016–17	60.8	60.8	115.8	2 746.5	2 819.5	3 842.0
2017–18	–	60.8	115.8	–	2 703.2	3 725.7

[1]ACE was shelved voluntarily by the CRA 4 Industry: to 340 t in 2007–08 and 250 t in 2008–09

Table 2: Reported standardised CPUE (kg/potlift) for *Jasus edwardsii* by QMA from 1979–80 to 2016–17. Sources of data: from 1979–80 to 1988–89 from the QMS-held FSU data (above the line); from 1989–90 to 2016–17 from the CELR data held by MPI, using the 'F2' algorithm corrected for 'LFX' destination code landings (see text for definition). The CRA 2 series beginning from 1989–90 has been separately estimated using a vessel explanatory variable constrained to vessels with at least five years in the fishery. –, no data. [Continued on next page]

Fishing year	CRA 1	CRA 2	CRA 3	CRA 4	CRA 5	CRA 6	CRA 7	CRA 8	CRA 9
1979–80	0.821	0.519	0.772	0.829	0.600	2.188	0.961	1.960	1.269
1980–81	0.986	0.624	0.856	0.803	0.730	2.019	0.845	1.705	1.378
1981–82	0.925	0.520	0.845	0.861	0.652	2.299	0.719	1.641	1.045
1982–83	1.000	0.433	0.913	0.927	0.719	1.663	0.464	1.404	0.874
1983–84	0.951	0.355	0.835	0.841	0.643	1.633	0.401	1.058	0.900
1984–85	0.882	0.343	0.676	0.763	0.651	1.303	0.537	1.024	0.859
1985–86	0.825	0.397	0.645	0.729	0.534	1.374	0.716	1.212	0.762
1986–87	0.806	0.359	0.560	0.775	0.470	1.504	0.819	1.077	0.883
1987–88	0.752	0.313	0.398	0.677	0.393	1.324	0.691	1.132	0.897
1988–89	0.661	0.341	0.410	0.570	0.343	1.271	0.406	0.848	0.893
1989–90	0.690	0.649	0.445	0.562	0.351	1.128	0.327	0.832	–
1990–91	0.600	0.553	0.423	0.517	0.353	1.179	0.422	0.808	0.835
1991–92	0.682	0.498	0.284	0.520	0.295	1.230	0.975	0.793	0.874
1992–93	0.601	0.445	0.240	0.499	0.286	1.128	0.392	0.673	0.948
1993–94	0.665	0.506	0.495	0.546	0.328	1.033	0.619	0.896	1.187
1994–95	0.852	0.614	0.963	0.696	0.356	1.008	0.455	0.798	0.952
1995–96	1.173	0.828	1.533	0.918	0.399	1.050	0.290	0.861	1.373
1996–97	1.004	1.006	1.920	1.234	0.520	1.084	0.245	0.806	1.163
1997–98	0.977	1.119	2.432	1.437	0.725	1.039	0.177	0.688	1.082
1998–99	1.064	1.148	2.054	1.637	0.857	1.276	0.256	0.703	1.432
1999–00	0.896	0.870	1.926	1.476	0.936	1.284	0.224	0.752	0.969
2000–01	1.155	0.732	1.338	1.382	1.198	1.220	0.341	0.914	1.210
2001–02	1.192	0.516	1.019	1.183	1.394	1.200	0.498	0.989	1.151
2002–03	1.122	0.388	0.674	1.217	1.571	1.307	0.602	1.154	1.500
2003–04	1.055	0.388	0.554	1.252	1.751	1.260	0.595	1.721	1.744
2004–05	1.335	0.461	0.444	0.954	1.348	1.443	0.881	1.890	2.161
2005–06	1.362	0.429	0.549	0.819	1.362	1.505	1.279	2.307	2.111
2006–07	1.709	0.508	0.555	0.675	1.400	1.756	1.755	2.797	2.187
2007–08	1.776	0.483	0.576	0.589	1.441	1.548	1.553	3.059	1.780
2008–09	1.720	0.455	0.660	0.744	1.661	1.687	1.786	4.108	1.330
2009–10	1.722	0.416	0.869	1.040	2.097	1.478	1.084	3.941	1.592
2010–11	1.521	0.370	1.186	1.037	2.041	1.554	0.803	3.231	2.326
2011–12	1.504	0.342	1.718	1.257	1.899	1.533	0.687	3.182	1.999

Table 2 [Continued]:

Fishing year	CRA 1	CRA 2	CRA 3	CRA 4	CRA 5	CRA 6	CRA 7	CRA 8	CRA 9
2012–13	1.701	0.359	2.392	1.409	1.769	1.542	0.680	3.316	2.979
2013–14	1.482	0.326	2.235	1.199	1.639	1.498	2.059	3.422	2.223
2014–15	1.343	0.294	2.047	1.049	1.793	1.406	2.094	3.253	2.332
2015–16	1.346	0.242	1.781	0.754	1.565	1.459	2.059	3.449	1.984
2016–17	1.191	0.253	1.777	0.653	1.735	1.875	2.782	3.858	1.965

1.1.1 Problems with rock lobster commercial catch and effort data

There are two types of data on the Catch Effort Landing Return (CELR) form: the top part of each form contains the fishing effort and an estimated catch associated with that effort. The bottom part of the form contains the landed catch and other destination codes, which may span several records of effort. Estimated catches from the top part of the CELR form often show large differences from the catch totals on the bottom part of the form, particularly in CRA 5 and CRA 8 (Vignaux & Kendrick 1998, Bentley et al. 2005). Substantial discrepancies were identified in 1997 between the estimated and weighed catches in CRA 5 (Vignaux & Kendrick 1998) and were attributed to fishers including all rock lobster catch in the estimated total, including those returned to the sea by regulation. This led to an overestimate of CPUE, but this problem appeared to be confined to CRA 5, and was remedied by providing additional instruction to fishers on how to properly complete the forms.

After 1998, all CELR catch data used in stock assessments have been modified to reflect the landed catch (bottom of form) rather than the estimated catch (top of form). This resulted in changes to the CPUE values compared to those reported before 1998.

In 2003, it was concluded that the method used to correct estimated to landed catch (‘Method C1’, Bentley et al. 2005) was biased because it dropped trips with no reported landings, leading to estimates of CPUE that were too high. In some areas, this bias was getting worse because of an increasing trend of passing catches through holding pots to maximise the value of the catch. The catch/effort data system operated by MPI does not maintain the link between catch derived from the effort expended on a trip with the landings recorded from the trip. Therefore, catches from previous trips, held in holding pots, can be combined with landings from the active trip.

Beginning in 2003, the catch and effort data used in these analyses were calculated using a revised procedure described as ‘Method B4’ in Bentley et al. (2005). This procedure sums all landings and effort for a vessel within a calendar month and allocates the landings to statistical areas based on the reported area distribution of the estimated catches. The method assumes that landings from holding pots tend to balance out at the level of a month. In the instances where there are vessel/month combinations with no landings, the method drops all data for the vessel in the month with zero landings and in the following month, with the intent of excluding uncertain data in preference to incorrectly reallocating landings.

In 2012, the RLFAWG agreed to change from method ‘B4’ to method ‘F2’, a new procedure designed to correct estimated catch data to reflect landings. The new procedure is thought to better represent the estimation/landing process and should be more robust to data errors and other uncertainties. The ‘F2’ method uses annual estimates, by vessel, of the ratio of landed catch divided by estimated catch to correct every estimated catch record in a QMA for the vessel for that year. Vessel-year combinations are removed entirely from the analysis when the ratio is less than 0.8 (overestimates of landed catch) or greater than 1.2 (underestimates of landed catch). Testing of the ‘F2’ method was undertaken to establish that CPUE series based on the new procedure did not differ substantially from previous series. In general, the differences tended to be minor for most QMAs, with the exception of CRA 1 and particularly CRA 9, where there were greater differences (Starr 2014). Additional work completed in June 2013 determined that the problems with the CRA 9 standardised CPUE analysis could be resolved if vessels that had landed less than 1 t in a year were excluded from the analysis (Breen 2014). Consequently, the standardised CPUE analyses reported in Table 2 use the F2 algorithm, scaled to the combined ‘L’, ‘F’ and ‘X’ landings (see following paragraph). This now includes CRA 5, which previously used the ‘B4’ algorithm because of the poor reporting practices used in the 1990s (Vignaux

& Kendrick 1998). CRA 5 was switched to the 'F2' algorithm as part of a 2015 stock assessment, to align it with the other QMAs and because the two algorithms estimate nearly identical CPUE indices before 2005.

The data used to calculate the standardised (Table 2) and arithmetic (Table 4) CPUE estimates have been subjected to error screening (Bentley et al. 2005) and the estimated catches have been scaled using the F2 algorithm to the combined landings made to Licensed Fish Receivers (destination code 'L'), Section 111 landings for personal use (destination code 'F') and legal discards (destination code 'X'). The RLFAWG accepted the use of these additional destination codes because of the increasing practice of discarding legal lobsters with the overall increase in abundance. The estimates of CPUE would be biased if discarded legal fish were not included in the analysis. The reporting of releases using destination code 'X' became mandatory on 1 April 2009, so this correction was not available before that date.

Methods for calculating the standardised and arithmetic CPUE estimates are documented in Starr (2017). The 2017 CRA 2 stock assessment determined that a better fit to the CPUE and length-frequency data could be obtained if an additional parameter describing a multiplicative increasing CPUE 'efficiency' was added to the model. However, the benefit from this additional parameter disappeared when the standardisation model added a vessel explanatory variable. This variable allowed the model to standardise for efficiency changes in the fleet configuration because vessels with lower CPUE coefficients appeared to leave the fishery from the late 1990s, resulting in higher unstandardised CPUE. The CRA 2 CPUE values in Table 2, beginning in 1989–90, have been standardised for this vessel effect, using vessels that had been in the fishery for at least five years. A vessel explanatory factor had not been previously used in the standardisation procedure because vessel coefficients were not consistently coded between the CELR and FSU datasets and vessels were known to primarily fish in single statistical areas, leading to potential confounding of vessel and statistical area effects. The inconsistencies in vessel coefficients were no longer an issue because the 2017 CRA 2 stock assessment estimated separate catchability parameters (q) for the FSU and CELR data, allowing for a CELR dataset standardisation model that included a vessel effect.

1.1.2 Description of fisheries

***Jasus edwardsii*, CRA 1 and CRA 2**

CRA 1 extends from Kaipara Harbour on the west coast to Te Arai Point, south of Whangarei (Figure 2). This QMA includes the Three Kings Islands, designated with a separate statistical area (901). Commercial fishing occurs on both sides of the North Island peninsula, as well as on the Three Kings.

A TAC was set for CRA 1 for the first time in 2015, even though the CRA 1 stakeholders elected to maintain the TACC at its original level (Table 1). Commercial landings have remained at or near the 131 t TACC since the early 1990s (Table 1). In the 2014–15 fishing year, there were 14 vessels operating in CRA 1, a total that has remained nearly unchanged since the mid-2000s (Starr 2016).

CRA 2 extends from Te Arai Point, south of Whangarei, to East Cape at the easternmost end of the Bay of Plenty. This QMA includes the Hauraki Gulf, both sides of the Coromandel, and all of the Bay of Plenty. Commercial fishing is mainly confined to the Bay of Plenty, extending from the eastern side of the Coromandel Peninsula to East Cape. Lobster potting also occurs around Little and Great Barrier Islands. There were 33 vessels operating in CRA 2 in 2015–16, a total that has been relatively constant since the mid-1990s (Starr 2017). This fishery supports processing and export operations primarily in Tauranga, Whitianga and Auckland. The current 416.5 t TAC for the fishery was set in 2014. The TAC comprises 140 t for recreational catch, 16.5 t for customary harvest, and 60 t for illegal removals. The CRA 2 industry voluntarily shelved 25 t of the 200 t TACC in 2015–16 even though the operation of the Rule 4 MP did not require a TACC reduction. The amount of shelving was increased to 49 t in 2016–17, and this amount of shelving has been carried forward into 2017–18.

CPUE levels in CRA 1 and CRA 2 differ: CRA 1 has always had higher catch rates than CRA 2, even in the 1980s when catch rates were generally lower. CPUE in CRA 1 had been near or above 1.5 kg/potlift after 2006–07, but dropped to 1.3 kg/potlift in 2014–15 and 2015–16. CRA 2 CPUE had been below 0.6 kg/potlift from 2001–02, dropping to below 0.4 kg/potlift in 2010–11 and below 0.3 kg/potlift in 2014–15 (Table 2). CRA 2 currently has the lowest CPUE of all nine CRA QMAs.

***Jasus edwardsii*, CRA 3, CRA 4 and CRA 5**

CRA 3 extends from East Cape to below the Mahia peninsula, to the Wairoa River (Figure 2). Commercial fishing occurs throughout this QMA. TACs and TACCs have been set for this QMA six times since the mid-2000s. Twenty-seven vessels caught at least 1 t of rock lobster in 2015–16 and the number of commercial vessels operating in CRA 3 has been below 30 since 2005–06 (Starr 2017). The CRA 3 TACC was lowered to 238 t from 261 t for the 2017–18 fishing year through the operation of the CRA 3 MP (Table 1).

The CRA 4 fishery extends from the Wairoa River on the east coast, southwards along the Hawke's Bay, Wairarapa and Wellington coasts, through Cook Strait and north to the Manawatu River. For 2016–17 the TACC was set at 397 t, lower than that specified by the management procedure. Allowances of 35 t were made for customary fishing; 85 t for recreational and 75 t for illegal removals. The CRA 4 TACC was dropped from 397 t to 289 t for the 2017–18 fishing year through the operation of a new CRA 4 MP resulting from the 2016 stock assessment.

The CRA 5 fishery extends from the western side of the Marlborough Sounds across to Cape Jackson and then southwards to Banks Peninsula. There are three distinct regions of commercial fishing – Picton/Port Underwood, Ward-Kaikoura-Motunau and Banks Peninsula, although a small number of commercial vessels work the area from Nelson through to D'Urville Island. The bulk of the commercial catch is taken from the area bounded by Tory Channel in the north and Motunau in the south.

The TAC is set at 467 t, with a TACC of 250 t and allowances of 40 t for customary catch, 87 t for recreational and 37 t for illegal removals.

CPUE trends have differed among these three QMAs, with CRA 3 CPUE peaking in 1997–98, CRA 4 in 1998–99, and CRA 5 in 2008–09 (Table 2). However, these QMAs all show approximately the same pattern: low CPUEs in the 1980s (below 1 kg/potlift) followed by a strong rise in CPUE beginning in the early 1990s (first in CRA 3, followed closely by CRA 4 and finally by CRA 5 in the late 1990s). CRA 3 and CRA 4 dropped from their respective peaks in the late 1990s to lows in the mid-2000s followed by a rising trend to 2012–13 in both QMAs. CPUEs in both QMAs have dropped in each year since the 2012–13 peak, with CRA 3 dropping 25% and CRA 4 dropping by 46% by 2015–16. CRA 5, unlike CRA 3 and CRA 4, while having dropped from the last peak in 2009–10, has fluctuated near a mean of 1.75 kg/potlift over the past five years.

***Jasus edwardsii*, CRA 6**

The region designated as CRA 6 is geographically very large, being all waters within a 200 nautical mile radius of the Chatham Islands and Bounty Islands, but the area being fished is restricted to a relatively narrow coastal margin adjacent to the Chatham Islands coastline. Mean annual CPUE in the Chatham Island fishery was higher than in the other New Zealand QMAs in the 1980s (Table 2). However, CPUE declined after the mid-1980s to levels similar to those observed in other QMAs (Table 2). CPUE has fluctuated around 1.5 kg/potlift since 2001–02, peaking in 2016–17 at 1.87 kg/potlift, the highest value since the mid-1990s.

***Jasus edwardsii*, CRA 7 and CRA 8**

The CRA 7 fishery extends from the Waitaki River south along the Otago coastline to Long Point. The TACC is set by the operation of a management procedure that was first implemented in 2013. The CRA 7 TAC is currently 132.5 t, with allowances of 10 t for customary catch, 5 t for recreational catch and 5 t for illegal removals and a TACC of 112.5 t. The TACC was raised for the 2016–17 fishing year through the operation of the CRA 7 MP. The CRA 7 commercial fishery runs with an MLS of 127 mm tail length for both males and females. The fishery is open to recreational fishing with MLS 54 mm TW for males and 60 mm TW for females.

The CRA 8 fishery is the largest South Island fishery geographically, extending from Long Point south to Stewart Island and the Snares, the islands and coastline of Foveaux Strait, and then northwards along the Fiordland coastline to Bruce Bay. From 1996 to the present, the TAC has been controlled by management procedures and the TACC has been fully caught from 1998 onwards. The current TAC is 1053 t with a TACC of 962 t and allowances of 30 t for customary, 33 t for recreational and 28 t for illegal catches.

Catch rates were generally lower in CRA 7 compared with those in CRA 8, with CPUE in CRA 7 being stable but low (often below 0.5 kg/potlift) until the early 2000s, while CRA 8 showed a similar pattern, but at a higher level (Table 2). Both QMAs then showed spectacular increases in CPUE, peaking in the late 2000s near 1.8 kg/potlift in CRA 7 and rising to more than 4 kg/potlift in CRA 8. The CRA 8 annual CPUE of greater than 4.0 kg/potlift observed in 2008–09 is the highest of any of the rock lobster QMAs over the 37 years on record (Table 2). CPUE declined by 62% in CRA 7 from 2008–09 to 2012–13 while the decline in CRA 8 was 23% between 2008–09 and 2011–12. CPUE in both these QMAs rose between 2012–13 and 2013–14, although the rise in CRA 8 was small (4%) compared to the 200% increase seen in CRA 7. A further 26% increase in CPUE was seen in CRA 7 in 2016–17 (from 2.1 to 2.8 kg/potlift; Table 2). The CRA 8 2016–17 CPUE index, at 3.8 kg/potlift, represents an 11% increase relative to 2015–16 and the highest CPUE since 2008–09.

Jasus edwardsii, CRA 9

The CRA 9 fishery is geographically large but has the smallest TACC of any region (with the exception of CRA 10, which is not commercially fished). The fishery extends from north of Bruce Bay to the Kaipara Harbour but commercial lobster fishing is constrained to the north-west coast of the South Island and the area between Patea and Kawhia, in particular the Taranaki coastline.

Mean annual CPUE was at or less than 1 kg/potlift from 1981–82 to 1994–95, followed by a strong increase that peaked in 2006–07, with CPUE exceeding 2 kg/potlift between 2004–05 and 2006–07. In recent years the low numbers of vessels fishing, poor reporting and the large size of the area have led to rejection of CRA 9 CPUE as an index of abundance in CRA 9.

Sagmariasus verreauxi, PHC stock

The packhorse rock lobster management area extends to all of New Zealand. QMS reported landings of the PHC stock more than halved between 1998–99 and 2001–02 and were below 30 t/year up to 2007–08 (Table 3). Landings have since exceeded 30 t/year, except for 2012–13, when 27.5 t were reported. Subsequent landings have been close to the TACC.

Jasus edwardsii CPUE by statistical area

Table 4 shows arithmetic statistical area CPUEs for the most recent six years, for all rock lobster statistical areas reported on CELR forms (Figure 2). The values of CPUE and the trends in the fisheries vary within and between CRA areas.

Table 3: Reported landings and TACC for *Sagmariasus verreauxi* (PHC) from 1990–91 to 2016–17. Data from QMR or MHR (after 1 Oct 2001). [Continued on next page]

Fishing year	Landings (t)	TACC (t)	Fishing year	Landings (t)	TACC (t)
1990–91	7.4	30.5[1]	2004–05	20.8	40.3
1991–92	23.6	30.5	2005–06	25.0	40.3
1992–93	11.1	40.3	2006–07	25.4	40.3
1993–94	5.7	40.3	2007–08	34.0	40.3
1994–95	7.9	40.3	2008–09	36.4	40.3
1995–96	23.8	40.3	2009–10	35.7	40.3
1996–97	16.9	40.3	2010–11	32.8	40.3
1997–98	16.2	40.3	2011–12	31.6	40.3
1998–99	16.2	40.3	2012–13	27.5	40.3
1999–00	12.6	40.3	2013–14	39.4	40.3
2000–01	9.8	40.3	2014–15	38.5	40.3

Table 3 [Continued]:

Fishing year	Landings (t)	TACC (t)	Fishing year	Landings (t)	TACC (t)
2001–02	3.4	40.3	2015–16	39.9	40.3
2002–03	8.6	40.3	2016–17	40.0	40.3
2003–04	16.4	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.

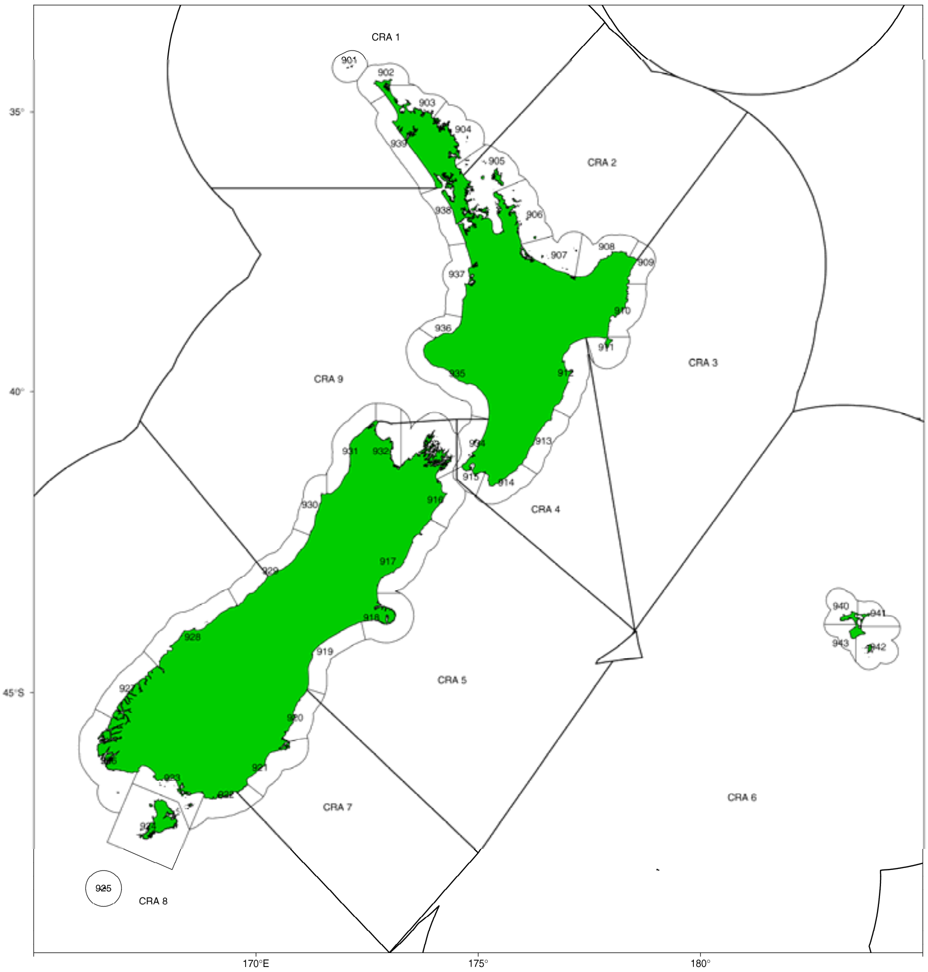


Figure 2: Rock lobster statistical areas as reported on CELR forms.

Table 4: Arithmetic CPUE (kg/potlift) for each statistical area for the six most recent fishing years. Data are from the MPI CELR database and estimated catches have been corrected by the amount of fish landed from the bottom part of the form using the 'F2' algorithm scaled to the 'LFX' destination code (see Section 1 in text for explanation). –, value withheld because fewer than three vessels were fishing or there was no fishing. [Continued on next page]

CRA	Stat Area	11/12	12/13	13/14	14/15	15/16	16/17	CRA	Stat Area	11/12	12/13	13/14	14/15	15/16	16/17
1	901	2.77	2.58	2.06	2.19	2.12	2.41	6	940	1.32	1.69	1.53	1.53	1.55	1.94
1	902	1.39	1.45	1.85	–	–	–	6	941	1.32	1.56	1.53	1.41	1.50	1.83
1	903	0.76	1.38	1.17	2.48	0.99	–	6	942	1.61	1.49	1.42	1.32	1.34	1.73
1	904	0.46	0.54	0.49	0.40	–	0.35	6	943	1.49	1.81	1.75	1.43	1.46	1.79
1	939	1.89	2.98	2.62	2.13	–	–	7	920	0.69	0.64	1.85	1.65	1.65	2.13
2	905	0.37	0.43	0.39	0.40	0.30	0.31	7	921	0.62	0.65	1.51	2.17	2.28	3.16
2	906	0.35	0.37	0.31	0.28	0.25	0.28	8	922	–	–	–	–	–	–
2	907	0.57	0.51	0.51	0.45	0.33	0.33	8	923	–	–	2.39	4.42	3.49	2.91
2	908	0.47	0.44	0.40	0.36	0.33	0.31	8	924	4.05	3.90	3.36	3.84	4.30	4.64
3	909	1.52	–	2.43	1.74	1.78	1.62	8	925	–	2.69	–	–	3.46	–
3	910	1.43	1.82	1.66	1.45	1.21	1.16	8	926	3.33	3.20	3.93	3.53	3.45	4.26
3	911	1.69	2.34	2.14	2.20	1.88	2.02	8	927	2.47	3.68	3.58	3.52	3.35	3.88
4	912	0.87	0.88	0.66	0.59	0.69	0.74	8	928	4.57	5.01	4.61	4.47	3.01	3.40
4	913	1.58	1.93	1.47	0.94	0.88	0.80	9	929	–	–	–	–	–	–

Table 4 [Continued]:

CRA	Stat Area	11/12	12/13	13/14	14/15	15/16	16/17	CRA	Stat Area	11/12	12/13	13/14	14/15	15/16	16/17
4	914	1.32	1.58	1.53	1.09	0.65	0.57	9	930	–	–	–	–	–	–
4	915	1.31	1.37	1.54	1.78	0.96	0.65	9	931	–	–	–	–	–	–
4	934	2.04	–	–	–	–	–	9	935	–	–	–	–	–	–
5	916	2.15	1.37	1.50	1.71	0.98	1.13	9	936	–	–	–	–	–	–
5	917	2.75	2.64	2.11	2.38	2.79	2.79	9	937	–	–	–	–	–	–
5	918	–	–	–	–	7.13	–	9	938	–	–	–	–	–	–
5	919	–	–	–	–	–	–								
5	932	–	–	–	–	–	–								
5	933	0.72	0.73	0.62	0.60	0.54	0.49								

1.2 Recreational fisheries

Recreational fisheries harvest can be estimated using either: 'onsite' or access point methods where participants are surveyed on the water or at boat ramps; or 'offsite' methods where post-event interviews and/or diaries are used to collect data. The first estimates in New Zealand were made using offsite telephone-diary surveys (Table 5). These surveys provided estimates of the numbers of lobsters harvested, which were converted to harvest by weight using mean rock lobster weights from boat ramps interviews or from commercial sampling data.

Table 5: Available estimates of recreational rock lobster harvest (in numbers and in t by QMA, where available) from regional telephone and diary surveys in 1992, 1993, 1994, 1996, 2000 and 2001 (Bradford 1997, 1998, Teirney et al. 1997, Boyd & Reilly 2004). 2011–12 data from National Panel Survey (Wynne-Jones et al. 2014, Heinemann et al. 2015), Kaikoura/Motunau 2012–13: Kendrick & Handley (2014); Northland 2013–14: Holdsworth 2014; western Bay of Plenty 2010 & 2011: Holdsworth (2016); –, not available. [Continued on next page]

QMA/FMA	Number	CV	Nominal point estimate
Recreational Harvest South Region 1 Sept 1991 to 30 Nov 1992			
CRA 5	65 000	31	40
CRA 7	8 000	29	7
CRA 8	29 000	28	21
Recreational Harvest Central Region 1992–93			
CRA 1	1 000	–	–
CRA 2	4 000	–	–
CRA 3	8 000	–	–
CRA 4	65 000	21	40
CRA 5	11 000	32	10
CRA 8	1 000	–	
Northern Region Survey 1993–94			
CRA 1	56 000	29	38
CRA 2	133 000	29	82
CRA 9	6 000	–	–
1996 Survey			
CRA 1	74 000	18	51
CRA 2	223 000	10	138
CRA 3	27 000	–	–
CRA 4	118 000	14	73
CRA 5	41 000	16	35
CRA 7	3 000	–	–
CRA 8	22 000	20	16
CRA 9	26 000	–	–
2000 Survey			
CRA 1	107 000	59	102.3
CRA 2	324 000	26	235.9
CRA 3	270 000	40	212.4
CRA 4	371 000	24	310.9
CRA 5	151 000	34	122.3
CRA 7	1 000	63	1.3
CRA 8	13 000	33	23.3
CRA 9	65 000	64	52.8
2001 Roll Over Survey			
CRA 1	161 000	68	153.5
CRA 2	331 000	27	241.4
CRA 3	215 000	48	168.7
CRA 4	289 000	22	350.5
CRA 5	226 000	22	182.4
CRA 7	10 000	67	9.4
CRA 8	29 000	43	50.9
CRA 9	34 000	68	27.7

Table 5 [Continued]:

QMA/FMA	Number	CV	Nominal point estimate
National panel survey: Oct 2011–Sep 2012			
CRA 1	29 720	30	23.98
CRA 2	58 413	24	40.86
CRA 3	13 912	33	8.07
CRA 4	53 813	17	44.17
CRA 5	47 493	23	43.47
CRA 7	357	103	0.23
CRA 8	5 149	60	6.93
CRA 9	15 530	30	17.96
Kaikoura & Motunau 2012–13:			
CRA 5	96 800	10	54.56
Northland: 1 Apr 2013–31 Mar 2014			
CRA 1	50 400	17	37.3
Western Bay of Plenty: CRA 2			
Nov 2010–Sep 2011	55 260	47	40.9
Oct 2011–Sep 2012	31 602	47	22.1

The harvest estimates provided by these telephone-diary surveys are not considered reliable by the Marine Amateur Fishing Working Group (MAFWG) because the method was prone to 'soft refusal' bias during recruitment and overstated catches during reporting (Wright et al. 2004). The recreational harvest estimates provided by the 2000 and 2001 telephone-diary surveys were thought by the MAFWG to be implausibly high for many species.

Onsite methods for estimating recreational harvest were developed to provide direct estimates of recreational harvest in fisheries suitable for this form of survey (e.g., Hartill et al. 2007). Onsite methods tend to be costly and difficult to mount, especially for 'diffuse' or specialised fisheries like rock lobster. Hartill (2008), in his review of options for monitoring rock lobster recreational catch, concluded that the best method to monitor these fisheries was an access point boat ramp survey, combined with telephone-diary or aerial overflight survey for scaling the estimates.

Problems with the earlier surveys led to the development of a rigorously designed National Panel Survey (NPS) for the 2011–12 fishing year (Heinemann et al. 2015). The NPS used face-to-face interviews of a random sample of 30 390 households to recruit a panel of 7013 fishers and non-fishers for a full year. The panel members were contacted regularly about their fishing activities and catch information was collected in standardised computer-assisted telephone interviews. Onsite surveys focused on rock lobster were completed for the western Bay of Plenty (CRA 2) in 2010 and 2011 (Holdsworth 2016), for CRA 5 (Kaikoura–Motunau only) from January–April 2013 (2012–13, Kendrick & Handley 2014) and for CRA 1 in 2013–14, extending from Rangiputa to Mangawhai Heads and covering most of Statistical Areas 903 and 904 (Table 5: Holdsworth 2014). This latter area is estimated to represent 70% of the total CRA 1 recreational catch.

Table 6: Historical recreational and customary catch estimates used in recent CRA assessments. All ramped catches started from 20% of the 1979 estimate of recreational catch. [Continued on next page]

QMA	First year	Last year	'Base' recreational catch (t)	Notes: Recreational Catch[7]	Customary catch (t)	Notes: Customary catch
CRA 1[1]	1945	2013	1994=40.152 1996=53.058 2011=24.089 2013=40.747	Ramped from 1945; after 1979, the mean unstandardised Area 903/904 SS CPUE in each year was scaled by the mean of the ratios of the 'base recreational catches' relative to the unstandardised SS CPUE	10	Constant from 1945
CRA 2[2]	1979	2016	1994=95.42 1996=149.9 2010=40.90 2011=40.86 2011=22.10	A scaling parameter between the 5 survey estimates and the CRA 2 SS commercial CPUE was estimated assuming a lognormal likelihood. A CV of 0.24 was assigned to the 2011 NPS estimate and the other 4 estimates used a CV=1.5 x 0.24 = 0.36	5	Constant from 1979

Table 6 [Continued]:

QMA	First year	Last year	'Base' recreational catch (t)	Notes: Recreational Catch7	Customary catch (t)	Notes: Customary catch
CRA 3[3]	1945	2013	1992=4.272 1996=14.418 2011=8.069	Ramped from 1945; after 1979, the CRA 3 SS CPUE in each year was scaled by the mean of the ratios of the 'base recreational catches' relative to the standardised SS CPUE	20	Constant from 1945
CRA 4[4]	1945	2015	45.833 (=mean of 1994/1996/2011 estimates)	Ramped from 1945; after 1979, the CRA 4 SS CPUE in each year was scaled by the ratio of the mean 'base recreational catches' relative to the mean of the standardised SS CPUE in 1994/1996/2011.	20	Constant from 1945
CRA 5[5]	1945	2014	1994=37.72 1996=23.08 2011=80	Fitted exponential function (Eq. 1) to the 1994, 1996 and assumed (80 t) 2011 recreational survey estimates to the unstandardised Area 917 CPUE estimates.	10	Constant from 1945
CRA 6	–	–	–	Not used	–	–
CRA 7[5]	1963	2014	5 t/year	Constant values were used from 1979 to 2014 and ramped values beginning at 1 t (=20% of constant value) in 1945 and ending at 5 t in 1979 were used from 1945 to 1979.	1	Constant from 1963
CRA 8[5]	1963	2014	20 t/year	Constant values were used from 1979 to 2014 and ramped values beginning at 1 t (=20% of constant value) in 1945 and ending at 5 t in 1979 were used from 1945 to 1979.	6 (15)	Constant at 6 t from 1963–2012 and then increased proportionately to 15 t in 2014
CRA 9[6]	1945	2012	2011=17.96	Ramped from 1945; after 1979, the CRA 9 SS CPUE in each year was scaled by the ratio of the 'base recreational catch' relative to the 2011 standardised SS CPUE.	1	Constant from 1963

[1] Starr et al. (2015a).

[2] See Section 1.2.1.

[3] Starr et al. (2015b).

[4] Starr et al. (2017).

[5] Starr et al. (2016).

[6] Breen (2014).

[7] The maximum of catches declared under the 1996 Fisheries Act Section 111 (Table 9) has been added to the recreational trajectory for every QMA in this table (except CRA 6).

Table 6 presents the recreational catch estimates used in all recent rock lobster stock assessments. The RLFAWG has little confidence in the early estimates of recreational catch, but believes that the NPS and recent onsite surveys have provided more reliable estimates of recreational catch in those QMAs with a relatively large number of participants.

1.2.1 CRA 2 recreational catch

Seven annual recreational survey catch estimates are available for CRA 2 (Table 7). Estimates from the two Kingett Mitchell National Surveys (Boyd et al. 2004, Boyd & Reilly 2004) were not accepted by the RLFAWG for the 2013 CRA 2 stock assessment (Starr et al. 2014a) because these survey estimates were considered implausibly high for CRA 2. The earlier 1994 and 1996 surveys, conducted by researchers at the University of Otago, were considered biased in a review of the available recreational surveys (unpublished minutes, Recreational Technical Working Group [NIWA, Auckland, 10–11 June 2004]) because the interview questions possibly underestimated fisher participation rates by allowing for an easy exit from the interview ('soft refusal' bias). These two early surveys continue to be used by the RLFAWG in spite of this advice because the estimates are plausible and no other recreational information is available for these years. Both the Boyd and the Otago surveys were potentially biased high because recreational logbook participants were not closely supervised and may not have accurately recorded their fishing activity. The much higher harvest estimates in the Boyd surveys were a result of higher claimed participation in saltwater fishing over the previous 12 months in the initial screening survey.

A large-scale population-based diary/interview survey was conducted under contract for MPI from 1 October 2011–30 September 2012 (National Panel Survey or NPS), with the intention of estimating FMA- and QMA-specific annual catches for all major finfish and non-finfish species (Heinemann et al. 2015). This survey was based on a design that resembled the New Zealand national census, making use of the census population strata ('mesh blocks' of dwellings as the basis for identifying recreational fishers. A door-to-door survey of households in randomly selected strata was used to select participants who would report their catch for an entire year. A structured and carefully designed Computer Assisted Telephone Interview (CATI) method was used to record harvest in detail from those who had fished. The survey results were thought to be plausible for CRA 2, with 69 fishers providing 168 interviews over the survey period (see Table 60 in Wynne-Jones et al. 2014) with a relatively low CV (= 0.24;
Table 8). This survey made estimates of the distribution of fishing platforms used to take lobsters in CRA 2, with motor boats accounting for about three quarters of the effort and only 13% coming from land (
Table 8). The primary capture method used to take rock lobster in CRA 2 is diving (83%) followed by potting (16%) (
Table 8).

Table 7: Information used to estimate recreational catch for CRA 2. The Holdsworth (2016) survey estimates are described in Starr (2017).

Survey	Numbers	Mean weight (kg)	Catch weight (t)	Assumed CV
1994 (Otago: Bradford 1997)	142,000	0.672[1]	95.42	1.5x0.24
1996 (Otago: Bradford 1998)	223,000	0.672[1]	149.86	1.5x0.24
2000 (Boyd & Reilly 2004)	324,000	–	235.9[2]	not used
2001 (Boyd et al. 2004)	331,000	–	241.4[2]	not used
2010 (Holdsworth 2016)	55,260	0.741	40.9	1.5x0.24
2011 (Holdsworth 2016)	31,602	0.700	22.1	1.5x0.24
2011 (NPS: Wynne-Jones 2014)	58,413	0.701[3]	40.86	0.24[4]
Section 111 reported landings				
Maximum reported landings (t) (in 2014–15)			2.036	

[1] SS mean weight (kg) calculated from commercial sampling data from 1994 to 1996 assuming recreational minimum legal sizes (Starr et al. 2003).
[2] As reported by Boyd & Reilly (2004) and Boyd et al. (2004).
[3] Hartill & Davey (2015).
[4] Estimate provided in Wynne-Jones et al. (2014).

Table 8: Fishing platform and capture method categories for CRA 2 during 2011–12 estimated by the national NPS recreational survey (Wynne-Jones et al. 2014). The final line shows the 2011–12 CRA 2 total estimates. CV = standard error of the estimate, which does not include error associated with the estimate of mean weight.

Category	Numbers	CV	Catch (t)	CV	Distribution (%)
Platform (Appendix 27.3 in Wynne-Jones et al. 2014)					
Trailer motor boat	36 489	0.27	25.49	0.27	62%
Larger motor boat or launch	8 231	0.46	5.76	0.46	14%
Trailer yacht	0		0		0%
Larger yacht or keeler	3 891	0.75	2.73	0.75	7%
Kayak canoe or rowboat	1 771	0.69	1.24	0.69	3%
Off land including beach rocks or jetty	7 855	0.28	5.49	0.28	13%
Something else	218	1.01	0.15	1.01	0%
Capture method (Appendix 27.4 in Wynne-Jones et al. 2014)					
Rod or line (not long line)	0		0		0%
Long-line including set line contiki or kite	0		0		0%
Net (not including landing net used if caught on line)	0		0		0%
Pot (e.g., for crayfish)	9 106	0.6	6.38	0.6	16%
Dredge grapple or rake	0		0		0%
Hand gather or floundering from shore	635	0.94	0.44	0.94	1%
Hand gather by diving	48 714	0.37	34.03	0.37	83%
Spearfishing	0		0		0%
Some other method	0		0		0%
Total	58 455	0.24	40.86[1]	0.24	100%

[1] Uses mean weight estimate of 701 g (Hartill & Davey 2015).

The NPS survey results from logbook participants were in terms of number of fish. Mean recreational catch weight for the most important finfish and non-finfish species QMAs was estimated in a parallel project (Hartill & Davey 2015).
A recreational catch vector was developed by assuming that recreational catch has been proportional to the CRA 2 SS abundance, as reflected by SS CPUE. By agreement in the RLFAWG, the recreational catch vector was based on five of the seven survey estimates (in t – see Table 7) from 1994 (Otago), 1996 (Otago), 2010 (Holdsworth), 2011 (Holdsworth) and the 2011 NPS survey. The 2011 NPS survey was assumed to be the least biased and most precise so the estimated CV for this survey (0.24) was assumed. The CVs for the remaining surveys were assumed to be 50% higher than that of the NPS survey. A scalar quantity q was estimated by obtaining the best fit to these survey estimates when minimising a lognormal distribution using the CVs indicated in Table 7:

$$W_t = w_t \; N_t$$

$$\hat{W}_t = \hat{q} \; CPUE_t \text{ if } t = 1 \text{ (1994 Otago)}, \; = 2 \text{ (1996 Otago)}, \; = 3 \text{ (2010 Holdsworth)}, \; = 4 \text{ (2011 Holdsworth)}, \; = 5 \text{ (2011 LSMS)}$$

$$\text{LL}=\sum_{t=1}^{5}\left(\frac{\left(\text{LN}(W_t)-\text{LN}(\hat{W}_t)\right)^2}{2\sigma_t^2}\right)$$

where

$w_t =$ mean spring/summer weight >= MLS for sampled lobster in year/survey t for CRA2

$N_t =$ mean number lobsters in year/survey t for CRA2

$CPUE_y =$ spring/summer standardised CPUE from 1979 to 2016 for CRA2

$\hat{W}_y =$ estimated recreational catch by weight for year y for CRA2

Recreational catch was estimated as follows:

$$\hat{W}_y = \hat{q} \; CPUE_y \text{ if } y >= 1979$$

$$\hat{W}_{1945} = 0.2 * \hat{W}_{1979}$$

$$\hat{W}_y = \hat{W}_{y-1} + \frac{(\hat{W}_{1979} - \hat{W}_{1945})}{(1979-1945)} \text{ if } y > 1945 \;\&\; y < 1979$$

The recreational catch trajectory closely matches the 2011 NPS and the 2010 Holdsworth observations, while missing the 2011 Holdsworth observation and both Otago observations (Figure 3). This pattern is consistent with the CV assumptions. The q parameter is estimated to be 96 t/CPUE-unit and the recreational catch vector accounts for about 2050 t of historical catch from 1979 to 2016. Recreational catch was split between seasons, with 79% assumed taken in the SS and the remainder in AW. The 79%/21% split between seasons is the mean of the seasonal splits observed from the 2011 CRA 2 NPS survey and the 2010/2011 values from the two surveys of the western Bay of Plenty (J. Holdsworth, pers. comm.).

For assessments conducted since 2006, the RLFAWG has included recreational landings made by commercial vessels under Section 111 of the Fisheries Act. Greenweight landings with destination code ‘F’ were extracted from the CRACE database (Bentley et al. 2005), which showed a maximum annual value of 2036 kg for CRA 2, occurring in 2014–15. The RLFAWG has agreed to add the maximum catch estimate to the estimated recreational catch in each year since 1979 (Figure 3), increasing the total 1979–2016 recreational catch in the model to 2130 t.

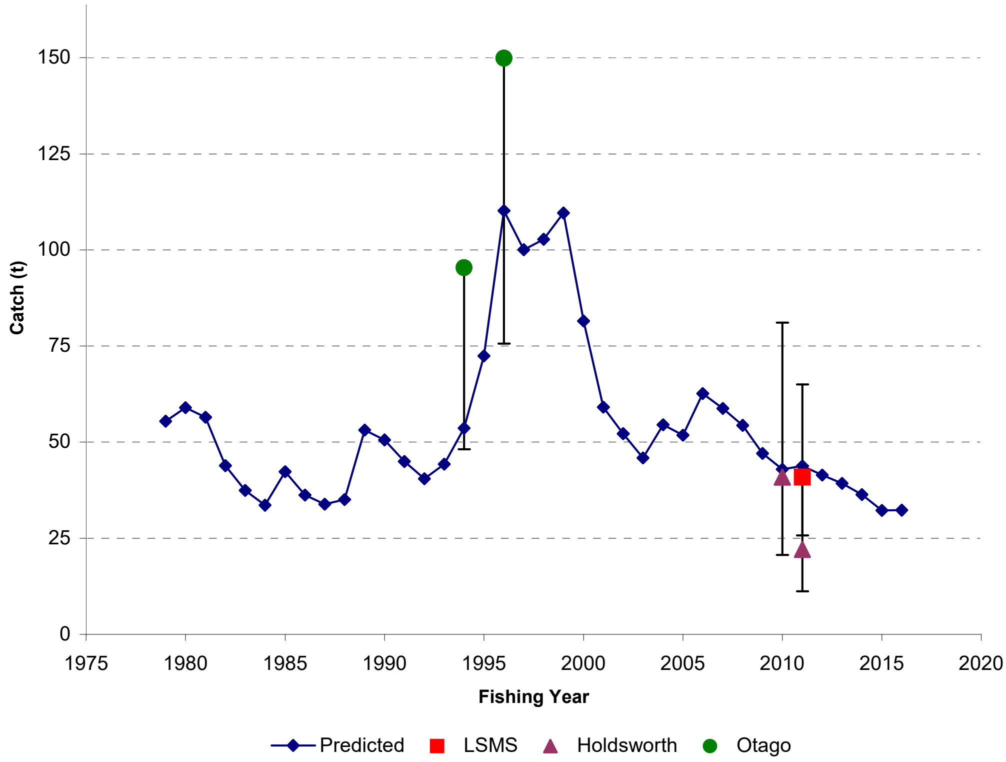


Figure 3: CRA 2 recreational catch trajectory (t) based on the SS seasonal CPUE series fitted to five recreational catch surveys (Table 7). Error bars are ±2 s.e.s, assuming a lognormal distribution, with the upper error bars for the two Otago estimates suppressed.

1.2.2 CRA 4 recreational catch

MPI, in its response to the request from the Rock Lobster Stock Assessment team for guidance on setting recreational catches, recommended the following for the CRA 4 recreational fishery:

> 'All available estimates of recreational rock lobster harvest by Quota Management Area are presented in the November 2015 Fisheries Assessment Plenary. The harvest estimates provided by the historical telephone diary surveys (1992, 1993, 1994, 1996, 2000 and 2001) are no longer considered reliable by the MPI Marine Amateur Fisheries Working Group.
>
> A recreational harvest estimate is available for CRA 4 from the 2011–12 National Panel Survey (NPS), which includes any charter fishing activity.
>
> MPI recommends that the 2011/12 NPS estimate for CRA 4 is used in the upcoming stock assessment. Given that there were a number of panellists making quite a few trips and the CV is relatively low, the NPS estimate for CRA 4 is considered reasonably robust. However, this is said in recognising that the NPS is unlikely to be reaching a high proportion of rock lobster fishers as finfish fishers, which could mean there is a negative bias in the catch estimates, but this has not been tested or quantified.'

The RLFAWG agrees that, because there were a number of panellists making quite a few trips and the CV is relatively low, the NPS estimate for CRA 4 would be considered reasonably robust. However, it is also recognised that the NPS was unlikely to be reaching as high a proportion of rock lobster fishers as finfish fishers, which could mean there is a negative bias in the rock lobster catch estimates, but this has not been tested or quantified. Apart from the NPS, recreational catches of rock lobster are poorly known throughout New Zealand, but it seems unlikely that recreational catch in CRA 4 would have been constant, given its proximity to Wellington and Hawke's Bay. The RLFAWG agreed for the 2003 CRA 4 stock assessment (Kim et al. 2004) to use a catch trajectory that reflected the changing abundance of lobster in this QMA, based on SS CPUE. This stock assessment calculated the ratios of the CPUE relative to the recreational survey catch weight, took the mean of these ratios, and applied it to the observed SS CPUE in all other years from 1979. All rock lobster stock assessments that use this procedure since 2003 have used the standardised SS CPUE from the entire QMA except for the 2014 CRA 1 stock assessment and the 2010 and 2015 CRA 5 stock assessments, which used unstandardised CPUE from statistical areas where the majority of the recreational catch was thought to be taken (see

Table 6 for details). When this method was implemented for the 2016 CRA 4 stock assessment (using the survey estimates in

Table 6), the estimated recreational catches were consistent with the 2011 NPS survey and the values used in the 2011 CRA 4 stock assessment.

$$
\begin{aligned}
{}^{q}W_y &= {}^{q}w_y \, {}^{q}N_y \\
{}^{q}S &= \left({}^{q}W_{94} / {}^{q}CPUE_{94} + {}^{q}W_{96} / {}^{q}CPUE_{96} + {}^{q}W_{11} / {}^{q}CPUE_{11} \right) / 3 \\
{}^{q}\hat{W}_i &= {}^{q}S * {}^{q}CPUE_i \text{ if } i >= 1979 \\
{}^{q}\hat{W}_{1945} &= 0.2 * {}^{q}\hat{W}_{1979} \\
{}^{q}\hat{W}_i &= {}^{q}\hat{W}_{i-1} + \frac{({}^{q}\hat{W}_{1979} - {}^{q}\hat{W}_{1945})}{(1979-1945)} \text{ if } i > 1945 \,\&\, i < 1979
\end{aligned}
$$

Eq. 1 where

y: subscripts 1994, 1996 and 2011

${}^{q}w_y =$ mean spring/summer weight >= MLS for sampled lobster in year y for QMA q

${}^{q}N_y =$ mean numbers lobster in survey year y for QMA q

${}^{q}CPUE_i =$ spring/summer standardised CPUE from 1979 to 2015 for QMA q

${}^{q}\hat{W}_i =$ estimated recreational catch by weight for year i for QMA q

${}^{q}S = 45.833$ t was used when Eq.1 was fitted to the survey estimates in

Table 6 and the estimated recreational catch trajectory is plotted in Figure 4. Recreational catch is split between seasons, with 90% assumed taken in the SS and the remainder in AW.

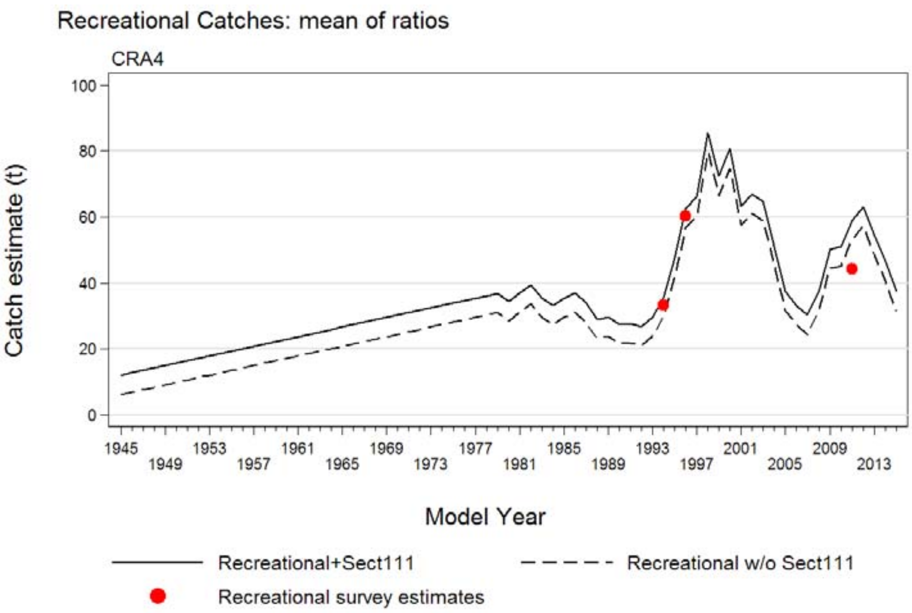


Figure 4: Recreational catch trajectories (t) for the 2016 stock assessment of CRA 4. Trajectories with and without the additional Section 111 catches are shown.

1.3 Section 111 commercial landings

Commercial fishermen are allowed to take home lobsters for personal use under Section 111 of the Fisheries Act. These lobsters must be declared on landing forms using the destination code ‘F’. The maximum in recent fishing years for these landings by QMA has ranged from about 440 kg (CRA 7) to just under 16 t (CRA 8) (Table 9).

Table 9: Section 111 commercial landings (in t, summed from landing destination code ‘F’) by fishing year and QMA. –, no data.

Fishing year	CRA 1	CRA 2	CRA 3	CRA 4	CRA 5	CRA 6	CRA 7	CRA 8	CRA 9
1992	0.01	–	–	–	–	–	–	–	–
1999	–	–	–	–	0.01	–	–	–	–
2000	0.00	–	–	–	0.03	–	–	–	–
2001	0.11	0.23	0.14	0.65	0.46	–	0.08	0.25	0.01
2002	0.49	0.61	0.50	2.66	1.96	–	0.15	1.95	0.91
2003	2.22	1.02	0.37	3.40	2.91	0.06	0.09	1.68	0.97
2004	3.55	0.73	0.31	3.71	3.19	0.09	0.10	3.51	1.64
2005	3.08	0.78	0.99	3.68	4.39	0.00	0.15	4.57	2.13
2006	5.02	1.28	0.98	3.11	5.10	0.02	0.29	5.81	1.22
2007	3.83	1.03	1.17	2.71	5.41	0.41	0.93	7.79	1.46
2008	3.63	1.18	1.37	2.19	6.11	0.54	1.50	9.57	1.60
2009	4.01	1.37	2.25	3.22	6.24	0.30	1.69	10.72	2.26
2010	3.67	1.19	2.18	4.70	6.58	0.28	0.43	13.54	1.85
2011	4.16	1.17	2.21	4.73	4.83	0.47	0.08	14.91	1.90
2012	4.21	1.19	2.58	5.83	7.22	1.03	0.10	15.82	1.85
2013	3.94	1.66	2.94	4.81	6.63	1.01	0.14	13.23	1.70
2014	3.58	2.04	3.03	5.18	6.12	0.63	0.13	13.93	3.76
2015	3.34	1.38	2.83	5.11	6.10	0.62	0.33	13.74	2.96
2016	3.01	1.17	3.05	4.20	5.69	0.83	0.44	12.88	1.88
Maximum	5.02	2.04	3.05	5.83	7.22	1.03	1.69	15.82	3.76
Maximum 2012–16	4.21	2.04	3.05	5.83	7.22	1.03	0.44	15.82	3.76

1.4 Customary non-commercial fisheries

CRA 2 customary catches were included in the 2013 stock assessment using a constant catch of 10 t/year over the entire reconstruction period of 1945 to 2012 (Starr et al. 2014a). When the RLFAWG discussed the data to be used in the 2017 CRA 2 stock assessment, there was consensus to lower the constant value used for this catch category to 5 t/year in recognition that some customary catch is included in the recreational catch estimate and advice that 10 t/year was likely too high.

Customary catches were split between seasons, with 90% assumed taken in the SS and the balance in the AW.

MPI were asked to provide estimates of customary catches to use in the CRA 2 stock assessment and an appreciation of their uncertainty. MPI’s information on customary harvest is incomplete, for various reasons, but the available information suggests the harvest is low.

1.5 Illegal catch

CRA 2 illegal catches from 1990 to 2001 were included in the 2013 stock assessment by using the values provided by MPI Compliance given in Table 10 (Starr et al. 2014a). A constant illegal catch of 88 t/year was used to fill in the missing years from 2002 to 2012. Years before 2001 without estimated illegal catches were interpolated. When the RLFAWG discussed the data to be used in the 2017 CRA 2 stock assessment, it was generally agreed that a constant illegal catch of 88 t/year beginning in 1996 was likely too large. The RLFAWG also agreed that the value of 88 t (= 83 + 5 t, Table 10) for 1996 was potentially real because of the high CPUE in that year but that illegal catches had been dropping since then. Consequently, the RLFAWG agreed to linearly decrease the illegal catch trajectory from 88 t in 1996 to an assumed value of 40 t in 2016. The MPI 2001 estimate of 88 t for CRA 2 illegal catch was discarded under this assumption.

In the past, MPI Compliance estimates for illegal catch have frequently been provided in two categories (‘reported’ or ‘R’ and ‘not reported’ or ‘NR’). The category of ‘commercial illegal reported’ or ‘reported’ (equals ‘R’ in Table 10) was assumed to represent illegal commercial catch that was eventually reported to the QMS as legitimate catch. Therefore this catch was subtracted from the reported commercial catch to avoid double-counting. Missing categories were treated as zeroes and the available values were used to estimate the overall proportion of R/NR for each QMA, which is then applied to all years (including interpolated years). MPI Compliance has stated that it no longer includes the 'R' category in its estimates because it takes into account the possibility of eventual reporting to the MHR, so the step of moving the estimated 'R' catches from 'commercial' to 'illegal' has now been discontinued for all CRA QMAs, beginning in 2012.

Table 10: Available estimates of illegal catches (t) by CRA QMA from 1990, as provided by MPI Compliance over a number of years. R (reported): illegal catch that will eventually be processed though the legal catch/effort system; NR (not reported): illegal catch outside of the catch/effort system. Cells without data or missing rows have been deliberately left blank. Years without any MPI estimates in any QMA have been suppressed in this table.

Fishing	CRA 1		CRA 2		CRA 3		CRA 4		CRA 5		CRA 6		CRA 7		CRA 8		CRA 9	
year	R	NR	R	NR	R	NR	R	NR	R	NR	R	NR	R	NR	R	NR	R	NR
1990	–	38	–	70	–	288.3	–	160.1	–	178	–	85	34	9.6	25	5	–	12.8
1992	–	11	–	37	–	250	–	30	–	180	–	70	34	5	60	5	–	31
1994	–	15	–	70	5	37	–	70	–	70	–	70	–	25	–	65	–	18
1995	–	15	–	60	0	63	–	64	–	70	–	70	–	15	–	45	–	12
1996	0	72	5	83	20	71	0	75	0	37	70	0	15	5	30	28	0	12
1997	–	–	–	–	4	60	–	–	–	–	–	–	–	–	–	–	–	–
1998	–	–	–	–	4	86.5	–	–	–	–	–	–	–	–	–	–	–	–
1999	–	–	–	–	0	136	–	–	–	–	–	–	–	23.5	–	54.5	–	–
2000	–	–	–	–	3	75	–	64	–	40	–	–	–	–	–	–	–	–
2001	–	72	–	88 [1]	0	75	–	–	–	–	–	10	–	–	–	–	–	1
2002	–	–	–	–	0	75	9	51	5	47	–	–	–	1	–	18	–	–
2003	–	–	–	–	0	89.5	–	–	–	–	–	–	–	–	–	–	–	–
2004	–	–	–	–	–	–	10	30	–	–	–	–	–	–	–	–	–	–
2011	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	3	–	–
2014	–	–	–	–	–	–	–	–	–	30	–	–	–	–	–	–	–	–
2015	–	–	–	–	–	–	–	40	–	–	–	–	–	–	–	–	–	–
2016	–	–	–	40 [2]	–	–	–	–	–	–	–	–	–	–	–	–	–	–

[1] This value discarded by RLFAWG agreement.
[2] This value is not an estimate: it is assumed by agreement by the RLFAWG.

Table 11: Export discrepancy estimates by year for all of New Zealand (McKoy, pers. comm.). The QMA export discrepancy catch is calculated using the fraction for the reported QMA commercial catch $C_{q,y}$ relative to the total New Zealand commercial catch C_y, starting with the total New Zealand export discrepancy for that year I_y: $I_{q,y} = I_y \left(C_{q,y} / C_y \right)$. This calculation is not performed for CRA 9 as there were no estimates of commercial catch available from 1974 to 1978. The average ratio of the export discrepancy catch for each QMA $\overline{P_q}$ relative to the reported QMA commercial catches is used in each CRA QMA to estimate illegal catches before 1990: $I_{q,y} = \overline{P}_q C_{q,y}$ if $y<1974 \| \left(y>1980 \& y<1990 \right)$.

Year	Estimates of total export discrepancies (t) I_y	QMA	$\overline{P}_q = \sum_{y=1974}^{1980} I_{q,y} \Big/ \sum_{y=1974}^{1980} C_{q,y}$
1974	463	CRA 1	0.192
1975	816	CRA 2	0.171
1976	721	CRA 3	0.164
1977	913	CRA 4	0.183
1978	1146	CRA 5	0.187
1979	383	CRA 6	0.181
1980	520	CRA 7	0.183
		CRA 8	0.187
		CRA 9	–

Illegal catch estimates before 1990 have been derived from unpublished estimates of discrepancies between reported catch totals and total exported weight that were developed for the period 1974 to 1980 (Table 11; McKoy, pers. comm.). For years before 1973 and from 1981–82 to 1989–90, illegal catch was estimated using the average ratio of annual exports of rock lobster relative to the reported catch in each year from 1974 to 1980 (Table 11). This ratio was calculated for each QMA by assuming that the exports are distributed by QMA in the same proportion as the reported catches. This procedure has also been applied to CRA 9 even though there are no commercial catch estimates available for this QMA from 1974 to 1978, using interpolation.

The RLFAWG members have little confidence in the estimates of illegal catch because the estimates cannot be verified.

1.6 Other sources of mortality

Other sources of mortality include handling mortality caused by the return of under-sized, high-grading, and berried female lobsters to the water and predation by octopus and other predators within pots. Octopus predation can be quantified from observer catch sampling data but is not used. The 2017 CRA 2 stock assessment assumed that handling mortality was 10% of returned lobsters until 1990 and then 5%, based on a literature review. The CRA 2 estimate is provided in Table 38.

1.7 Time series of mortalities

Plots of all rock lobster catches by QMA from 1945 are presented in Figure 5. Commercial catches before 1979 have been obtained from unpublished reports (Annala, pers. comm.). Historical estimates of recreational, customary and illegal catches have been generated for each stock assessment and these have been extended using the same rules for those assessments that are not current. In some instances (CRA 6 and CRA 9), there has never been a formal stock assessment. Finally, a TAC is plotted for the seven QMAs that have one.

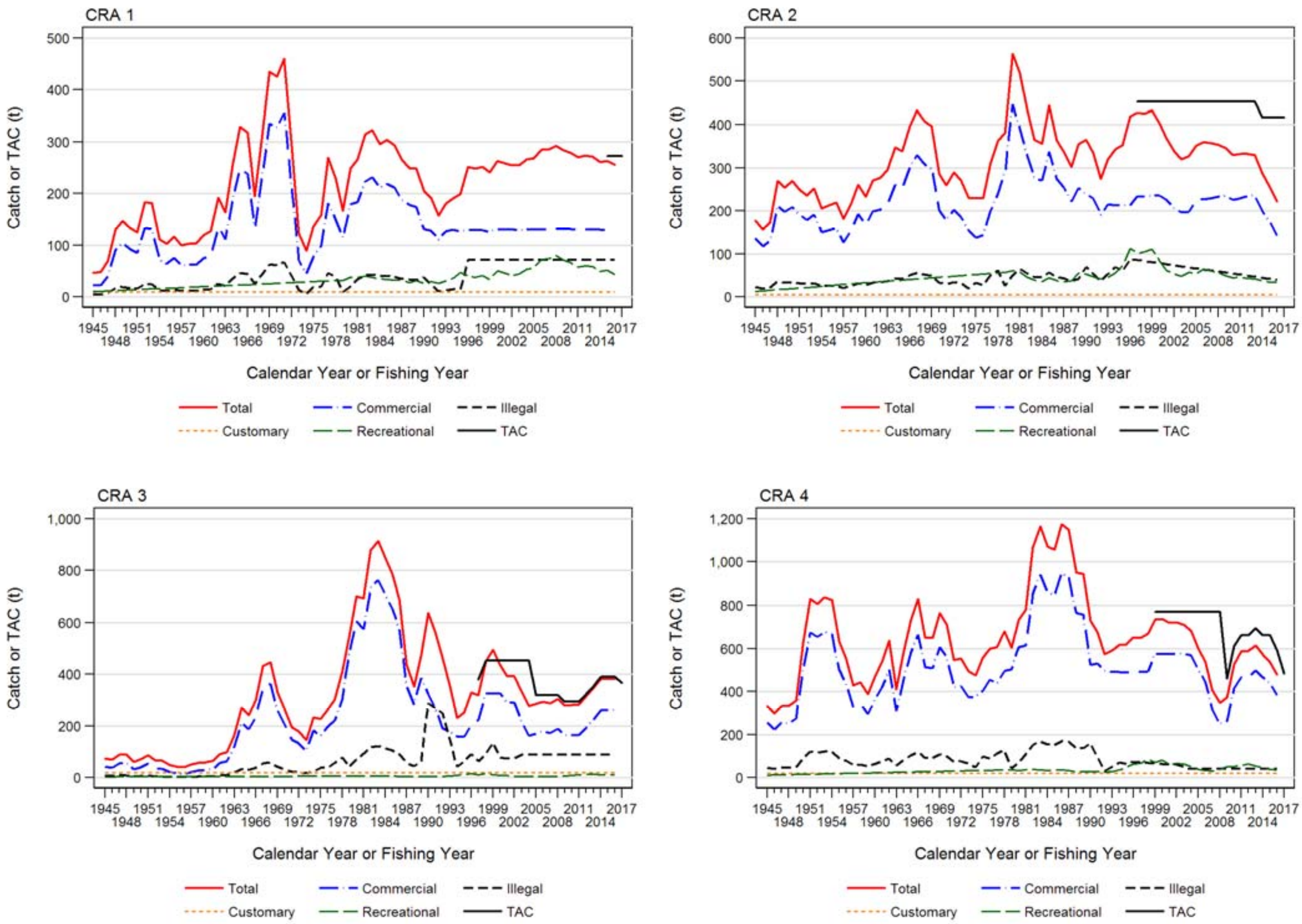


Figure 5: Catch trajectories (t) from 1945 to 2016 and TACs (if in place) from the year of establishment to 2017 for CRA 1 to CRA 4, showing current best estimates for commercial, recreational, customary and illegal categories. Also shown is the sum of these four catch categories. Note that calendar year catches are plotted from 1945 to 1977. Statutory fishing year (1 April to 31 March) catches are plotted from 1979 on. Catches for 1978 are for 15 months, including January to March 1979. [Continued on next page]

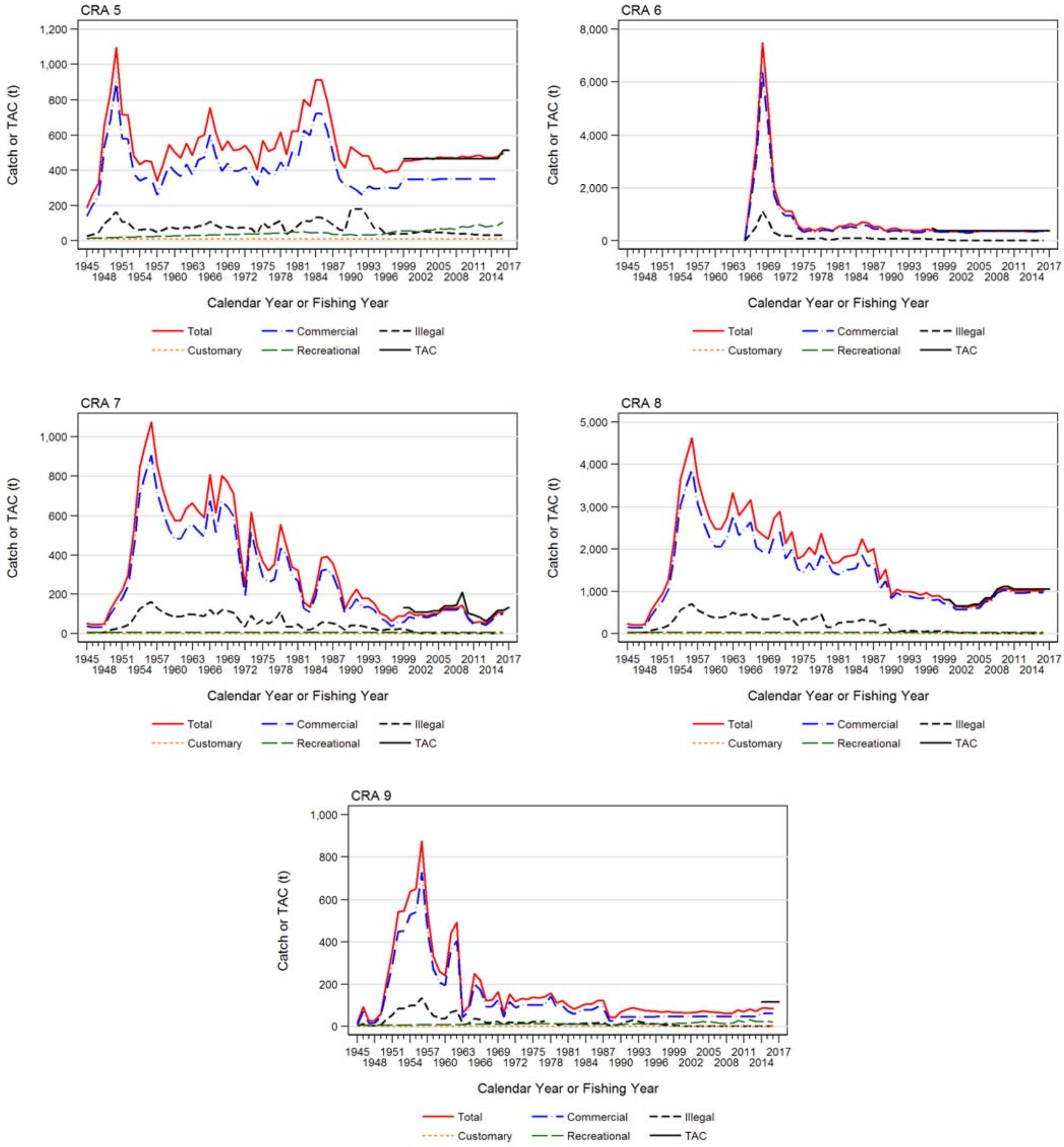


Figure 5 [Continued]: Catch trajectories (t) from 1945 to 2016 and TACs (if in place) from the year of establishment to 2017 for CRA 5 to CRA 9.

2. BIOLOGY

Although lobsters cannot be aged in numbers sufficient for use in fishery assessments, they are thought to be relatively slow-growing and long-lived. *J. edwardsii* and *S. verreauxi* occur both in New Zealand and southern Australia. The following summary applies only to *J. edwardsii* in New Zealand.

Sexual maturity in females is reached from 34–77 mm TW (about 60–120 mm carapace length), depending on locality within New Zealand. For instance, in CRA 3, 50% maturity appears to be realised near 40 mm TW while most females in the south and south-east of the South Island do not breed before reaching MLS.

Mating takes place after moulting in autumn, and the eggs hatch in spring into the short-lived naupliosoma larvae. Most of the phyllosoma larval development takes place in oceanic waters tens to hundreds of kilometres offshore over at least 12 months. Near the edge of the continental shelf the final-stage phyllosoma metamorphoses into the settling stage, the puerulus. Puerulus settlement takes place mainly at depths less than 20 m, but not uniformly over time or between regions. Settlement indices measured on collectors can fluctuate widely from year to year.

Values used for some biological parameters in stock assessments are shown in Table 12.

Table 12: Values used for some biological parameters.

1. Natural mortality (*M*) [1]

Area	Both sexes
CRA 1, 2 ,3, 4, 5, 7, 8	0.12

[1] This value has been used as the mean of an informative prior; *M* was estimated as a parameter of the model and is usually substantially updated.

2. Fecundity = a TW^b (TW in mm) (Breen & Kendrick 1998)[2]

Area	*a*	*b*
NSN	0.21	2.95
CRA 4 & CRA 5	0.86	2.91
NSS	0.06	3.18

[2] Fecundity has not been used by post-1999 assessment models.

3. Weight = a TW^b (weight in kg, TW in mm) (Breen & Kendrick 1998, Ministry of Fisheries unpublished data)

	Females		Males	
Area	***a***	***b***	***a***	***b***
CRA 1, 2, 3, 4, 5	1.30 E-05	2.5452	4.16 E-06	2.9354
NSS	1.04 E-05	2.6323	3.39 E-06	2.9665

Long-distance migrations of rock lobsters have been observed in some areas. During spring and early summer, variable proportions of usually small males and immature females move various distances against the current from the east and south coasts of the South Island towards Fiordland and south Westland.

2.1 Growth modelling

The primary sources of information for growth are tag-recapture and catch sampling data. Lobsters have been caught, measured, tagged and released, then recaptured and remeasured at some later time (and in some instances re-released and re-recaptured later). Since 1998, statistical length-based models have been used to estimate the expected increment-at-size, which is represented stochastically by growth transition matrices for each sex. Growth increments-at-size are assumed to be normally distributed with means and variances determined from the growth model. The transition matrices contain the probabilities that a lobster will move into specific size bins given its initial size.

The growth model contains parameters for expected increment at 50 mm and 80 mm TW, a shape parameter (1 = linear), the CV of the increment for each sex, and the observation error.

Since 2006, the growth model applied to the tag-recapture data has been a continuous model – giving a predicted growth increment for any time at liberty – whereas the older versions assumed specific moulting periods between which growth did not occur. For assessment models used from 2006 to 2014, records from lobsters at liberty for fewer than 30 days were excluded. In that period, the robust likelihood fitting procedure precluded the need for extensive grooming of outliers. In 2015 the grooming was relaxed so that records from lobsters at liberty for less than 1 day were excluded. Lobsters at liberty for short time periods provide the growth models with information on observation error. Growth parameters are estimated simultaneously with other parameters of the assessment model in an integrated way, so that growth estimates might be affected by the size frequency and CPUE data as well as the tag-recapture data.

2.2 Settlement indices

Annual levels of puerulus settlement have been collected from 1979 at sites in Gisborne, Napier, Castlepoint, Kaikoura, Moeraki, Chalky Inlet, Halfmoon Bay and Jackson Bay (Table 13). Each site has at least one group of three collectors that are checked monthly when possible, and the monthly catches of the puerulus from each collector are used as the basis for producing a standardised index of settlement (Forman et al. 2017). Standardised settlement indices are available for each key site (Table 14).

Table 13: Location of collector groups used for the standardisation of puerulus settlement indices, the years of operation, and the number of collectors monitored within each group at the last sampling.

QMA	Key site	Collector groups	Years of operation	Number of collectors
CRA 3	Gisborne	Whangara (GIS002)	1991–present	5
		Tatapouri (GIS003)	1994–2006	5
		Kaiti (GIS004)	1994–present	5
CRA 4	Napier	Port of Napier (NAP001)	1979–present	5
		Westshore (NAP002)	1991–1999	3
		Cape Kidnappers (NAP003)	1994–present	5
		Breakwater (NAP004)	1991–2002	3
CRA 4	Castlepoint	Castlepoint (CPT001)	1983–present	9
		Orui (CPT002)	1991–present	5
		Mataikona(CPT003)	1991–2006	5
CRA 5	Kaikoura	South peninsula (KAI001)	1981–present	5
		South peninsula (KAI002)	1988–2003	3
		North peninsula (KAI003)	1980–present	5
		North peninsula (KAI004)	1992–2003	3
		South Kaikoura (KAI005)	2008–present	3
		Hamuri Bluff (KAI006)	2008–present	3
		Gooch Bay (KAI008)	1980–1983	3
		Middle South Coast (KAI009)	1981–1988	3
CRA 7	Moeraki	Wharf (MOE002)	1990–2006	3
		Pier (MOE007)	1998–present	6
CRA 8	Halfmoon Bay	Wharf (HMB001)	1980–present	8
		Thompsons (HMB002)	1988–2002	3
		Old Mill (HMB003)	1990–2002	3
		The Neck (HMB004)	1992–2002	3
		Mamaku Point (HMB005)	1992–2002	3
CRA 8	Chalky Inlet	Chalky Inlet (CHI001)	1986–2004	5
			2010 –2012	4
CRA 8	Jackson Bay	Wharf (JAC001)	1999–present	5
		Jackson Head (JAC002)	1999–2006	3

Table 14: Standardised puerulus settlement indices by fishing year 1 April–31 March (source: A. McKenzie, NIWA). –, no usable sampling was done; 0.00: no observed settlement. [Continued on next page]

Fishing year	Gisborne CRA 3	Napier CRA 4	Castlepoint CRA 4	Kaikoura CRA 5	Moeraki CRA 7	Halfmoon Bay CRA 8	Chalky Inlet CRA 8	Jackson Bay CRA 8
1979	–	0.78	–	–	–	–	–	–
1980	–	1.25	–	–	–	–	–	–
1981	–	2.05	–	0.53	–	8.14	–	–
1982	–	1.14	2.44	0.72	–	0.39	–	–
1983	–	1.33	1.19	0.16	–	3.92	–	–
1984	–	0.41	0.72	0.37	–	0.30	–	–
1985	–	0.22	0.57	0.23	–	0.00	0.36	–
1986	–	–	0.84	0.08	–	0.12	0.21	–
1987	3.24	–	1.64	1.03	–	1.59	1.42	–
1988	2.76	1.36	0.93	0.39	–	0.22	1.31	–
1989	0.97	1.18	1.14	0.78	–	0.60	1.64	–
1990	0.43	1.04	1.09	1.54	–	0.43	1.84	–
1991	1.05	2.45	2.12	6.58	0.00	0.93	1.03	–
1992	2.80	2.09	2.10	5.13	0.09	0.54	0.52	–
1993	1.75	2.21	1.05	2.01	0.00	0.00	0.14	–
1994	3.00	1.53	0.87	1.06	0.00	1.19	1.64	–
1995	1.07	1.06	0.91	0.59	0.07	0.40	0.40	–
1996	1.64	1.54	1.26	0.62	0.61	0.33	1.76	–

Table 14 [Continued]:

Fishing year	Gisborne CRA 3	Napier CRA 4	Castlepoint CRA 4	Kaikoura CRA 5	Moeraki CRA 7	Halfmoon Bay CRA 8	Chalky Inlet CRA 8	Jackson Bay CRA 8
1997	0.98	1.08	1.68	1.94	0.26	0.56	1.41	–
1998	1.77	0.97	1.05	1.88	0.35	0.30	0.50	–
1999	0.28	0.43	0.34	1.25	0.06	0.23	1.70	0.24
2000	0.90	0.73	0.52	1.27	2.67	1.22	1.26	0.50
2001	1.12	1.23	0.70	0.53	1.11	1.75	0.60	0.20
2002	0.94	1.45	0.76	3.25	0.58	1.47	1.42	1.28
2003	2.71	1.31	0.93	3.31	4.82	3.94	1.56	0.48
2004	0.71	1.06	0.49	1.00	0.24	0.16	0.30	0.36
2005	2.46	1.28	1.26	2.20	0.05	0.00	–	1.20
2006	0.27	0.65	0.47	1.07	0.04	0.13	–	0.23
2007	0.36	0.92	1.03	1.66	0.04	0.48	–	0.21
2008	0.63	0.64	1.04	1.59	0.07	0.09	–	0.08
2009	1.69	0.89	1.07	0.52	0.44	1.03	–	0.14
2010	0.61	0.94	1.16	1.25	0.97	1.66	7.03	1.80
2011	0.18	0.49	0.89	0.56	0.69	0.14	1.44	1.97
2012	0.66	0.70	0.58	1.11	0.80	0.18	4.37	6.83
2013	0.92	0.95	1.69	0.71	1.17	0.76	–	11.95
2014	0.39	1.03	0.69	1.28	0.34	0.87	–	19.06
2015	1.48	1.05	1.65	0.86	7.73	0.56	–	4.92
2016	1.15	0.68	1.85	2.78	2.81	1.38	–	11.64

3. STOCKS AND AREAS

There is no evidence for genetic subdivision of lobster stocks within New Zealand based on biochemical genetic and mitochondrial DNA studies. The observed long-distance migrations in some areas and the long larval life probably result in genetic homogeneity among areas. Gene flow at some level probably occurs to New Zealand from populations in Australia (Chiswell et al. 2003).

Subdivision of stocks on other than genetic grounds has been considered (Booth & Breen 1992, Bentley & Starr 2001). There are geographic discontinuities in the prevalence of antennal banding, size at onset of maturity in females, migratory behaviour, fishery catch and effort patterns, phyllosoma abundance patterns and puerulus settlement levels. These observations led to division of the historical NSI stock into three substocks (NSN, NSC and NSS) for assessments in the 1990s. Cluster analysis based on similarities in CPUE trends between rock lobster statistical areas provided support for those stock definitions (Bentley & Starr 2001).

Since 2001 these historical stock definitions have not been used, and rock lobsters in each of the CRA QMA areas have been assumed to constitute separate Fishstocks for the purposes of stock assessment and management.

Sagmariasus verreauxi forms one stock centred in northern New Zealand and may be genetically subdivided from populations of the same species in Australia.

4. DECISION RULES AND MANAGEMENT PROCEDURES

This section presents evaluations of the existing CRA 1, CRA 2, CRA 3, CRA 4, CRA 5, CRA 7 and CRA 8 management procedures (MPs) for the 2018–19 fishing year, based on CPUE data extracted in November 2017 and standardised as described below. All rules have been evaluated through simulation from operating models based on the stock assessment results (MP evaluations or MPEs). New MPs were developed in 2017 for CRA 2 and will likely be used to set catch limits for the 2018–19 fishing year.

Except for CRA 3, the MPs for each stock use either 'plateau step' or 'plateau slope' harvest control rules, which are described by Breen et al. (2017). For each stock, the specific rule parameters are given and the rules are illustrated. These rules give the TACC for the next fishing year as a function of the offset-year CPUE calculated in November.

4.1 Data preparation

For MP operations, CPUE is calculated for the offset year, October through September. The values used here are based on data extracts from the Warehou database (combined replogs 11340 and 11437) received 01 September (11340 – for all data up to 31 March 2017) and 03 November (11437 – for 01 April–30 September 2017 data).

All CPUE indices used in the MPs are in units of kg/potlift and TACCs are in t. Year codes represent the second part of each offset year; *viz.* 2015 is the 2014/15 offset year. These indices, with the exception of CRA 8, were evaluated based on the F2_LFX algorithm. The CRA 8 MP uses the F2_LF algorithm. The F2 algorithm is used to convert estimated catches into landed greenweight and is described in Starr (2017). The codes 'L', 'F' and 'X' represent MPI landing destination codes 'landed to a Licensed Fish Receiver', 'landed under the provisions of Section 111' and 'legal-sized discards', respectively.

The CRA 7 CPUE series dropped the Dec–May data beginning with Dec 2013 because of a major change to the MLS regime, making those months not comparable with data collected before 2013.

CPUE standardisation follows the suggestion of Francis (1999) and calculates 'canonical' coefficients and standard errors for each year. Each standardised index is scaled by the geometric mean of the simple arithmetic CPUE indices (using the summed annual catch divided by summed annual effort for each offset year). The geometric mean CPUE is preferred to the arithmetic mean because it is less affected by outliers. This procedure scales the standardised indices to CPUE levels consistent with those observed by fishermen.

4.2 Management Procedure for CRA 1

First year with MP	2015
First year of current MP	2015
Review scheduled	2019
Input CPUE	offset year F2-LFX
Output	TACC
Type of rule	generalised plateau step rule
Latent year?	No
Minimum change	5%
Maximum change	none
2017–18 TAC	273.062
2017–18 customary allowance	20
2017–18 recreational allowance	50
2017–18 other mortality allowance	72
Total non-commercial allowance	142
2017–18 TACC	131.062

Table 15: Parameters for the CRA 1 generalised plateau step rule.

Par	Function	CRA 1 rule 9d value
par1	rule type	4
par2	CPUE at TACC = 0	0.1
par3	CPUE at plateau left	1.1
par4	CPUE at plateau right	1.7
par5	plateau height	131.062
par6	step width	0.25
par7	step height	0.05
par8	minimum change	0.05
par9	maximum change	0
par10	latent year switch	0

The CRA 1 rule (Table 15) is based on work conducted in 2014 by Webber & Starr (2015), using an operating model derived from the CRA 1 stock assessment model. A TAC was set for CRA 1 for the first time for the 2015–16 fishing year, with the Minister setting allowances for non-commercial catches. Before 2015–16, there was only a TACC and no allowances.

In November 2014, standardised offset-year CPUE was 1.5803 kg/potlift, which gave a suggested 2015–16 TACC of 131.062 t. The Minister accepted rule 9d and assigned allowances (customary 20 t, recreational 50 t and other mortality 72 t) to give a 2015–16 TAC of 273.062 t (Table 16). In November 2015, offset-year CPUE had decreased but remained on the plateau so the 2016–17 TACC was unchanged. In November 2016, offset-year CPUE had increased by 9% but remained on the plateau, so the MP result was that the 2017–18 TACC of 131.062 t was unchanged. In November 2017, offset-year CPUE had decreased by 10% relative to 2016 (Figure 6), but remained on the plateau, so the MP result was an unchanged 2018–19 TACC of 131.062 t (Figure 7).

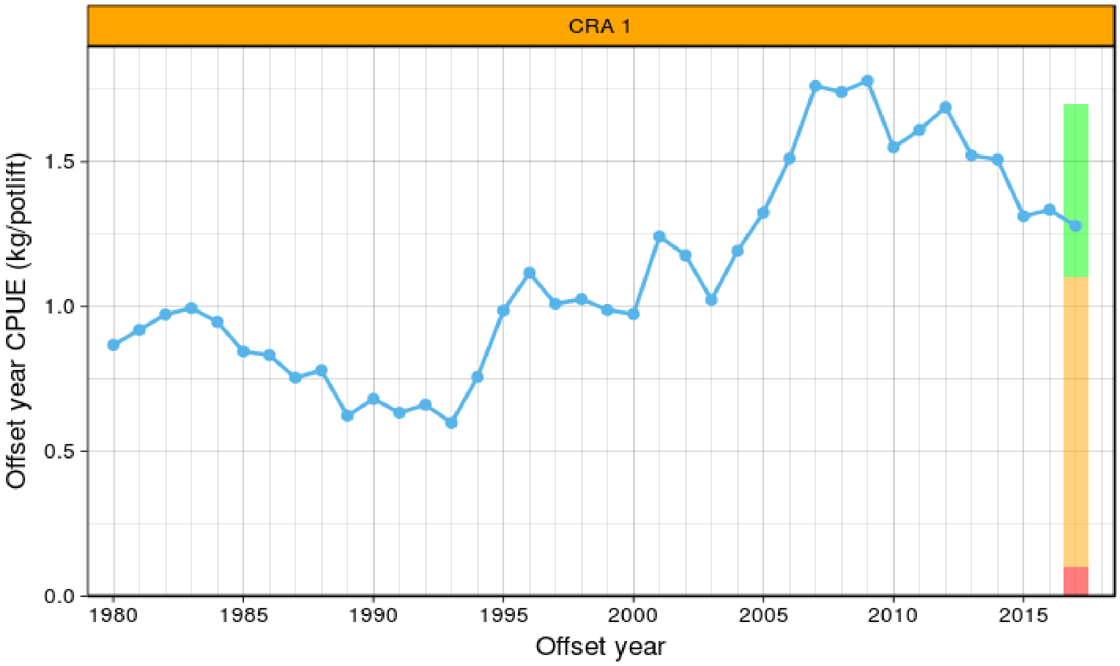


Figure 6: Offset-year CPUE (F2-LFX) (kg/potlift) for CRA 1. The coloured bar represents the plateau (green), the slope (orange), and the CPUE at which the TACC = 0 (red) of the current CRA 1 management procedure.

Table 16: History of the CRA 1 management procedure. 'Rule result' is the result of the management procedure after operation of all its components including thresholds.

Year	Applied to fishing year	Offset CPUE (kg/potlift)	Rule result: TACC (t)	Applied TACC (t)	Applied TAC (t)
2014	2015–16	1.5803	131.062	131.062	273.062
2015	2016–17	1.3154	131.062	131.062	273.062
2016	2017–18	1.4289	131.062	131.062	273.062
2017	2018–19	1.2792	131.062		

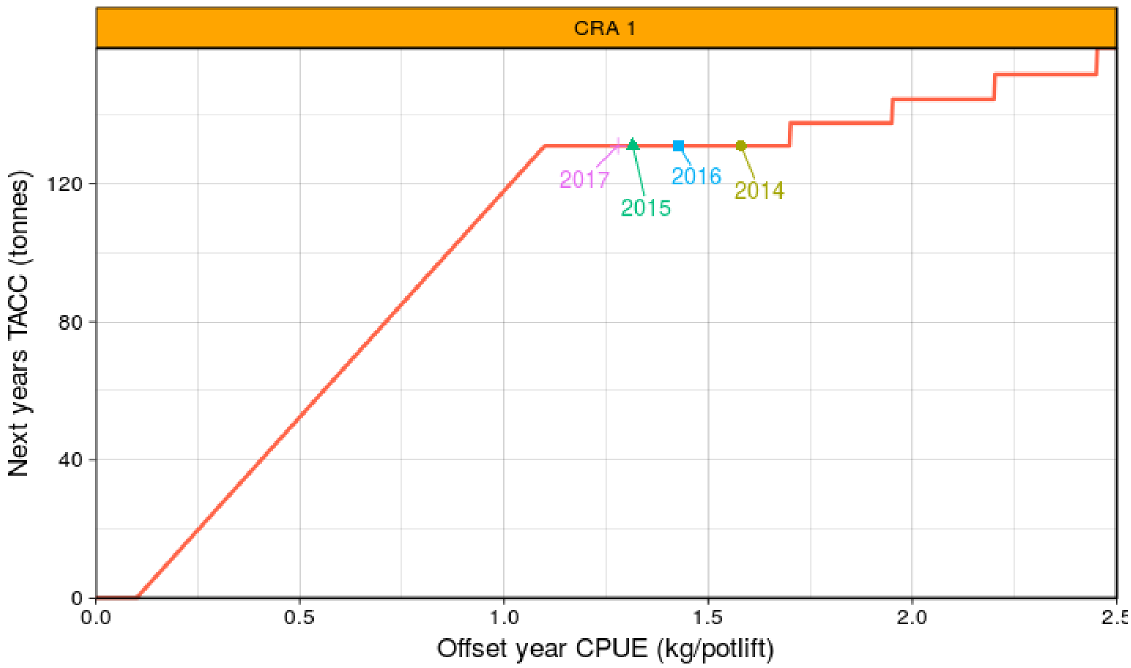


Figure 7: The current CRA 1 harvest control rule. The coloured symbols show the 2014 to 2017 offset-year CPUE and the resulting TACCs.

4.3 Management Procedure for CRA 2

First year with MP	2014
First year of current MP	2014
Review scheduled	2017
Input CPUE	offset year F2-LFX
Output	TACC
Type of rule	generalised plateau step rule
Latent year?	no
Minimum change	5%
Maximum change	none
2017–18 TAC	416.5
2017–18 customary allowance	16.5
2017–18 recreational allowance	140
2017–18 other mortality allowance	60
Total non-commercial allowance	216.5
2017–18 TACC	200

The current CRA 2 rule (Table 17) is based on work conducted in 2013 by Starr et al. (2014b), using an operating model based on the CRA 2 stock assessment model. This first MP for the stock was used to recommend catch limits for the 2014–15 fishing year.

In November 2013, standardised offset-year CPUE was 0.367 kg/potlift, which gave a suggested 2014–15 TACC of 200 t, a drop from the 2013–14 TACC of 236 t. The Minister accepted this rule result and assigned the allowances set in 1997–98 (customary 16.5 t, recreational 140 t and other mortality 60 t) to give a 2014–15 TAC of 416.5 t (Table 18). In November 2014, offset-year CPUE was 0.3361 kg/potlift, which gave a 2015–16 TACC that remained on the plateau. The Minister accepted this result and retained the current allowances. In November 2015, CPUE decreased to 0.2991 kg/potlift, which was just below the plateau, giving a preliminary rule result of 199.397 t for the TACC. Because this would be a change of only 0.3%, it was less than the minimum change threshold of 5% and the MP result was no change to the 2016–17 TACC. However, the CRA 2 industry voluntarily shelved 49 t of ACE, resulting in a functional TACC of 151 t for 2016–17.

In November 2016, CPUE was 0.2953, again just below the plateau. The preliminary rule result was a 2017–18 TACC of 196.884, which implied a change of only 2%, which is less than the minimum change threshold of 5%, resulting in no change to the 2017–18 TACC. The CRA 2 industry again voluntarily shelved 49 t of ACE, resulting in a functional TACC of 151 t for 2017–18. In November 2017, CPUE was 0.2885 (Figure 8), once again just below the plateau (Figure 9). This CPUE was only 3.8% below the left-hand edge of the plateau at 0.3 kg/potlift, which is less than the minimum change threshold of 5%, so the MP result was no change to the 2018–19 TACC. This result is based on the current CRA 2 MP. A new stock assessment for CRA 2 was evaluated in 2017 (see Section 6.2), a year ahead of the original schedule. It is expected that this assessment will result in the selection of a new MP for CRA 2, which will supersede the rule evaluation in Table 18.

Table 17: Parameters for the CRA 2 generalised plateau step rule.

Par	Function	CRA 2 rule 4
par1	rule type	4
par2	CPUE at TACC = 0	0
par3	CPUE at plateau left	0.3
par4	CPUE at plateau right	0.5
par5	plateau height	200
par6	step width	0.1
par7	step height	0.1
par8	minimum change	0.05
par9	maximum change	0
par10	latent year switch	0

Table 18: History of the CRA 2 management procedure. 'Rule result' is the result of the management procedure after operation of all its components including thresholds. The superscript † indicates that the TACC was functionally 151 t after voluntary shelving.

Year	Applied to fishing year	Offset CPUE (kg/potlift)	Rule result: TACC (t)	Applied TACC (t)	Applied TAC (t)
2013	2014–15	0.3668	200.0	200.0	416.5
2014	2015–16	0.3361	200.0	200.0	416.5
2015	2016–17	0.2991	200.0	200.0†	416.5
2016	2017–18	0.2953	200.0	200.0†	416.5
2017	2018–19	0.2885	200.0		

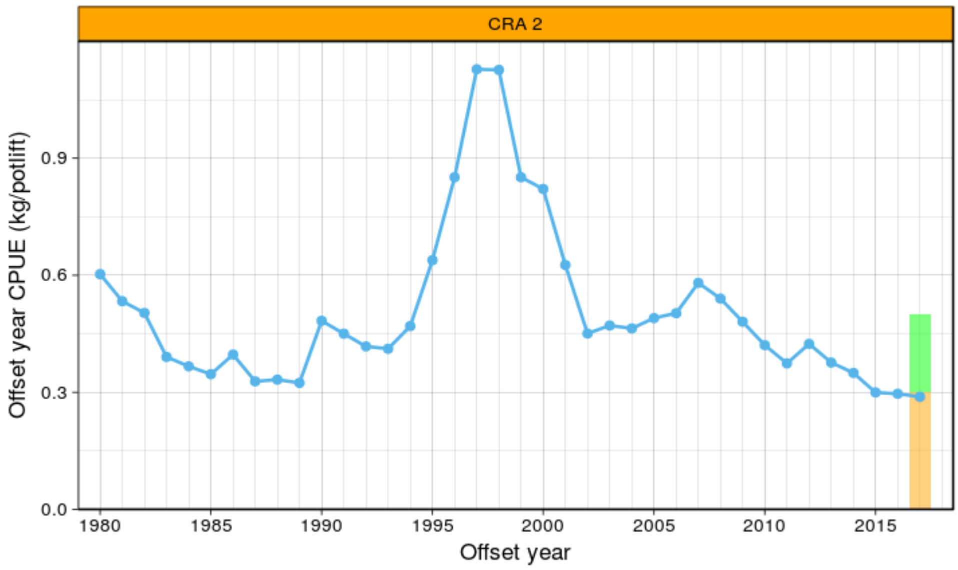


Figure 8: Offset-year CPUE (F2-LFX) (kg/potlift) for CRA 2. The coloured bar represents the plateau (green) and the slope (orange) of the current CRA 2 management procedure.

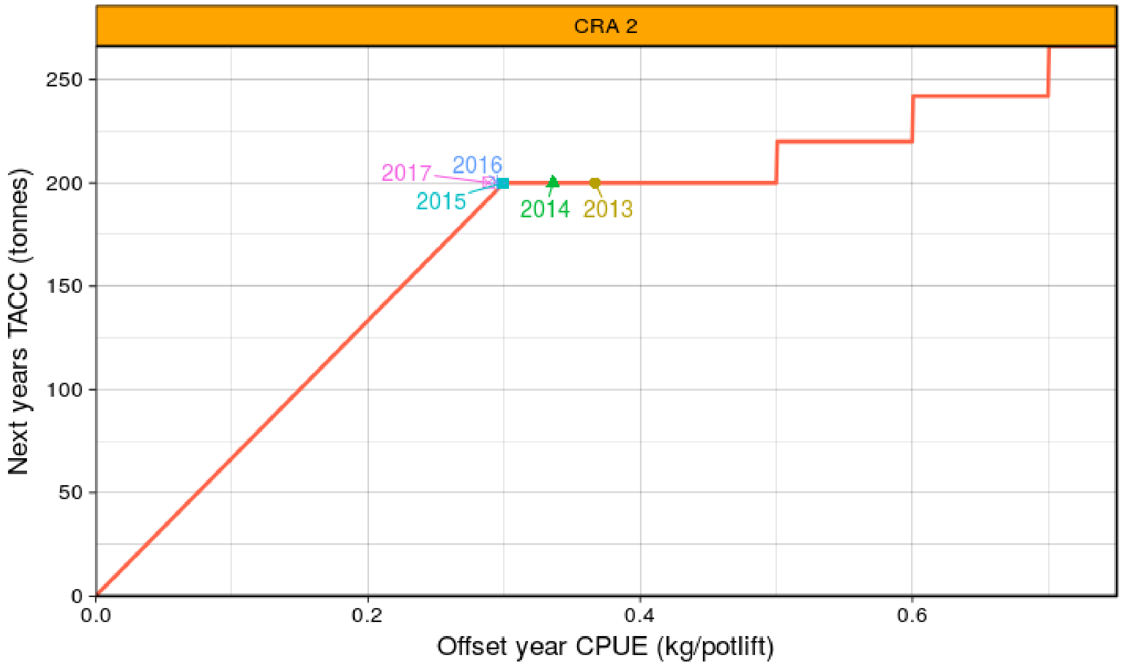


Figure 9: The current CRA 2 management procedure. The coloured symbols show the 2013 to 2017 offset-year CPUE and the resulting TACCs. Note that the functional TACCs for 2016 and 2017 were 151 t after voluntary shelving.

4.4 Management Procedure for CRA 3

First year with MP	2010
First year of current MP	2015
Review scheduled	2019
Input CPUE	offset year F2-LFX
Output	TACC
Type of rule	modified plateau slope rule
Latent year?	no
Minimum change	5%
Maximum change	none
2017–18 TAC	366.86
2017–18 customary allowance	20
2017–18 recreational allowance	20
2017–18 other mortality allowance	89
Total non-commercial allowance	129
2017–18 TACC	237.86

The CRA 3 rule (Table 19) is based on work conducted in 2014 by Haist et al. (2015), using an operating model derived from the 2014 CRA 3 stock assessment model. The new harvest control rule is a modified plateau slope rule. The modification involves a) fixing the intercept to zero, b) having two straight-line segments between zero and the left of the plateau and c) having a different slope equation from the generalised rule (see Breen et al. 2017 for a description of this rule). Rule parameters (Table 19) are defined differently from those in the other rules.

Table 19: Parameters for the CRA 3 plateau slope rule evaluated in 2014, and values for the rule agreed by the Minister in 2015.

Par	Function	CRA 3 rule 4 value
par1	rule type	6
fixed	CPUE at TACC = 0	0.0
par2	CPUE at first inflection	1.0
par3	left plateau	2.0
par4	right plateau	3.0
par5	plateau height	260
par6	slope	50
par7	TACC at first inflection	180
par8	minimum change	0.05
par9	maximum change	0.0
par10	latent year	0

In November 2014, standardised offset-year CPUE was 2.2139 kg/potlift, which gave a 2015–16 TACC on the main plateau. The Minister accepted this result and retained the previous non-commercial allowances (customary 20 t, recreational 20 t and illegal 89 t) to give a 2015–16 TAC of 390 t (Table 20). Note that the MP result was a TACC of 260 t, but the TACC was set at 260.95 t to be consistent with the existing TACC. In November 2015, CPUE decreased and was no longer on the plateau; the preliminary rule result was a 2016–17 TACC of 250.736 t. Because this would have been a TACC change of 3.9%, which was less than the minimum change threshold of 5%, the MP result was no change in the TACC.

In November 2016, CPUE had decreased to 1.7232 kg/potlift, to the left of the plateau, and the provisional 2017–18 TACC was 237.857 t. This was a decrease of 8.95% from the 2016–17 TACC of 260.95, which was greater than the 5% minimum change threshold, resulting in a 2017–18 TACC of 237.857 t (Table 20). In November 2017, CPUE increased to 1.7873 kg/potlift (Figure 10), which was a 3.7% increase from 1.7232 kg/potlift in 2016 (Figure 11). The MP resulted in no change to the 2018–19 TACC because the change in CPUE was less than the 5% minimum change threshold (Table 20).

Table 20: History of the current CRA 3 management procedure. 'Rule result' is the result of the management procedure after operation of all its components including thresholds.

Year	Applied to fishing year	Offset CPUE (kg/potlift)	Rule result: TACC (t)	Applied TACC (t)	Applied TAC (t)
2014	2015–16	2.2139	260.000	260.95	389.95
2015	2016–17	1.8842	260.000	260.95	389.95
2016	2017–18	1.7232	237.857	237.86	366.86
2017	2018–19	1.7873	237.857		

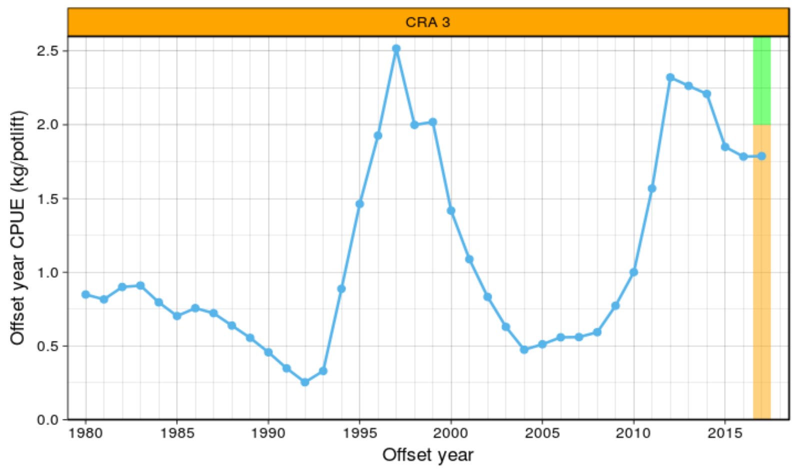


Figure 10: Offset-year CPUE (F2-LFX) (kg/potlift) for CRA 3. The coloured bar represents the plateau (green) and the slope (orange) of the current CRA 3 management procedure.

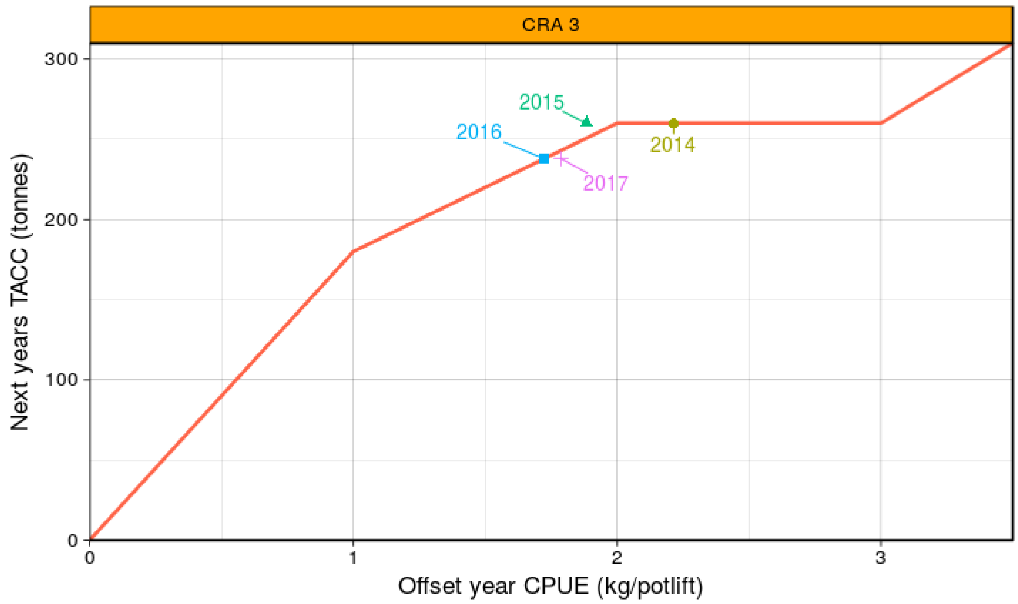


Figure 11: History of the current CRA 3 management procedure. The coloured symbols show the 2014 to 2017 offset-year CPUE and the resulting TACCs.

4.5 Management Procedure for CRA 4

First year with MP	2007
First year of current MP	2017
Review scheduled	2021
Input CPUE	offset year F2_LFX
Output	TACC
Type of rule	generalised plateau step rule
Latent year?	no
Minimum change	5%
Maximum change	none
2017–18 TAC	484
2017–18 customary allowance	35
2017–18 recreational allowance	85
2017–18 other mortality allowance	75
Total non-commercial allowance	195
2017–18 TACC	289

Table 21: Parameters for the CRA 4 generalised plateau step rule.

Par	Function	CRA 4 rule 6 value
par1	rule type	4
par2	CPUE at TACC = 0	0.0
par3	left plateau	0.9
par4	right plateau	1.3
par5	plateau height	380
par6	step width	0.1
par7	step height	0.053
par8	minimum change	0.05
par9	maximum change	0
par10	latent year switch	0

The current CRA 4 MP is based on a stock assessment conducted in 2016 (Breen et al. 2017) which was used as the operating model for the MPE. The Minister adopted rule 6 in March 2017, with parameter values shown in Table 21. The standardised offset-year CPUE (F2-LFX) in November 2016 was 0.6851 kg/potlift, which resulted in a 2017–18 TACC recommendation of 289.264 t (Table 22). The Minister retained the existing non-commercial allowances to set a 2017–18 TAC of 484 t, using allowances of 35 t for customary, 85 t for recreational and 75 t for other mortalities.

In November 2017, the offset-year CPUE (F2-LFX) was 0.7550 kg/potlift (Figure 12), a 10% increase from 0.6851 kg/potlift in 2016. Both values are on the slope to the left of the plateau, which starts at 0.9 kg/potlift (Figure 13). The change in CPUE is greater than the minimum change threshold of 5%, with a rule result to increase the 2018–19 TACC from 289 to 318.779 t (Table 22).

Table 22: History of the CRA 4 management procedure. 'Rule result' is the result of the management procedure after operation of all its components including thresholds.

Year	Applied to fishing year	Offset CPUE (kg/potlift)	Rule result: TACC (t)	Applied TACC (t)	Applied TAC (t)
2016	2017–18	0.6851	289.264	289	484
2017	2018–19	0.7550	318.778		

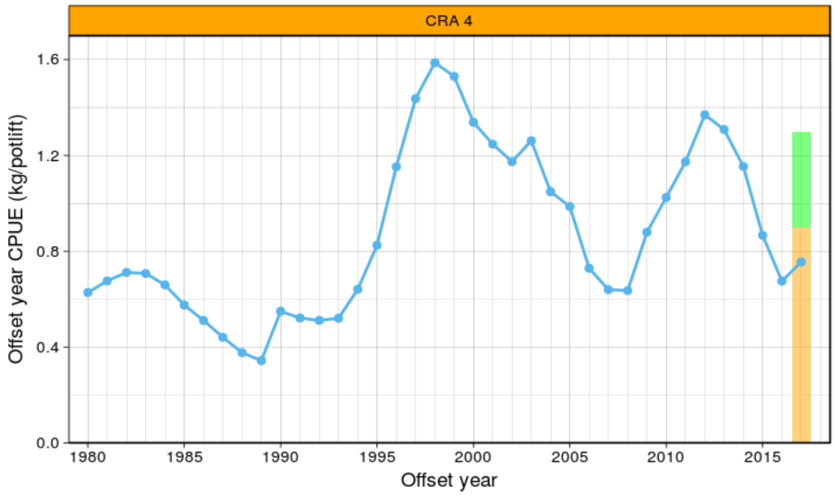


Figure 12: Offset-year CPUE (F2-LFX) (kg/potlift) for CRA 4. The coloured bar represents the plateau (green) and the slope (orange) of the current CRA 4 management procedure.

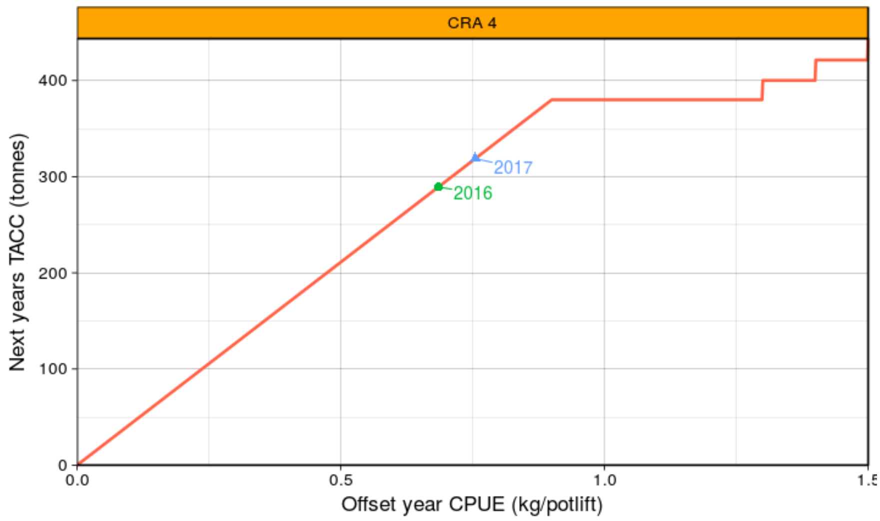


Figure 13: History of the current CRA 4 management procedure. The coloured symbols show the 2016 to 2017 offset-year CPUE and the 2017 TACC.

4.6 Management Procedure for CRA 5

First year with MP	2009
First year of current MP	2016
Review scheduled	2020
Input CPUE	offset year F2-LFX
Output	TACC
Type of rule	generalised plateau step rule
Latent year?	no
Minimum change	5%
Maximum change	none
2017–18 TAC	514
2017–18 customary allowance	40
2017–18 recreational allowance	87
2017–18 other mortality allowance	37
Total non-commercial allowance	164
2017–18 TACC	350

The current CRA 5 MP is based on evaluations made in 2015 by Starr & Webber (2016), using an operating model based on a stock assessment in the same year.

Table 23: Parameters for the CRA 5 generalised plateau step rule.

Par	Function	CRA 5 rule 45 value
par1	rule type	4
par2	CPUE at TACC = 0	0.3
par3	left plateau	1.2
par4	right plateau	2.2
par5	plateau height	350
par6	step width	0.2
par7	step height	0.055
par8	minimum change	0.05
par9	maximum change	0
par10	latent year switch	0

The current CRA 5 MP (Table 23) is based on a stock assessment conducted in 2015 (Starr & Webber 2016), which was used as the operating model for the MPE. The Minister adopted rule 45, retained the customary and other mortality allowances (40 and 37 t, respectively) from the 2015–16 TAC and increased the recreational allowance from 40 to 87 t, resulting in a 2016–17 TAC of 514 t (Table 24).

In November 2015, the offset-year CPUE was 1.789 kg/potlift, which was on the plateau and indicated no change to the 2016–17 TACC. In November 2016, offset-year CPUE was evaluated to be 1.5902 kg/potlift, which was also on the plateau, resulting in no change to the 2017–18 TACC. The November 2017 offset-year CPUE was 2.0482 kg/potlift, a 29% increase from 1.5902 in 2016 (Figure 14). This CPUE is less than 2.2 kg/potlift, which defines the upper limit of the plateau, and thus results in no change to the 2018–19 TACC (Figure 15).

Table 24: History of the existing CRA 5 management procedure. 'Rule result' is the result of the management procedure after operation of all its components including thresholds.

Year	Applied to fishing year	Offset CPUE (kg/potlift)	Rule result: TACC (t)	Applied TACC (t)	Applied TAC (t)
2015	2016–17	1.7890	350	350	514
2016	2017–18	1.5902	350	350	514
2017	2018–19	2.0482	350		

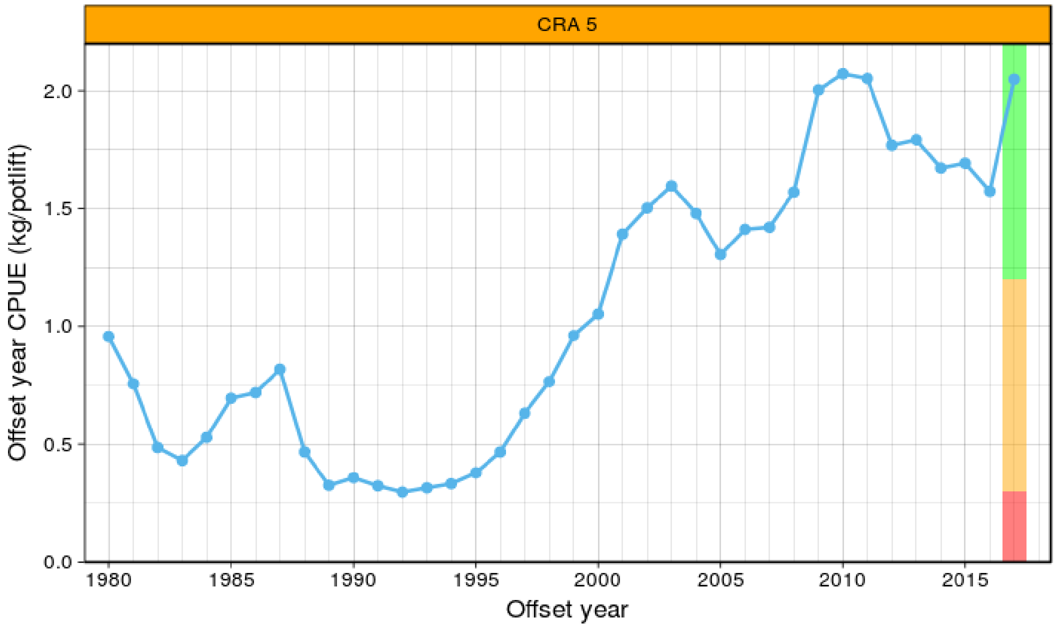


Figure 14: Offset-year CPUE (F2-LFX) (kg/potlift) for CRA 5. The coloured bar represents the plateau (green), the slope (orange), and the CPUE at which the TACC = 0 (red) of the current CRA 5 management procedure.

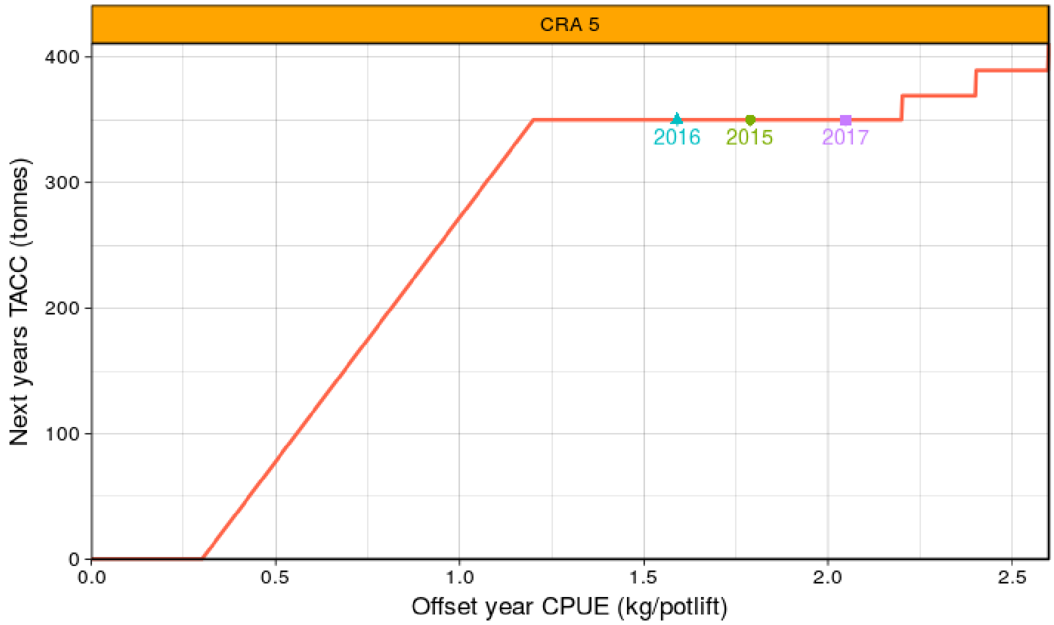


Figure 15: History of the current CRA 5 management procedure. The coloured symbols show the 2015 to 2017 offset-year CPUE and resulting TACCs.

4.7 Management Procedure for CRA 7

First year with MP	1996
First year of current MP	2013
Review scheduled	2020
Input CPUE	offset year F2-LFX
Output	TACC
Type of rule	generalised plateau slope rule
Latent year?	no
Minimum change	10%
Maximum change	50%
2017–18 TAC	132.52
2017–18 customary allowance	10.0
2017–18 recreational allowance	5.0
2017–18 other mortality	5.0
Total non-commercial allowance	20.0
2017–18 TACC	112.52

The CRA 7 MP is based on MPEs made in 2012 (Haist et al. 2013), which used an operating model based on the 2012 joint stock assessment for CRA 7 and CRA 8. These rules were evaluated in 2012 and again in 2015. The current MP (Table 25) is the latest in a series of MPs that have been operating in CRA 7 since the mid-1990s (Starr et al. 1997, Bentley et al. 2003, Breen et al. 2008).

Table 25: Parameters for the CRA 7 generalised plateau slope rule.

Par	Function	CRA 7 rule 39 value
par1	rule type	3
par2	CPUE at TACC = 0	0.17
par3	left plateau	1.00
par4	right plateau	1.75
par5	plateau height	80
par6	slope	3.0
par7	step height	n.a.
par8	minimum change	0.1
par9	maximum change	0.5
par10	latent year switch	0

The standardised offset-year CPUE (F2_LFX) in November 2012 was 0.625 kg/potlift, giving a 2013–14 TACC of 43.96 t. The Minister accepted this result, rounded it to 44 t, and used the allowances from the 2012–13 TAC (customary 10 t, recreational 5 t, other mortality 5 t) to set a 2013–14 TAC of 64 t (Table 26). In November 2013, the offset-year CPUE (F2_LFX) had more than doubled to 1.356 kg/potlift, which suggested a 2014–15 TACC of 80 t. This increase was greater than the maximum allowed increase of 50%, so the 2014–15 TACC was increased by 50% to 66 t (**Table 26**). In November 2014, the offset-year CPUE (F2_LFX) had increased to 2.304 kg/potlift, resulting in a 2014–15 TACC of 97.72 t.

The rule was reviewed in 2015 but was not changed (see Haist et al. 2016). In November 2015, CPUE had decreased by 4% to 2.212 kg/potlift, with a preliminary rule result for the 2016–17 TACC of 94.797 t. Because this change was less than the minimum change threshold of 10%, the MP result was no change to the 2016–17 TACC. In November 2016, the offset-year CPUE (F2_LFX) had increased to 2.776 kg/potlift, giving a 2017–18 TACC of 112.512 t. The increase of 25% was greater than the 10% minimum change threshold, so the MP result was an increase in the 2017–18 TACC to 112.512 t. The Minister rounded this result to 112.52 t and retained the existing allowances to set a 2017–18 TAC of 132.52 t (**Table 26**). The November 2017 offset-year CPUE was 2.328 kg/potlift, a 16% decrease from 2.766 in 2016 (Figure 16). The preliminary 2018–19 TACC from the harvest control rule was 98.499 t, a 12.5% decrease from the current TACC of 112.52 t. Because this is greater than the minimum change threshold of 10%, the result is a 12.5% decrease in the 2018–19 TACC to 98.499 t (Figure 17).

Table 26: History of the CRA 7 management procedure. 'Rule result' is the result of the management procedure after operation of all its components including thresholds.

Year	Applied to fishing year	Offset CPUE (kg/potlift)	Rule result: TACC (t)	Applied TACC (t)	Applied TAC (t)
2012	2013–14	0.625	43.960	44.00	64.00
2013	2014–15	1.356	66.000	66.00	86.00
2014	2015–16	2.304	97.720	97.72	117.72
2015	2016–17	2.212	97.720	97.72	117.72
2016	2017–18	2.766	112.512	112.52	132.52
2017	2018–19	2.328	98.499		

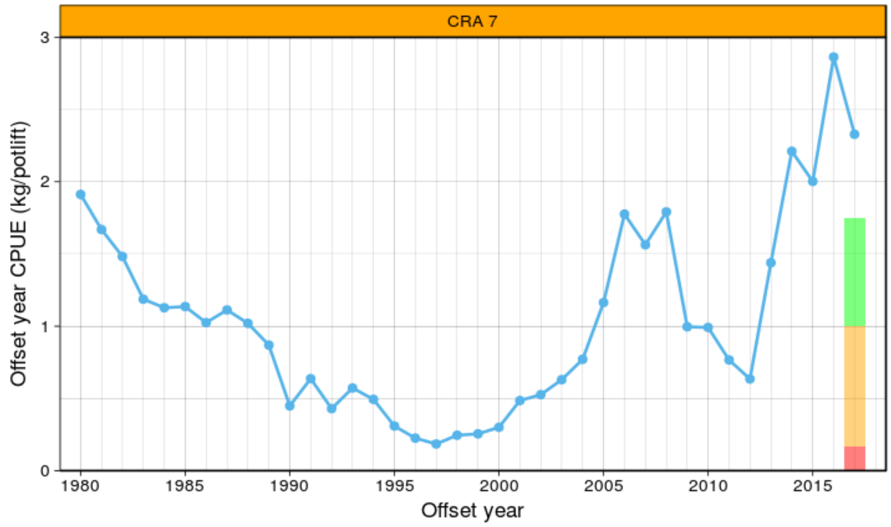


Figure 16: Offset-year CPUE (F2-LFX) (kg/potlift) for CRA 7. The coloured bar represents the plateau (green), the slope (orange), and the CPUE at which the TACC = 0 (red) of the current CRA 7 management procedure.

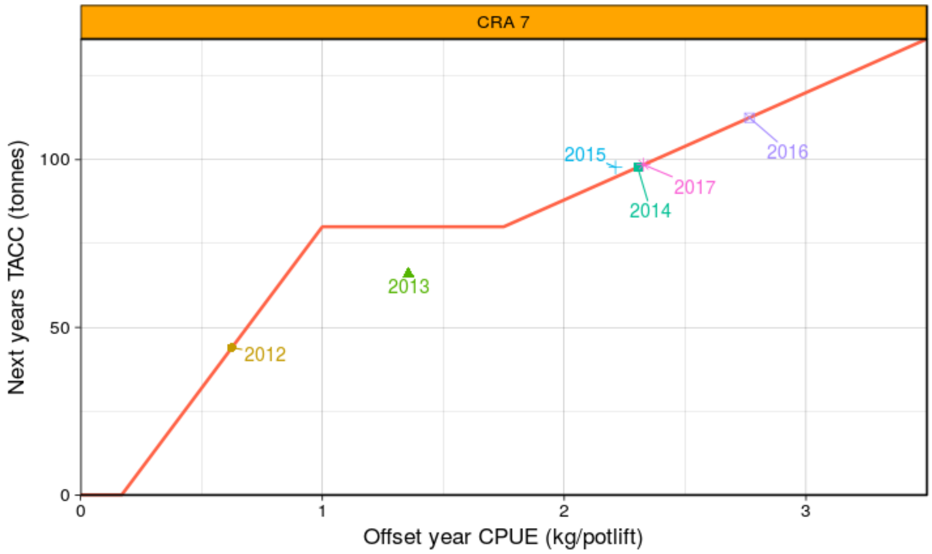


Figure 17: History of the current CRA 7 management procedure. The coloured symbols show the 2012 to 2017 offset-year CPUE and the resulting TACCs.

4.8 Management Procedure for CRA 8

First year with MP	1996
First year of current MP	2016
Review scheduled	2020
Input CPUE	offset year F2-LF (‘money fish CPUE’)
Output	TACC
Type of rule	generalised plateau slope rule
Latent year?	no
Minimum change	5%
Maximum change	no
2017–18 TAC	1053
2017–18 customary allowance	30
2017–18 recreational allowance	33
2017–18 other mortality allowance	28
Total non-commercial allowance	91
2017–18 TACC	962

The CRA 8 MP is based on evaluations made in 2015 (Haist et al. 2016), using an operating model that was based on a combined CRA 7/CRA 8 stock assessment conducted in 2015. The definition of the input CPUE was changed from F2_LFX to F2_LF, excluding large lobsters discarded because of their lower market value (estimated from the landing code ‘Destination X’; see Starr 2017). The current MP (Table 27) is the latest in a series of MPs that have been operating in CRA 8 since the mid-1990s (Starr et al. 1997, Bentley et al. 2003, Breen et al. 2008).

Table 27: Parameters for the CRA 8 generalised plateau slope rule.

Par	Function	CRA 8 rule
par1	rule type	4
par2	CPUE at TACC = 0	0.5
par3	left plateau	1.9
par4	right plateau	3.2
par5	plateau height	962
par6	step width	0.5
par7	step height	0.055
par8	minimum change	0.05
par9	maximum change	0
par10	latent year switch	0

In November 2015, the offset-year CPUE (F2_LF) was 3.0624 kg/potlift, which was on the plateau and resulted in no change to the 2016–17 TACC of 962 t. In November 2016, offset-year CPUE (F2_LF) was 3.0254 kg/potlift, also on the plateau, so the MP result was no change to the 2017–18 TACC. The November 2017 offset-year CPUE (F2_LF) was 3.7113 kg/potlift, a 23% increase from 3.0254 in 2016 (Figure 18). This CPUE was above the upper limit of the rule plateau (Figure 19), with the MP giving a 2018–19 TACC of 1070.7 t, an 11.3% increase from the 2017–18 TACC of 962 t. Because this is greater than the minimum change threshold of 5%, the MP recommendation is an 11.3% increase in the 2018–19 TACC to 1070.7 t (Table 28).

Table 28: History of the CRA 8 management procedure. ‘Rule result’ is the result of the management procedure after operation of all its components including thresholds. Note that CPUE before 2013–14 was estimated with a different algorithm from the current method.

Year	Applied to fishing year	Offset CPUE (kg/potlift)	Rule result: TACC (t)	Applied TACC (t)	Applied TAC (t)
2015	2016–17	3.0620	962.0	962	1053
2016	2017–18	3.0254	962.0	962	1053
2017	2018–19	3.7113	1070.7		

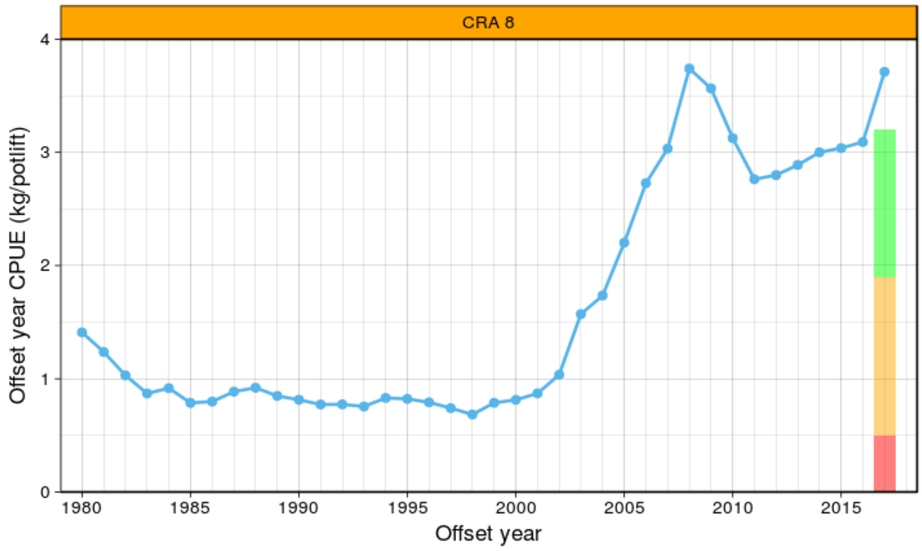


Figure 18: Offset-year CPUE (F2-LF) (kg/potlift) for CRA 8. The coloured bar represents the plateau (green), the slope (orange), and the CPUE at which the TACC = 0 (red) of the current CRA 8 management procedure.

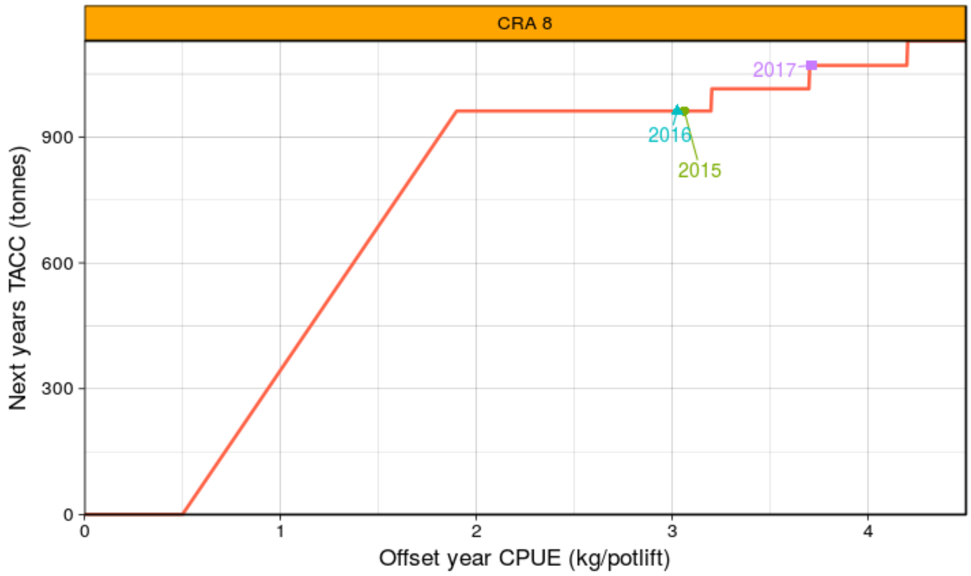


Figure 19: History of the current CRA 8 management procedure. The coloured symbols show the 2015 to 2017 offset-year CPUE and the resulting TACCs.

4.9 Management Procedure for CRA 9

A management procedure for CRA 9, based on a Fox surplus-production stock assessment model and MPEs, was used for the 2014–15 fishing year (Breen 2014). However, an audit of the CRA 9 CPUE data in 2015 suggested that the CRA 9 CPUE index was not a reliable indicator of abundance in CRA 9 because of the small number of vessels fishing in recent years (six or fewer), problems with reporting, and the large size of the CRA 9 area, with changes in the area fished affecting CPUE substantially. The National Rock Lobster Management Group (NRLMG) agreed in 2016 to reject the CRA 9 management procedure.

5. ENVIRONMENTAL AND ECOSYSTEM CONSIDERATIONS

This section was last updated for the November 2012 Plenary after review by the Aquatic Environment Working Group. This summary is from the perspective of the rock lobster fisheries; a more detailed summary from an issue-by issue perspective is available in the Ministry’s Aquatic

Environment and Biodiversity Annual Review (http://www.mpi.govt.nz/news-resources/publications.aspx).

The environmental effects of rock lobster fishing have been covered more extensively by Breen (2005) and only those issues deemed most important, or of particular relevance to fisheries management, are covered here.

5.1 Ecosystem role

Rock lobsters are predominantly nocturnal (Williams & Dean 1989). Their diet is reported to be comprised primarily of molluscs and other invertebrates (Booth 1986, Andrew & Francis 2003). Survey and experimental work has shown that predation by rock lobsters in marine reserves is capable of influencing the demography of surf clams of the genus *Dosinia* (Langlois et al. 2005, Langlois et al. 2006).

Predation by rock lobsters has been suggested as contributing to trophic cascades in a number of studies in New Zealand (e.g., Babcock et al. 1999, Edgar & Barrett 1999). Schiel (2013), in reviewing the Leigh Marine Reserve story, questions whether results from north-eastern New Zealand are generally applicable to the rest of New Zealand. Schiel (1990) argued that sea urchins did not seem to demonstrate widescale dominance outside north-eastern New Zealand, although at that time there were limited surveys elsewhere, and suggested that sea urchin outbreaks were rare in southern waters despite heavy lobster fishing at that time. Schiel & Hickford (2001) found that barrens were more characteristic of kelp communities north of Cook Strait. In the south they were not common. A literature review (Breen unpublished) suggests that the evidence for lobster-driven trophic cascades in New Zealand is very thin.

Published scientific observations support predation upon rock lobsters by octopus (Brock et al. 2003), rig (King & Clarke 1984), blue cod, groper, southern dogfish (Pike 1969) and seals (Yaldwyn 1958, cited in Kensler 1967).

5.2 Fishery interactions (fish and invertebrates)

The levels of incidental catch landed from rock lobster potting were analysed for the period 1989–2003 (Table 26 in Bentley et al. 2005). Non-rock lobster catch landed ranged from 2 to 11% of the estimated rock lobster catch weight per QMA over this period. These percentages are based on estimated catches only and it is likely that not all bycatch is reported (only the top five species are requested) and that the quality of the weight estimates will vary between species There were 129 species recorded landed from lobster pots over this period. The most frequently reported incidental species caught (comprising on average greater than 99% of the bycatch per QMA) were, in decreasing order of catch across all stocks: octopus, conger eel, blue cod, trumpeter, sea perch, red cod, butterfish and leatherjackets.

5.3 Fishery interactions (seabirds and mammals)

Recovery of shags from lobster pots has been documented in New Zealand. One black shag (*Phalacrocorax carbo*) of 41 recovered dead from a Wairarapa banding study was found drowned in a crayfish pot hauled up from 12 m depth (Sim & Powlesland 1995). A survey of rock lobster fishers on the Chatham Islands (Bell 2012) reported no shag bycatch in the past five years (2007–08 to 2011–12 fishing season), only 2 shag captures between five and ten years ago (2001–02 to 2006–07 fishing season), and 18 shags caught more than 10 years ago (prior to 2000–01 season). The fishers suggested the lack of reported shag captures in the past five years was attributable to changes in pot design and baiting methodologies.

From January 2000 there have been 18 reported entanglements of 16 marine mammals attributed to commercial or recreational rock lobster pot lines from around New Zealand, mainly around Kaikoura (DOC Marine Mammal Entanglement Database, available from the DOC Kaikoura office). No mortalities were observed, although mortalities are likely to be caused by prolonged entanglement, and therefore might not be observed within the same area. CRA 5 commercial fishermen work to a voluntary code of practice to avoid entanglements, recreational fishers do not. The commercial fishermen in CRA 5 also cooperate with the Department of Conservation to assist releases when entanglements occur.

5.4 Benthic impacts

Potting is the main method of targeting rock lobster and is usually assumed to have very little direct impact on non-target species. No information exists regarding the benthic impacts of potting in New Zealand.

A study on the impacts of lobster pots was completed in a report on the South Australian rock lobster fisheries (Casement & Svane 1999). This fishery is likely to be the most comparable to New Zealand as the same species of rock lobster is harvested and many of the same species are present, although the details of pots and how they are fished may differ. The report concluded that the mass of algae removed in pots probably has no ecological significance.

Two other studies provide results from other parts of the world, but the comparability of these studies to New Zealand is questionable given differences in species and fishing techniques. The Western Australia Fishery Department calculated the proportion of corals (the most sensitive fauna) likely to be impacted by potting, and concluded it was low, i.e., between 0.1 and 0.3% per annum (Department of Fisheries Western Australia 2007). This kind of calculation for the New Zealand fishery would require better habitat maps than currently exist for most parts of the coast (Breen 2005) as well as finer-scale catch information than the Ministry currently possesses. Direct effects of potting on the benthos have been studied in Great Britain (Eno et al. 2001) and four weeks of intensive potting resulted in no significant effects on any of the rocky-reef fauna quantified. Observations in this paper indicated that sea pens were bent (but not damaged) and one species of coral was damaged by pots.

The only regulatory limitation on where lobster pots can be used is inside marine reserve boundaries; however, in Fiordland, four areas within marine reserves have been designated for commercial pot storage due to the shortage of suitable space (Fiordland Marine Guardians 2008). Likewise, in the Taputeranga marine reserve (Wellington) an area is designated for vessel mooring and the storage of ‘holding pots’ by commercial fishermen.

5.5 Other considerations

An area near North Cape is currently closed to packhorse lobster fishing to mitigate sub-legal handling disturbance in this area. This closure was generated due to the smaller sizes of animals there and results from a tagging study that showed movement away from this area into nearby fished areas (Booth 1979).

5.6 Key information gaps

Breen (2005) identified that the most likely areas to cause concern for rock lobster fishing in a detailed risk assessment were: ghost fishing, everyday bycatch and its effect on bycatch species, effects on habitats and protected species, and indirect effects on marine communities caused by the removal of large predators. At this time no prioritisation has been applied to this list.

6. STOCK ASSESSMENT

A new stock assessment was conducted in 2017 for CRA 2 and is summarised below. This section also repeats stock assessment results for other stocks from previous mid-year Plenary documents: text relating to other stocks has not been updated from the originals and reflects the TAC, TACC and allowances that were current at the time each assessment was completed.

6.1 CRA 1

This section describes a stock assessment for CRA 1 conducted in 2014.

Model structure

A single-stock version of the multi-stock length-based model (MSLM, Haist et al. 2009) was fitted to data from CRA 1, including seasonal standardised CPUE from 1979 to 2013, length frequencies from observer and voluntary (logbook) catch sampling, and tag-recapture data. Historical catch rate data from 1963 to 1973 was not included. The model used an annual time step from 1945 through 1978 and then used a seasonal time step with autumn–winter (AW, April through September) and spring–summer (SS) from 1979 through 2013. The model had 93 length bins, 31 for each sex group (males, immature and mature females), each 2 mm TW wide, beginning at a left-hand edge of 30 mm TW.

The reconstruction assumed that the stock was unexploited before 1945. MLS and escape gap regulations in 1945 differed from those in 2013. To accommodate these differences, the model incorporated a time series of MLS regulations by sex and modelled escape gap regulation changes by estimating separate selectivity functions before and after 1993. A comparison of landed commercial grade weights with observer length-frequency data converted to an equivalent weight distribution indicated that it was not necessary to adjust for the discarding of legal lobsters in CRA 1. Data used in the assessment and their sources are listed in Table 29.

Table 29: Data types and sources available for the 2014 stock assessment of CRA 1. Fishing years are named from the first nine months, i.e., 1998–99 is called 1998. N/A – not applicable or not used; MPI – NZ Ministry for Primary Industries; NZ RLIC – NZ Rock Lobster Industry Council Ltd.; FSU – Fisheries Statistics Unit; CELR – catch and effort landing returns; NIWA – National Institute of Water and Atmosphere.

		CRA 1	
Data type	Data source	Begin year	End year
CPUE	FSU & CELR	1979	2013
Observer proportions-at-size	MPI and NZ RLIC	1997	2013
Logbook proportions-at-size	NZ RLIC	1993	2013
Tag recovery data	NZ RLIC & MFish	1975	2013
Historical MLS regulations	Annala (1983), MPI	1950	2013
Escape gap regulation changes	Annala (1983), MPI	1945	2013
Puerulus settlement	NIWA	N/A	N/A
Retention	NZ RLIC	N/A	N/A

The assessment assumed that recreational catch was proportional to the combined unstandardised SS CPUE from Statistical Areas 903 and 904 (east coast, North Island) from 1979 through 2013. Recreational surveys from 1994, 1996, 2011 and 2013 were used to calculate the mean ratio of recreational catch to the SS CPUE. This ratio was used to estimate recreational catch for 1979–2013 based on the SS CPUE. It was assumed that recreational catch increased linearly from 20% of the 1979 value in 1945 to the 1979 value.

The initial population in 1945 was assumed to be at an unfished equilibrium. Each season, the number of male, immature female and mature female lobsters in each size class were updated as a result of:

a) **Recruitment:** Each year, new recruits to the model were added equally for each sex for each season as a normal distribution with a mean size (32 mm) and standard deviation (2 mm), truncated at the smallest size class (30 mm). Recruitment in a specific year was determined by the parameters for base recruitment and parameters for the deviations from base recruitment. The vector of recruitment deviations in natural log space was assumed to be normally distributed with a mean of zero. Recruitment deviations were estimated for 1945 through 2011.

b) **Mortality:** Natural, fishing and handling mortalities were applied to each sex category in each size class. Natural mortality was assumed to be constant and independent of sex and length. Fishing mortality was determined from observed catch and model biomass, modified by legal sizes, sex-specific vulnerabilities and selectivity. Handling mortality was assumed to be 10% for fish returned to the water. Two fisheries were modelled: one that operated only on fish above the size limit, excluding berried females (size-limited (SL) fishery – consisting of legal commercial and recreational) and one that did not respect size limits and restrictions on berried females (non-size-limited (NSL) fishery – the illegal fishery plus the Maori customary fishery). Selectivity and vulnerability functions were otherwise the same for the SL and NSL fisheries.

Vulnerability by sex category and season was estimated relative to males in AW, which were assumed to have the highest vulnerability. Instantaneous fishing mortality rates for each fishery were calculated using Newton-Raphson iterations (three and five iterations were trialed, and three iterations were used after finding little difference) using catch, model biomass and natural mortality.

c) **Fishery selectivity:** A three-parameter fishery selectivity function was assumed, with parameters describing the shapes of the ascending and descending limbs and the size at which vulnerability is at a maximum. Selectivity was estimated separately for males and females over two separate epochs, pre- and post-1993. As in previous assessments, the descending limb of the selectivity curve was fixed to prevent underestimating the vulnerability of large lobsters.

d) **Growth and maturation:** For each size class and sex category, a growth transition matrix specified the probability of an individual lobster remaining in the same size class or growing into each of the other size classes, including smaller size classes. Maturation of females was estimated as a two-parameter logistic curve from the maturity-at-size information in the size-frequency data.

Model fitting
A total negative log-likelihood function was minimised using AD Model Builder™. The model was fitted to standardised CPUE using a lognormal likelihood, to proportions-at-length with a multinomial likelihood and to tag-recapture data with a robust normal likelihood. For the CPUE likelihoods, CVs for each index value were initially set at the standard error from the General Linear Model (GLM) analysis. Process error was subsequently added to these CVs.

Proportions-at-length, assumed to be representative of the commercial catch, were available (see Table 29) from observer catch sampling and voluntary logbooks. These data were summarised by area/month strata and weighted by the commercial catch taken in each stratum, the number of lobsters measured and the number of days sampled. Data from observers and logbooks were fitted separately. Fitting the length data followed the procedure used in 2013 for CRA 2, which differed from previous assessments that normalised across males, immature and mature females before fitting, thus fixing the sex ratios to those observed in the data. For this assessment, proportions were normalised and fitted within each sex category, with the model also estimating proportions-at-sex using a multinomial likelihood. These data were weighted within the model using the method of Francis (2011). One length-frequency sample was removed from the dataset because of the enormous residuals (greater than 800) generated when fitting to these data.

In the base case and all the sensitivity runs but one, it was assumed that CPUE was directly proportional to the vulnerable biomass. All runs assumed no stock-recruit relationship. Base case explorations involved experimentally weighting the datasets and inspecting the resulting standard deviations of normalised residuals and medians of absolute residuals, estimating the growth, maturity and selectivity parameters and experimenting with the fitting method for proportions-at-length. The tagging data were fitted well in this model and it was not necessary to fix the growth CV as has been done in most previous rock lobster stock assessments.

Parameters estimated in the base case and their priors are provided in Table 30. Informed normal priors were used to constrain the selectivity parameters for both sexes. This step was necessary because there were no length-frequency data available to inform the first epoch, which ended in 1992 (the length-frequency data started in 1993). The mean of the prior for each selectivity parameter was taken from the median of the posterior for the same parameter from the 2013 CRA 2 stock assessment and a CV of 20% was assumed. Fixed parameters and their values are given in Table 31.

Model projections

Bayesian inference was used to estimate the uncertainty in model estimates and short-term projections. This procedure was conducted in the following steps:

1. Model parameters were estimated by AD Model Builder™ using maximum likelihood and the prior probability distributions. These estimates are called the MPD (mode of the joint posterior distribution) estimates.
2. Samples from the joint posterior distribution of parameters were generated with Markov chain Monte Carlo (MCMC) simulations using the Metropolis-Hastings algorithm. Twenty-two million simulations were done, starting from the base case MPD, and 1000 samples were saved.
3. From each sample of the posterior, 4-year projections (2014–17) were generated using the 2013 catches, with annual recruitment randomly sampled from a distribution based on the model's estimated recruitments from 2002–11.

Table 30: Parameters estimated and priors used in the base case assessment for CRA 1. Prior type abbreviations: U – uniform, N – normal, L – lognormal.

Parameter	Prior type	No. of parameters	Bounds	Mean	SD	CV
ln(*R0*) (mean recruitment)	U	1	1–25	–	–	–
M (natural mortality)	L	1	0.01–0.35	0.12	–	0.4
Recruitment deviations	N [1]	67	-2.3–2.3	0	0.4	
ln(*qCPUE*)	U	1	-25–0	–	–	–
Increment at TW=50 (male & female)	U	2	1–20	–	–	–
ratio of TW=80 increment to TW=50 increment (male & female)	U	2	0.001–1.000	–	–	–
shape of growth curve (male & female)	U	2	0.1–15.0	–	–	–
TW at 50% probability female maturation	U	1	30–80	–	–	–
difference between TWs at 95% and 50% probability female maturation	U	1	3–60	–	–	–
Relative vulnerability (all sexes and seasons)	U	4	0.01–1.0	–	–	–
Shape of selectivity left limb (males & females)	N	2	1–50	males=4.1; females=9,2	males=0.82; females=1.84	–
Size at maximum selectivity (males & females)	N	2	30–90	males=55; females=64	males=11; females=12.8	–

[1] Normal in natural log space = lognormal (bounds equivalent to –10 to 10).

Table 31: Fixed values used in base case assessment for CRA 1.

Value	CRA 1
Shape parameter for CPUE vs biomass	1.0
Minimum std. dev. of growth increment	1.6
Std. dev. of observation error of increment	0.6
Shape of growth density-dependence	0.0
Handling mortality	10%
Process error for CPUE	0.25
Year of selectivity change	1993
Current male size limit (mm TW)	54
Current female size limit (mm TW)	60
First year for recruitment deviations	1945
Last year for recruitment deviations	2011
Relative weight for male length frequencies	2.52
Relative weight for immature female length frequencies	1.0
Relative weight for mature female length frequencies	2.23
Relative weight for proportions-at-sex	14
Relative weight for CPUE	2.8
Relative weight for tag-recapture data	0.7

Performance indicators and results

Vulnerable biomass in the assessment model was determined by the MLS, selectivity, relative sex and seasonal vulnerability and berried state for mature females. All mature females in AW were assumed to be berried and not vulnerable to the SL fishery, and not berried, and thus vulnerable, in SS.

Agreed indicators are summarised in Table 32. After inspection of the vulnerable biomass trajectory, the RLFAWG agreed to keep *Bref* as defined in the previous (2002) stock assessment (mean 1979–88 biomass), using the current MLS and selectivity.

Base case results (Figure 20 and Table 33) suggest that AW biomass decreased to a low point in the early 1970s, remained low until the mid-1990s and has increased since. Median projected biomass, with current catches over four years, was slightly higher than the current biomass. Estimated current biomass is well above *Bref* and neither current nor projected biomass was near the soft limit of 20% *SSB0*.

MCMC sensitivity trials were also made:

- *Uniform M*: same as the base case except that *M* was estimated with an uninformative prior
- *Alt recreational catch*: uses an alternative procedure to estimate recreational catch, resulting in an increasing catch series
- *Half illegal catch*: uses half the base case illegal catch trajectory
- *Double illegal catch*: uses twice the base case illegal catch trajectory
- *Fixed M=0.2*: same as the base case except *M* fixed at 0.2.

Results from the base case and sensitivity trials are compared in Table 33.

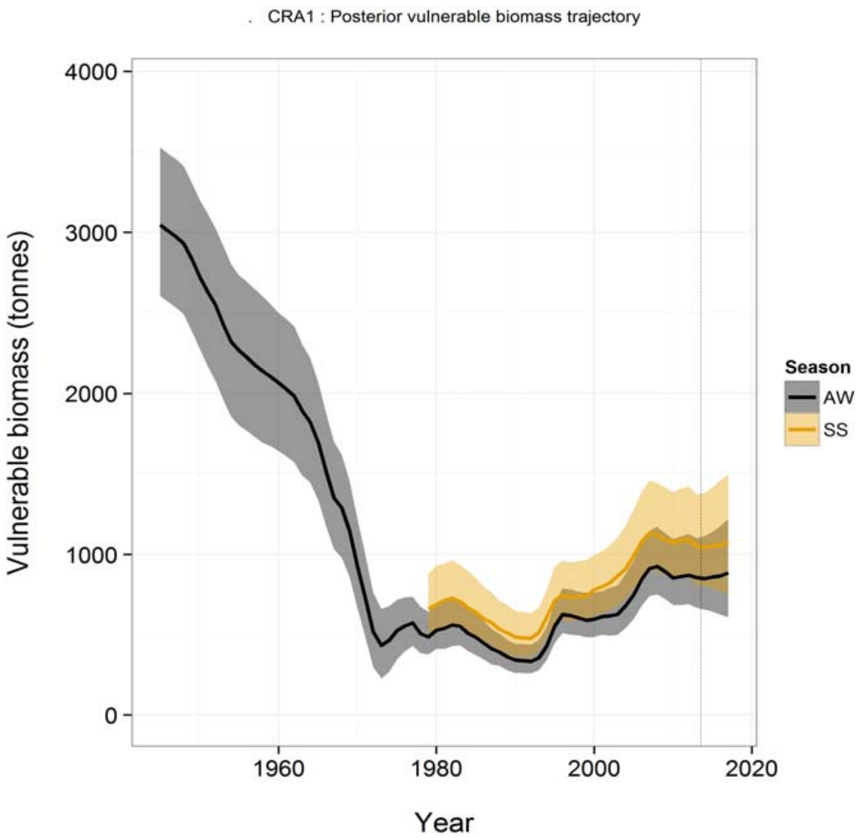


Figure 20: Posterior distributions of the CRA 1 base case vulnerable biomass and projected vulnerable biomass by season from 1945 to 2013. Shaded areas show the 90% credibility intervals and the solid line is the median of the posterior distributions. The vertical line shows 2013, the final fishing year of the model reconstruction. Biomass before 1979 is annual, but is plotted using the AW coding.

Table 32: Performance indicators used in the CRA 1 stock assessment.

Reference points	Description
Bmin	The lowest beginning AW vulnerable biomass in the series
Bcurrent	Beginning of season AW vulnerable biomass for 2014
Bref	Beginning of AW season mean vulnerable biomass for 1979–88
Bproj	Projected beginning of season AW vulnerable biomass (i.e., 2017)
Bmsy	Beginning of season AW vulnerable biomass associated with *MSY*, calculated by doing deterministic forward projections with recruitment *R0* and current fishing patterns
MSY	Maximum sustainable yield (sum of AW and SS SL catches) found by searching across a range of multipliers on *F*.
Fmult	The multiplier that produced *MSY*
SSBcurr	Current spawning stock biomass at start of AW season
SSBproj	Projected spawning stock biomass at start of AW season (2017)
SSBmsy	Spawning stock biomass at start of AW season associated with *MSY*

CPUE indicators	Description
CPUEcurrent	CPUE at *Bcurrent*
CPUEproj	CPUE at *Bproj*
CPUEmsy	CPUE at *Bmsy*

Performance indicators	Description
Bcurrent / Bmin	ratio of *Bcurrent* to *Bmin*
Bcurrent / Bref	ratio of *Bcurrent* to *Bref*
Bcurrent / Bmsy	ratio of *Bcurrent* to *Bmsy*
Bproj / Bcurrent	ratio of *Bproj* to *Bcurrent*
Bproj / Bref	ratio of *Bproj* to *Bref*
Bproj / Bmsy	ratio of *Bproj* to *Bmsy*
SSBcurr/SSB0	ratio of *SSBcurrent* to *SSB0*
SSBproj/SSB0	ratio of *SSBproj* to *SSB0*
SSBcurr/SSBmsy	ratio of *SSBcurrent* to *SSBmsy*
SSBproj/SSBmsy	ratio of *SSBproj* to *SSBmsy*
SSBproj/SSBcurr	ratio of *SSBproj* to *SSBcurrent*
USLcurrent	The current exploitation rate for SL catch in AW
USLproj	Projected exploitation rate for SL catch in AW (2017)
USLproj/USLcurrent	ratio of SL projected exploitation rate to current SL exploitation rate
Btotcurrent	Total biomass (all sizes and sex, regardless of maturity) at beginning of AW 2014
Btotcurrent/Btot0	Total biomass[2014]/[equilibrium unfished total biomass]
Ntotcurrent	Total numbers (all sizes and sex, regardless of maturity) at beginning of AW 2014
Ntotcurrent/Ntot0	Total numbers[2014]/[equilibrium unfished total numbers]

Probabilities	Description
P*(Bcurrent > Bmin)*	probability *Bcurrent* > *Bmin*
P*(Bcurrent > Bref)*	probability *Bcurrent* > *Bref*
P*(Bcurrent > Bmsy)*	probability *Bcurrent* > *Bmsy*
P*(Bproj > Bmin)*	probability *Bproj* > *Bmin*
P*(Bproj > Bref)*	probability *Bproj* > *Bref*
P*(Bproj > Bmsy)*	probability *Bproj* > *Bmsy*
P*(Bproj > Bcurrent)*	probability *Bproj* > *Bcurrent*
P*(SSBcurr>SSBmsy)*	probability *SSBcurr>SSBmsy*
P*(SSBproj>SSBmsy)*	probability *SSBproj>SSBmsy*
P*(USLproj>USLcurr)*	probability SL exploitation rate *proj* > SL exploitation rate *current*
P*(SSBcurr<0.2SSB0)*	soft limit: probability *SSBcurrent* < 20% *SSB0*
P*(SSBproj<0.2SSB0*	soft limit: probability *SSBproj* < 20% *SSB0*
P*(SSBcurr<0.1SSB0)*	hard limit: probability *SSBcurrent* < 10% *SSB0*
P*(SSBproj<0.1SSB0)*	hard limit: probability *SSBproj* < 10% *SSB0*
P(*Bcurr*<50%*Bref*)	soft limit: probability *Bcurr* < 50% *Bref*
P(*Bcurr*<25%*Bref*)	hard limit: probability *Bcurr* < 25% *Bref*
P(*Bproj*<50%*Bref*)	soft limit: probability *Bproj* < 50% *Bref*
P(*Bproj*<25%*Bref*)	hard limit:probability *Bproj*< 25% *Bref*

Table 33: Assessment results: median and probability indicators for CRA 1 from the base case MCMC and sensitivity trials. Biomass in t and CPUE in kg/pot. [Continued on next page]

Indicator	basecase	uniform *M*	Alt recrea-tional catch	Half illegal catch	Double illegal catch	Fixed *M*=0.2
Bmin	315.1	332.9	340.3	286.4	402.8	433.6
Bcurr	850.5	882.3	889.0	779.5	1 076.0	1 187.4
Bref	493.1	509.5	516.1	451.9	618.5	690.4
Bproj	884.4	926.4	931.4	808.2	1 105.3	1 213.0
Bmsy	421.0	415.3	427.2	370.3	493.8	268.2
MSY	161.1	166.2	160.5	176.9	137.1	228.4
Fmult	1.92	2.07	1.80	2.16	1.74	6.43
SSBcurr	811.2	823.7	831.9	734.6	975.3	974.0
SSBproj	820.3	846.2	851.9	745.4	983.2	1 002.2
SSBmsy	485.1	476.6	472.0	442.1	535.8	397.9
CPUEcurrent	1.36	1.36	1.35	1.36	1.35	1.35
CPUEproj	1.39	1.41	1.39	1.41	1.37	1.37
CPUEmsy	0.635	0.589	0.607	0.609	0.585	0.249
Bcurr/Bmin	2.66	2.64	2.60	2.66	2.63	2.68
Bcurr/Bref	1.73	1.73	1.72	1.73	1.73	1.71
Bcurr/Bmsy	2.00	2.15	2.09	2.09	2.16	4.45
Bproj/Bcurr	1.02	1.03	1.03	1.03	1.02	1.02
Bproj/Bref	1.78	1.80	1.78	1.77	1.77	1.75
Bproj/Bmsy	2.08	2.23	2.19	2.18	2.21	4.54
SSBcurr/SSB0	0.500	0.513	0.514	0.507	0.514	0.684
SSBproj/SSB0	0.506	0.522	0.523	0.514	0.518	0.700
SSBcurr/SSBmsy	1.66	1.74	1.75	1.66	1.81	2.45
SSBproj/SSBmsy	1.68	1.77	1.80	1.68	1.83	2.51
SSBproj/SSBcurr	1.01	1.02	1.01	1.01	1.01	1.02
USLcurrent	0.0845	0.0817	0.083	0.093	0.067	0.0601
USLproj	0.0837	0.0798	0.079	0.092	0.067	0.0610
USLproj/USLcurrent	1.00	0.99	0.98	1.00	1.02	1.02
Btotcurrent	1949	2006	2,014	1,768	2,421	2636
Btotcurrent/Btot0	0.395	0.412	0.412	0.398	0.425	0.627
Ntotcurrent	3 205 570	3 327 850	3 345 750	2 926 430	4 039 080	4 638 490
Ntotcurrent/Ntot0	0.622	0.635	0.648	0.616	0.656	0.800
P(Bcurr>Bmin)	1	1	1	1	1	1
P(Bcurr>Bref)	1	1	1	1	1	1
P(Bcurr>Bmsy)	1	0.999	1	0.999	1	1
P(Bproj>Bmin)	1	1	1	1	1	1
P(Bproj>Bref)	0.999	1	1	0.998	1	0.999
P(Bproj>Bmsy)	0.997	0.998	0.998	0.996	0.999	1
P(Bproj>Bcurr)	0.576	0.611	0.612	0.592	0.552	0.562
P(SSBcurr>SSBmsy)	1	1	1	1	1	1
P(SSBproj>SSBmsy)	0.998	1	0.999	0.997	0.999	1
P(USLproj>USLcurr)	0.507	0.478	0.443	0.486	0.533	0.577
P(SSBcurr<0.2SSB0)	0	0	0	0	0	0
P(SSBproj<0.2SSB0	0	0	0	0	0	0
P(SSBcurr<0.1SSB0)	0	0	0	0	0	0
P(SSBproj<0.1SSB0)	0	0	0	0	0	0

The median *Bref* was larger than the median *Bmsy* in all trials. Current biomass was larger than *Bmin* and *Bmsy* with 100% probability in all cases. Projected biomass was greater than the current biomass with greater than 50% probability in all trials. Projected biomass had a median of over double *Bmsy*, and the probability of being above *Bmsy* was near 100% in all cases.

Indicators based on *SSBmsy*

The historical track of biomass versus fishing intensity is shown in Figure 21. The phase space in the plot is spawning biomass on the abscissa and fishing intensity on the ordinate. Thus high biomass/low fishing intensity is in the lower right-hand corner, where a stock would be when fishing first began, and low biomass/high intensity is in the upper left-hand corner, where an uncontrolled fishery is likely to go. The x-axis is spawning stock biomass *SSB* in year *y* as a proportion of the unfished spawning stock, *SSB0*. *SSB0* is constant for all years of a run, but varies through the 1000 samples from the posterior distribution.

The y-axis is fishing intensity in year *y* as a proportion of the fishing intensity (*Fmsy*) that would have given MSY under the fishing patterns in year *y*. Fishing patterns include MLS, selectivity, the seasonal catch split and the balance between SL and NSL catches. *Fmsy* varies every year because the fishing patterns change. It was calculated with a 50-year projection for each year in each run, with the NSL catch held constant at that year's value, deterministic recruitment at *R0* and a range of multipliers on the SL catch *F*s estimated for year *y*. The *F* that gave MSY is *Fmsy*, and the multiplier was *Fmult*.

Each point on Figure 21 shows the median of the posterior distributions of biomass ratio and fishing intensity ratio. The vertical line in the Figure 21 is the median (line) and 90% interval (shading) of the posterior distribution of *SSBmsy* as a proportion of *SSB0*. This ratio was calculated using the fishing pattern in 2013. The horizontal line in Figure 21 is drawn at 1, the fishing intensity associated with *Fmsy*. The bars at the final year of the plot show the 90% intervals of the posterior distributions of biomass ratio and fishing intensity ratio.

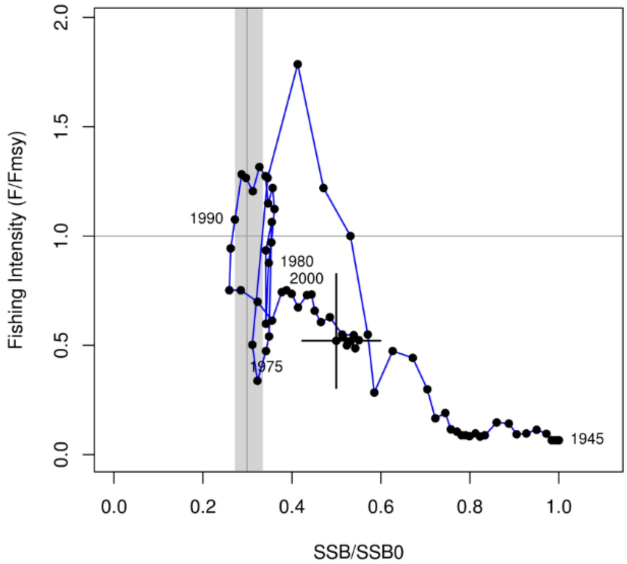


Figure 21: Snail trail summary of the CRA 1 base case model. The line tracks the median values for each axis from the MCMC posteriors and the cross marks the 90% credibility interval on both axes for the final model year (2013). The vertical line in the figure is the median (line) and 90% interval (shading) of the posterior distribution of *SSBmsy*. This ratio was calculated using the fishing pattern in 2013. The horizontal line in the figure is drawn at 1, the fishing intensity associated with *Fmsy*.

6.2 CRA 2

This section describes a stock assessment for CRA 2 conducted in 2017. This assessment marks the transition from the multi-stock length-based model (MSLM) of Haist et al. (2009) to the new lobster stock dynamics (LSD) model (Webber, pers. comm.). This change was made to consolidate the code in a software environment with fewer constraints than in the previous ADMB software environment. Extensive testing was made to satisfy the stock assessment team that the two models provided equivalent results.

Length-frequency sampling and tagging

The CRA 2 fishing industry made a strong commitment to the voluntary logbook programme when it was first introduced in 1993 and has continued to use this design as the primary source of stock monitoring information in this fishery. CRA 2 was also identified in the mid-1990s as an important region for tagging experiments, which resulted in considerable tagging effort expended in this QMA. There is also an auxiliary observer sampling programme in CRA 2. Twelve sampling days have been assigned to this programme in recent years; the primary purpose of this additional sampling to serve as a check on the voluntary logbook programme. Both sets of data were used in the 2017 stock assessment.

Model structure, including changes from 2013 CRA 2 stock assessment

The 2017 CRA 2 stock assessment made the following modelling changes from the 2013 stock assessment:

- the reconstruction starts in 1979 from a size distribution in equilibrium with R_0 and an initial estimated exploitation rate;
- was fitted to two CPUE series: FSU from 1979 to 1988 and CELR from 1989 to 2016, with the CELR series standardised by including a vessel explanatory variable based on vessels with at least five years in the fishery;
- no density-dependent growth;
- only fit to the first tag-recapture event, discarding all subsequent recovery events;
- size distribution sample weights by year, season and sampling source (logbook and catch sampling) are now scaled by the number of size measurements in each of the three sex categories (male, immature female, mature female).

The following assumptions are consistent with those made for the 2013 CRA 2 stock assessment:

- a single-stock model combining all information from Statistical Areas 905, 906, 907 and 908;
- a seasonal time step with autumn–winter (AW, April through September) and spring–summer (SS) from 1979 through 2016;
- 93 length bins, 31 for each sex category (males, immature and mature females), each 2 mm TW wide, beginning at left-hand edge 30 mm TW;
- MLS and escape gap regulations are changed over the model reconstruction period. These changes were modelled by incorporating a time series of MLS regulations by sex. Escape gap regulation changes were modelled by estimating separate selectivity functions before and after 1993;
- it was determined from the logbook data that the discard of large lobsters is not frequent in CRA 2, making it unnecessary to model this process at this time.

Data used and their sources are listed in Table 34 and Figure 22.

The assessment assumed that recreational catch was proportional to SS CPUE from 1979 through 2016. Estimates from three large-scale ‘off-site’ CRA 2 recreational surveys in 1994, 1996 and 2011 along with two ‘on-site’ western Bay of Plenty recreational surveys in 2010 and 2011 were fitted to the SS CPUE indices, assuming a lognormal distribution, to estimate a scaling factor that was used to scale the SS CPUE observations to the total annual CRA 2 recreational catch from 1979–2016.

Table 34: Data types and sources for the 2017 stock assessment of CRA 2. Fishing years are named from the first nine months, i.e., 1998–99 is called 1998. N/A – not applicable or not used; MPI – NZ Ministry for Primary Industries; NZ RLIC – NZ Rock Lobster Industry Council Ltd.; FSU: Fisheries Statistics Unit; CELR: catch and effort landing returns; NIWA: National Institute of Water and Atmosphere.

		CRA 2	
Data type	Data source	Begin year	End year
CPUE	FSU	1979	1988
CPUE	CELR	1989	2016
Observer proportions-at-size	MPI and NZ RLIC	1986	2016
Logbook proportions-at-size	NZ RLIC	1993	2016
Tag recovery data	NZ RLIC & MPI	1983	2016
Historical MLS regulations	MPI	1979	2016
Escape gap regulation changes	Annala (1983), MPI	1979	2016
Puerulus settlement	NIWA	N/A	N/A
Retention	NZ RLIC	N/A	N/A

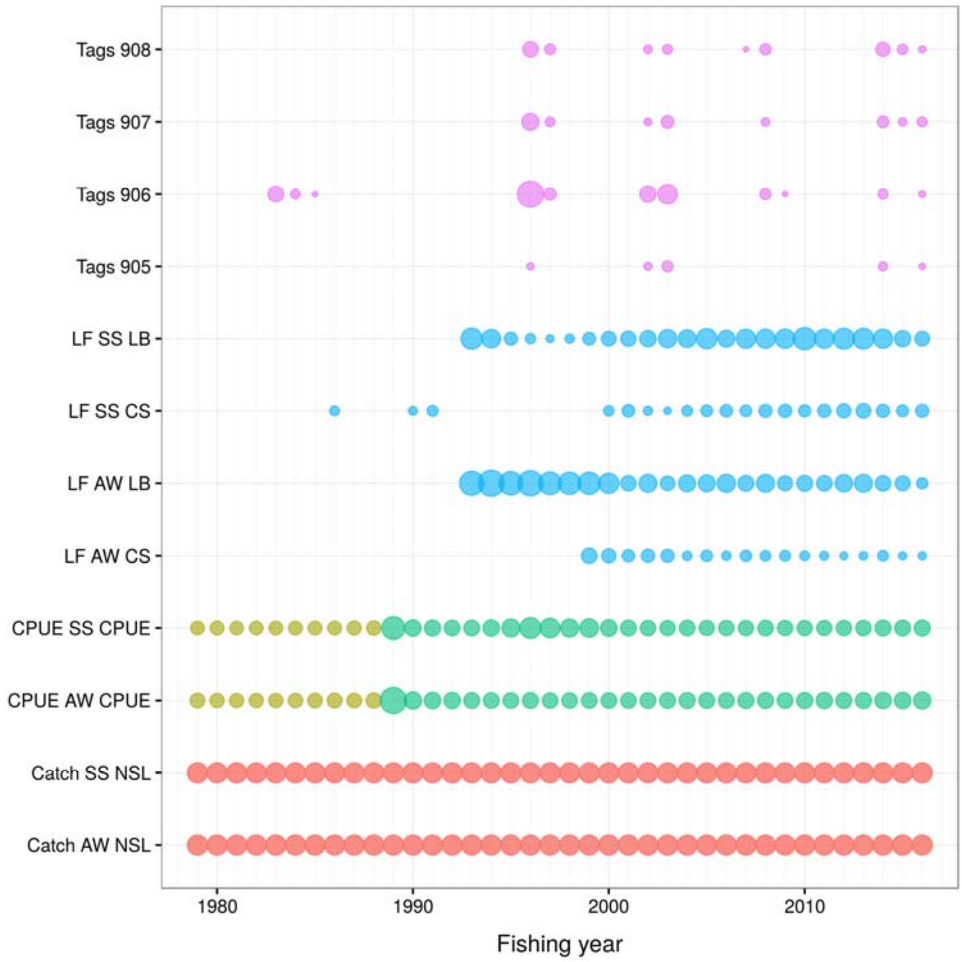


Figure 22: Data extent by fishing year used in the CRA 2 stock assessment. The size of each bubble represents the relative amount of data for each data type.

The numbers of male, immature female and mature female lobsters in each size class were updated in each season as a result of:

a) **Recruitment:** New recruits to the model were added equally for each sex for each season as a normal distribution with a mean size (32 mm) and standard deviation (2 mm), truncated at the smallest size class (30 mm). Recruitment in a specific year was determined by the mean recruitment parameter and the estimated annual deviations from mean recruitment. The vector of recruitment deviations in log space was assumed to be normally distributed with a mean of zero. Recruitment deviations were estimated for 1979 through 2014. The 2015 and 2016 recruitment deviations were fixed to be the same as the 2014 recruitment deviation.

b) **Mortality:** Natural, fishing and handling mortalities were applied to each sex category in each size class. Natural mortality was assumed to be constant and independent of sex and length. Fishing mortality was determined from observed catch and model biomass, modified by legal sizes, sex-specific vulnerabilities, and selectivity. Handling mortality was assumed to be 10% for lobsters returned to the water before CRA entered the QMS in 1990 and was 5% for discarded lobsters thereafter. Two fisheries were modelled: one that operated only on fish above the MLS, excluding berried females (SL fishery – including legal commercial and recreational) and one that did not respect size limits and restrictions on berried females (NSL fishery – the illegal fishery plus the Maori customary fishery). Selectivity and vulnerability functions were otherwise the same for the SL and NSL fisheries. Vulnerability by sex category and season was estimated relative to males in AW, which were assumed to have the highest vulnerability. Instantaneous fishing mortality rates for each fishery were calculated using Newton-Raphson iteration (three iterations) from catch, model biomass and natural mortality.

c) **Fishery selectivity:** A three-parameter fishery selectivity function was assumed, with parameters describing the shapes of the ascending and descending limbs and the size at which vulnerability is at a maximum. Selectivity was estimated for two separate epochs, pre-1993 and 1993–2016. As in previous rock lobster stock assessments, the descending limb of the selectivity curve was fixed at a high value to prevent underestimating vulnerability of large lobsters.

d) **Growth and maturation:** For each size class and sex category, a growth transition matrix specified the probability of an individual remaining in the same size class or moving into all other size classes. Maturation of females was estimated as a two-parameter logistic curve.

Model fitting

The best fit to the data was obtained by maximising the total likelihood function using Stan, an 'open-source' modelling language optimised for performing Bayesian analyses. The model was fitted to both standardised CPUE series assuming a lognormal distribution, to proportions-at-length with multinomial distribution, to sex ratios using multinomial distribution, and to tag-recapture data with robust normal distribution. For the CPUE likelihoods, CVs for each index value were initially set at the standard error from the GLM analysis along with an additional 25% of process error.

Proportions-at-length, assumed to be representative of the commercial catch, were available (see Table 34 and Figure 22) from observer catch sampling and voluntary logbooks: data were summarised for each data source by area/month strata and weighted by the commercial catch taken in each stratum, the number of lobsters measured by sex category, and the number of days sampled. Data from observers and logbooks were fitted separately, with proportions normalised and fitted within each sex class, and with the model estimating proportions-at-sex separately using a multinomial distribution. These data were weighted within the model using the iterative method of Francis (2011).

In all model runs, it was assumed that CPUE was directly proportional to vulnerable biomass, that growth was not density-dependent, and that there is no stock-recruit relationship. Parameters estimated, along with the priors, are provided in Table 35. Fixed parameters and their values are given in Table 36.

Table 35: Parameters estimated and priors used in the base case assessment for CRA 2. Prior type abbreviations: U – uniform; N – normal; L – lognormal. [Continued on next page]

Season	Sex	Par	Lower bound	Upper bound	Prior type	Prior mean	Prior std/CV	Initial value
		R_0	1	7e10				18
		M	0.01	0.35	2	0.12	0.4	0.12
		Rdevs[1]	-2.3	2.3	1	0	*sigmaR*	0
		qFSU	1e-11	1	0			-6
		qCELR	1e-11	1	0			-6
		U_{init}	0	1	0			0
		q-drift	-0.08	0.08	0			0
		mat50	30	80	1	50	15	50
		mat95	1	60	1	10	10	5
	male	*Galpha*	1	20	0			3.5
	male	*Gdiff*	0.001	1	0			0.8
	female	*Galpha*	1	20	0			3.5
	female	*Gdiff*	0.001	1	0			0.5
	male	*Gshape*	0.1	15	1	4.81	1.0	4.8
	male	*GCV*	0.01	2	1	0.59	0.3	0.59
	female	*Gshape*	0.1	15	1	4.51	1.0	4.5
	female	*GCV*	0.01	2	1	0.82	0.3	0.82
		Gobs	0.00001	10	1	1.48	0.074	0.4
	male	*SelLH*	1	50	0			4.1
	female	*SelLH*	1	50	0			9.2
	male	*SelMax*	30	90	0			55
	female	*SelMax*	30	90	0			64
SS	male	*vuln1*	0.01	1	0			0.8
AW	immafem	*vuln2*	0.01	1	0			0.84
SS	imma & matfem	*vuln3*	0.01	1	0			0.8
AW	matfem	*vuln4*	0.01	1	0			0.8

[1] Normal in log space = lognormal (bounds equivalent to –10 to 10).

Table 36: Fixed values used in base case assessment for CRA 2.

Quantity	Value	Quantity	Value
	Weights		Fixed parameters
tags	1	*sigmaR*	0.4
CELR CPUE	2.7	*CPUEpow*	1
FSU CPUE	3	*GDD*	0
sex ratio	22.0	*SelRH*	200
length frequencies	7.3	male length-weight *a*	4.16E-06
		male length-weight *b*	2.9354
		female length-weight *a*	1.30E-05
process error FSU/CELR 1979-2016	0.25	female length-weight *b*	2.5452
Newton-Raphson iterations	3		Other
last year of estimated *Rdevs*	2014	handling mortality, 1979-89	0.10
years for *Rdev* projections	2005–14	handling mortality, 1990-2016	0.05
		min survival proportion	0.02
		CRA 2 reference years	1979–81
		projected SL catch	184
		projected NSL catch	45
		marine reserve proportion	0
		male bins	4 to 31
		female immature bins	4 to 20
		female mature bins	6 to 31

Bayesian inference

Bayesian inference was used to estimate parameter uncertainty. This procedure was conducted in the following steps:

1. Model parameters were estimated by the LSD model using maximum likelihood and the prior probability distributions. These estimates are called the MAP (maximum a posteriori) estimates.
2. Samples from the joint posterior distribution of parameters were generated with Markov chain Monte Carlo (MCMC) simulations using the Hamiltonian Monte Carlo (HMC) algorithm.
3. Four chains, each with a burn-in period of 500 samples and length of 500 samples, were made, retaining every second sample, for a total of 1000 samples in the posterior distribution.

Performance indicators and results

Vulnerable biomass in the assessment model was determined by the MLS, selectivity, relative sex and seasonal vulnerability, and berried state for mature females. All mature females were assumed to be berried during the AW season, thus not vulnerable to the SL fishery, and not berried and vulnerable in the SS season.

Agreed indicators are summarised in Table 37. B_{REF}, based on the 1979–81 vulnerable biomass calculated with the current MLS and selectivity, was carried over from the 2013 CRA 2 stock assessment. However, this three-year period, which was characterised by an apparently stable and low (relative to peak abundance in 1996) trajectory in the 2013 assessment, shifted in the 2017 assessment to a steeply descending biomass trajectory starting from a level that was as high or higher than the 1996 peak (Figure 23).

Base case results (Figures 23 and 24, and Table 38) suggested that the AW biomass decreased to a low point in 1992, increased to a peak in the mid-1990s, and decreased rapidly until 2002. There was a short period of increased biomass to 2007, followed by a steadily decreasing trend to 2016. Median estimated biomass at the beginning of 2017 was about 21% of B_{REF} (90% credibility interval: 17–26%) (Table 38).

Table 37: Reference points, performance indicators and stock status probabilities for the CRA 2 stock assessment.

Reference points	Description
H_{2016}	Handling mortality (t) in final fishing year
SSB_0	Female spawning stock biomass during AW season associated with unfished equilibrium
SSB_{2016}	Female spawning stock biomass at end of 2016 AW season
B_{REF}	Beginning of AW season mean vulnerable biomass for the 1979–81 reference period
B_{MIN}	The lowest beginning AW vulnerable biomass in the series
B_{2017}	Beginning of season AW vulnerable biomass for 2017

Performance indicators	Description
SSB_{2016} / SSB_0	ratio of SSB_{2016} to SSB_0
B_{2017} / B_{REF}	ratio of B_{2017} to B_{REF}
B_{2017} / B_{MIN}	ratio of B_{2017} to B_{MIN}

Probabilities	Description
P(SSB_{2016} < 0.2 SSB_0)	soft limit CRA 2: probability SSB_{2016} < 20% SSB_0
P(SSB_{2016} < 0.1 SSB_0)	hard limit CRA 2: probability SSB_{2016} < 10% SSB_0
P(B_{2017} > B_{REF})	probability B_{2017} > B_{REF}
P(B_{2017} > B_{MIN})	probability B_{2017} > B_{MIN}
P(B_{REF} > B_{MIN})	probability B_{REF} > B_{MIN}

Note that B_{MSY} has been removed from this table as the RLFAWG and Plenary determined that more work needed to be conducted to evaluate how this quantity is determined for rock lobsters.

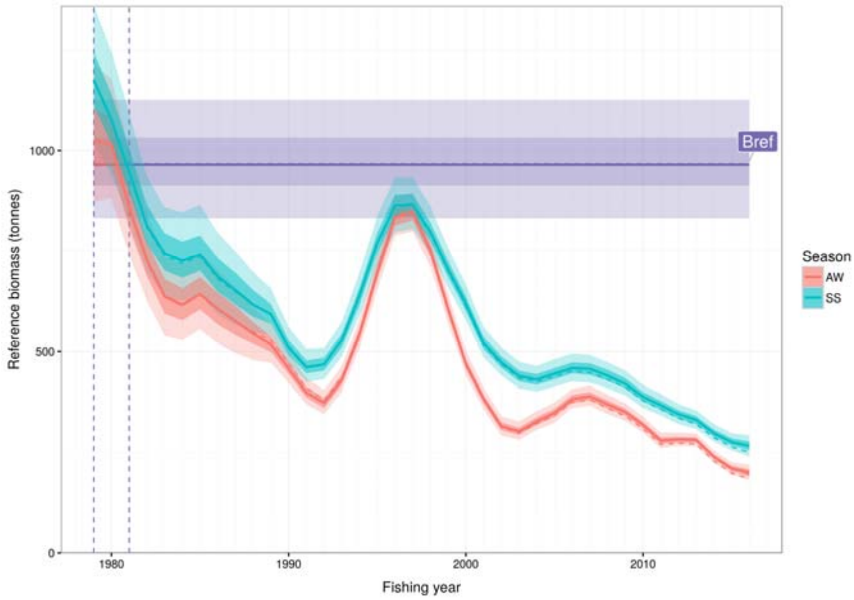


Figure 23: CRA 2 base case vulnerable reference biomass over the model reconstruction period and B_{REF} (the 1979–81 reference period identified using purple vertical dashed lines). Solid lines indicate the median vulnerable biomass by season, shading indicates the 50% and 90% credible intervals for each series, dashed lines indicate the MAP. The biomass in each year uses the final reconstruction year's selectivity and MLS.

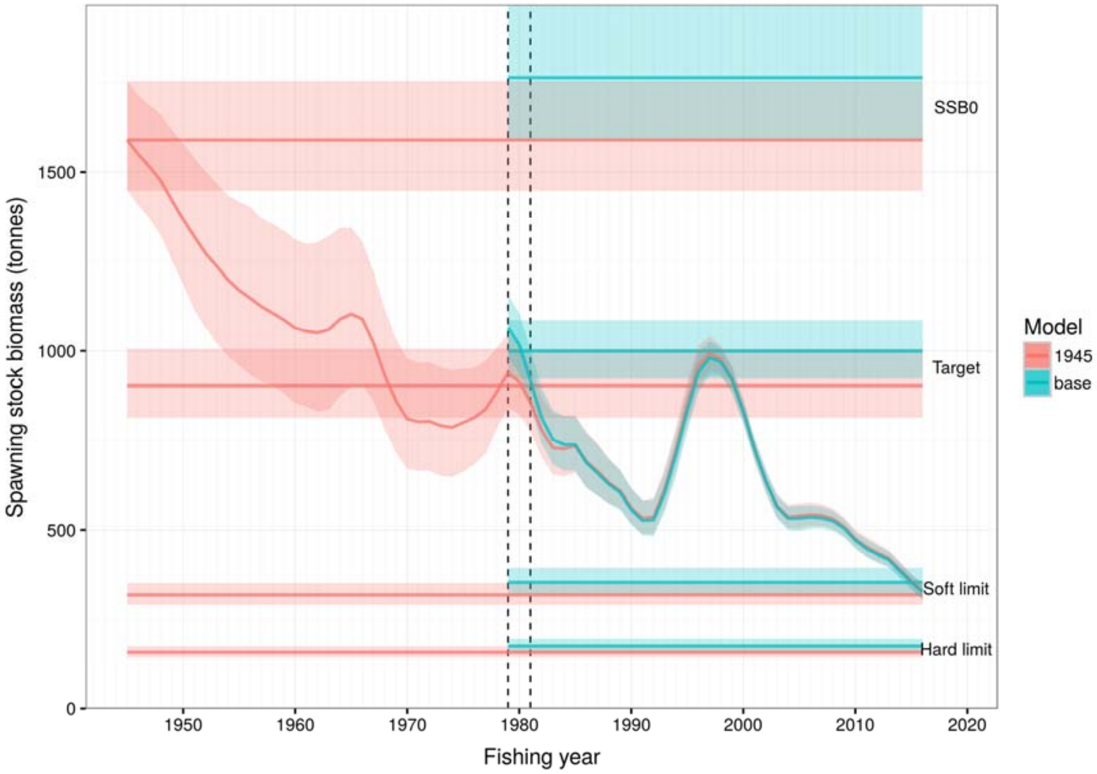


Figure 24: CRA 2 posterior distribution of the spawning stock biomass (*SSB*) trajectory for the base case model run and the model run that begins in 1945. Also plotted for each model run is the posterior distribution of the unfished SSB (SSB_0), the reference biomass (the mean *SSB* between 1979 and 1981), the soft limit (20% SSB_0), and the hard limit (10% SSB_0). The reference period is indicated using vertical dashed black lines.

Table 38: CRA 2 base case and sensitivity run MCMC outputs, reporting the 5%, 50% (median), and 95% quantiles of the posterior distributions. Growth increment values in mm TW, biomass values in t, and R_0 in numbers. '–': not applicable. [Continued on next page]

	Base			Start 1945			2× recreational catch			q-drift		
	5%	50%	95%	5%	50%	95%	5%	50%	95%	5%	50%	95%
Likelihoods and diagnostic statistics												
LFs-sdnr	0.613	0.772	1.126	0.616	0.773	1.143	0.604	0.760	1.053	0.614	0.772	1.091
LFs-MAR	0.101	0.104	0.106	0.101	0.104	0.106	0.101	0.104	0.106	0.101	0.104	0.107
LFs-LL	22 990	23 010	23 020	23 000	23 010	23 020	22 990	23 000	23 010	22 990	23 010	23 020
Tags-sdnr	1.373	1.418	1.467	1.371	1.417	1.463	1.372	1.417	1.462	1.374	1.418	1.465
Tags-MAR	0.662	0.679	0.698	0.662	0.680	0.698	0.663	0.680	0.698	0.662	0.680	0.700
Tags-LL	4 430	4 442	4 455	4 430	4 442	4 456	4 430	4 442	4 456	4 430	4 441	4 453
CELR sdnr	1.078	1.173	1.274	1.065	1.162	1.270	1.060	1.160	1.261	1.066	1.163	1.266
CELR MAR	0.589	0.734	0.876	0.560	0.704	0.841	0.599	0.735	0.883	1.012	1.504	2.289
CELR LL	-99.44	-93.58	-86.34	-100.20	-94.21	-86.91	-100.40	-94.26	-87.44	-100.10	-94.15	-87.17
FSU-sdnr	1.188	1.307	1.436	1.048	1.199	1.382	1.179	1.281	1.408	1.198	1.301	1.438
FSU-MAR	0.660	0.873	1.133	0.665	0.875	1.118	0.656	0.869	1.124	0.662	0.873	1.132
FSU-LL	-35.79	-32.84	-29.20	-38.67	-35.27	-30.70	-36.06	-33.41	-29.84	-35.64	-32.93	-29.32
CR-sdnr	–	–	–	0.969	1.206	1.484	–	–	–	–	–	–
CR-MAR	–	–	–	0.432	0.717	1.091	–	–	–	–	–	–
CR-LL	–	–	–	-25.86	-23.12	-19.19	–	–	–	–	–	–
Sex-sdnr	1.035	1.070	1.112	1.037	1.071	1.109	1.054	1.086	1.121	1.045	1.078	1.118
Sex-MAR	0.566	0.595	0.628	0.565	0.596	0.630	0.573	0.604	0.635	0.569	0.598	0.631
Sex-LL	7 882	7 888	7 894	7 882	7 888	7 894	7 885	7 890	7 895	7 883	7 888	7 895
Prior	-1.77	7.68	19.40	-15.53	-4.43	9.18	-1.74	7.48	18.75	-1.72	8.18	19.09
Function value	35 210	35 220	35 230	35 170	35 180	35 190	35 200	35 210	35 220	35 210	35 220	35 230
Model parameters												
R_0	559 600	633 000	730 400	522 300	594 200	669 900	571 700	653 300	739 200	564 600	643 500	725 000
M	0.150	0.164	0.179	0.158	0.172	0.189	0.132	0.146	0.161	0.152	0.167	0.182
U_{init}	0.118	0.157	0.203	–	–	–	0.130	0.169	0.216	0.108	0.149	0.192
q-CR	–	–	–	0.0207	0.0278	0.0382	–	–	–	–	–	–
q-FSU	0.0005	0.0006	0.0007	0.0005	0.0006	0.0007	0.0005	0.0006	0.0007	0.0005	0.0006	0.0007
q-CELR	0.0013	0.0014	0.0015	0.0013	0.0014	0.0015	0.0012	0.0013	0.0014	0.0012	0.0013	0.0015
q-drift	–	–	–	–	–	–	–	–	–	-0.0006	0.0043	0.0089
mat50	48.96	49.88	50.71	48.82	49.79	50.60	49.05	49.95	50.82	48.92	49.85	50.65

Table 38 [Continued]:

	Base			Start 1945			2× recreational catch			q-drift		
	5%	50%	95%	5%	50%	95%	5%	50%	95%	5%	50%	95%
Model parameters												
mat95Add	8.46	10.50	13.41	8.18	10.46	13.18	8.30	10.61	13.48	8.35	10.42	13.45
GalphaM	6.65	6.82	7.00	6.64	6.80	6.97	6.63	6.81	6.99	6.64	6.81	6.99
GbetaM	2.62	2.88	3.20	2.61	2.84	3.15	2.61	2.87	3.17	2.60	2.85	3.13
GshapeM	2.02	2.55	3.18	1.93	2.457	3.11	1.96	2.53	3.15	1.95	2.51	3.10
GCVM	0.42	0.44	0.46	0.42	0.44	0.46	0.42	0.44	0.46	0.42	0.44	0.46
GalphaF	4.55	4.72	4.88	4.59	4.74	4.90	4.57	4.74	4.90	4.57	4.73	4.89
GbetaF	1.12	1.19	1.27	1.13	1.21	1.30	1.12	1.20	1.28	1.12	1.19	1.28
GshapeF	4.12	4.43	4.71	4.17	4.47	4.77	4.12	4.42	4.69	4.15	4.45	4.74
GCVF	0.74	0.78	0.82	0.73	0.77	0.82	0.73	0.77	0.82	0.73	0.77	0.82
StdObs	0.90	1.00	1.11	0.90	1.01	1.11	0.91	1.01	1.10	0.90	1.01	1.11
vuln1	0.63	0.66	0.69	0.65	0.68	0.71	0.63	0.65	0.68	0.64	0.67	0.70
vuln2	0.51	0.60	0.70	0.50	0.59	0.71	0.49	0.59	0.70	0.50	0.59	0.71
vuln3	0.52	0.56	0.62	0.52	0.57	0.63	0.51	0.56	0.62	0.52	0.57	0.62
vuln4	0.47	0.51	0.56	0.47	0.51	0.56	0.46	0.51	0.56	0.47	0.51	0.56
SelLH1M	2.78	23.42	46.67	2.60	22.04	47.32	3.30	26.39	47.55	3.02	23.20	47.29
SelMax1M	32.00	45.48	67.63	31.64	45.77	67.00	31.16	44.01	67.09	31.97	46.07	66.32
SelLH1F	3.26	11.65	33.01	2.60	11.03	31.90	2.85	12.05	34.28	2.34	10.10	30.87
SelMax1F	49.19	61.77	78.41	48.28	61.20	77.83	48.44	63.15	80.68	47.37	60.22	76.62
SelLH2M	4.38	4.67	4.96	4.38	4.67	4.95	4.42	4.67	4.95	4.41	4.66	4.96
SelMax2M	55.38	55.87	56.37	55.44	55.90	56.40	55.42	55.84	56.33	55.44	55.88	56.39
SelLH2F	6.89	7.26	7.66	6.89	7.26	7.68	6.91	7.35	7.73	6.89	7.27	7.69
SelMax2F	62.51	63.15	63.79	62.52	63.14	63.85	62.53	63.22	63.88	62.50	63.15	63.82
Derived quantities												
H_{2016}	2.251	2.424	2.618	2.213	2.396	2.588	2.586	2.782	3.011	2.272	2.463	2.676
SSB_0	1 582	1 763	1 966	1 444	1 588	1 753	1 954	2 191	2 442	1 555	1 743	1 935
SSB_{REF}	922	999	1 086	813	903	1 006	1 048	1 139	1 234	936	1 017	1 098
SSB_{2016}	306	328	353	304	327	350	344	369	400	293	316	342
B_0	3 391	3 798	4 299	2 883	3 217	3 604	4 149	4 743	5 345	3 283	3 733	4 173
B_{REF}	831	965	1 125	882	1 005	1 160	896	1 044	1 210	864	1 007	1 183
B_{MIN}	182	199	217	182	201	221	203	223	243	171	190	211
B_{2017}	173	203	242	167	197	232	186	222	265	152	184	222
SSB_{2016}/SSB_0	0.163	0.185	0.211	0.183	0.205	0.231	0.148	0.168	0.194	0.162	0.182	0.207
SSB_{2016}/SSB_{REF}	0.297	0.326	0.357	0.322	0.362	0.403	0.294	0.324	0.356	0.283	0.311	0.345
SSB_{REF}/SSB_0	0.503	0.567	0.637	0.489	0.567	0.661	0.452	0.522	0.594	0.517	0.584	0.656
B_{2017}/B_O	0.042	0.052	0.064	0.049	0.061	0.075	0.038	0.047	0.058	0.040	0.049	0.061
B_{2017}/B_{REF}	0.171	0.211	0.261	0.160	0.195	0.240	0.172	0.214	0.264	0.141	0.183	0.234
B_{2017}/B_{MIN}	0.917	1.020	1.174	0.872	0.978	1.118	0.883	0.994	1.135	0.847	0.965	1.107
B_{REF}/B_0	0.204	0.253	0.318	0.260	0.313	0.374	0.174	0.219	0.280	0.215	0.271	0.345
Probabilities												
$P(SSB_{2016}<0.2SSB_0)$		0.816			0.340			0.970			0.893	
$P(SSB_{2016}<0.1SSB_0)$		0			0			0			0	
$P(SSB_{2016} > SSB_{REF})$		0			0			0			0	
$P(B_{2017} > B_{REF})$		0			0			0			0	
$P(B_{2017} > B_{MIN})$		0.614			0.391			0.473			0.323	

Three sensitivity runs relative to the base case included:

a) starting the model from 1945 as done in the previous CRA 2 stock assessment;
b) doubling the recreational catch; and
c) estimating an additional multiplicative parameter (q-drift), which described increased fishing efficiency over time.

Results from the base case and the three sensitivity trials are compared in Table 38.

B_{2017} was about the same size as B_{MIN} but was smaller than B_{REF} with 100% probability for the base case and all three sensitivity runs (Table 38).

Indicators based on SSB_{REF}

The historical sequence of biomass versus fishing intensity is shown in Figure 25. The plot shows relative spawning biomass on the x-axis and relative fishing intensity on the y-axis; thus high biomass/low fishing intensity is in the lower right-hand corner, where a stock would be when fishing first began, and low biomass/high intensity is in the upper left-hand corner, where an uncontrolled fishery is likely to go. The x-axis is spawning stock biomass *SSB* in year *y* as a proportion of the unfished spawning stock (SSB_0). SSB_0 is constant for all years of a run, but varies through the 1000 samples from the posterior distribution.

The y-axis is fishing intensity in year *y* as a proportion of the fishing intensity (F_{REF}) that results in SSB_{REF} under the fishing pattern in year *y*. Fishing patterns include MLS, selectivity, the seasonal catch split, and the balance between SL and NSL catches. F_{REF} varies among years because fishing patterns change in each year and is calculated by projecting deterministically for 50 years to reach equilibrium. Each projection is done by holding the NSL catch constant, assuming recruitment at R_0, and applying a range of stepped multipliers to the AW and SS SL fishing mortalities (F_y). The *F* that results in SSB_{REF} at the end of the projection is F_{REF}. This projection procedure is followed in every year for each sample in the MCMC posterior.

The median track in Figure 25 suggests that fishing intensity has exceeded F_{REF} in every year starting in 1979, the first model year. The only years that the *SSB* was above SSB_{REF} were 1979 and 1980. As the stock declined from 1979 to 1990 the fishing intensity increased. Stock status then began to improve and fishing intensity declined from 1990 as stock abundance increased. Fishing intensity and relative biomass neared the centre of the figure from 1996 to 1998, as abundance peaked near SSB_{REF} and fishing mortality approached F_{REF}. The trend reversed after 1998, with the stock dropping below 20% SSB_0 in 2015 and fishing mortality exceeding three times F_{REF} after 2001 (Figure 25). Fishing intensity began to drop after 2013 in response to drops in the SL catch but has stayed well above three times F_{REF}. Stock status has continued to decline in spite of the decline in fishing mortality, with the median estimate of SSB_{2016} at 19% SSB_0 (90% credibility interval from 16–21% SSB_0; Table 38).

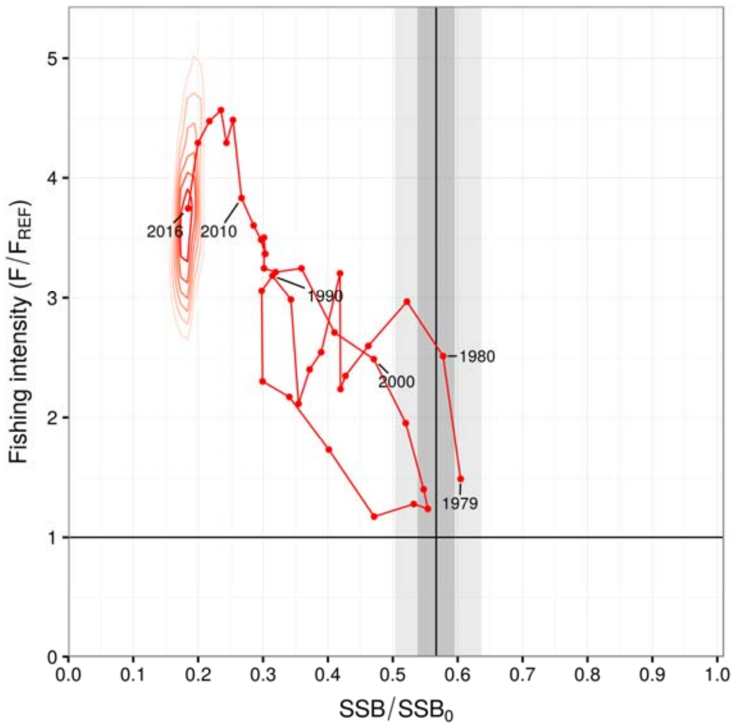


Figure 25: Phase plot summarising the *SSB* history of the CRA 2 stock. The x-axis is the AW spawning stock biomass *SSB* in each year as a proportion of the unfished spawning stock biomass (SSB_0). The y-axis is fishing intensity in each year as a proportion of the fishing intensity (F_{REF}) that gives SSB_{REF} under the fishing patterns in that year. Each point on the figure shows the median of the posterior distributions of biomass ratio and fishing intensity ratio for one year. The vertical line in the figure is the median (line), 70%, and 90% interval (shading) of the posterior distribution of SSB_{REF}. This ratio was calculated using the fishing pattern in 2016. The horizontal line in the figure is drawn at 1, the fishing intensity associated with F_{REF}. The contour density for the final year of the plot (2016) shows the posterior distributions of the two ratios.

Multi-area modelling of CRA 2

An exploratory multi-area CRA 2 stock assessment model was developed in conjunction with the overall CRA 2 stock assessment. Each of the four CRA 2 statistical areas were modelled separately with some independent (e.g., R_0, U_{init}) and some shared parameters (e.g., *M*, vulnerabilities, selectivities split into three areas, growth split into two areas). Summing the vulnerable or spawning stock biomass over all four areas resulted in similar biomass trajectories to the base case assessment model in both shape and overall biomass. However, stock size, trends in abundance, and stock status indicators differed among the four areas with some areas with lower stock status than others. Multi-area models have not yet been used for finer-scale management of rock lobster stocks, but this approach shows considerable potential for such applications.

Future research considerations

The RLFAWG and Plenary identified a number of potentially useful avenues of exploration to evaluate or improve this assessment in the future. Improvements related to the development of the CPUE standardisation (GLM) and its use in the stock assessment model include:

- Include alternative CPUE formulations in the stock assessment model itself as sensitivities to more fully evaluate their consequences.
- Develop logbook CPUE series where possible. Display comparisons of this series with the current CPUE series. Include the logbook series in the model as well.
- Implement vessel as an explanatory variable in all future rock lobster CPUE standardisations. Investigate sequential coding of the same vessel in the model to determine whether there are ‘learning’ effects, or examine individual vessels for trends in residuals over time.
- Investigate the distribution of the vessel correction factors (VCF) that scale estimated catch into landed greenweight in the F2_LFX algorithm.
- Use a smoother to determine the minimum amount of process error to add and use this (to avoid overfitting) instead of the arbitrary 25% process error that is added at present.

Other improvements include:

- Explore alternative reference points (targets and limits) for CRA 2 (and rock lobster stocks in general). For example, evaluate the consistency and efficacy of B_{REF} targets, and develop a dynamic B_{MSY}.
- Examine the effects of including a stock-recruitment relationship in the model.
- Investigate the implications of not estimating recruitment deviations for the period with no relevant data or, alternatively, the implications of estimating recruitment deviations for all years.
- Investigate the effects of changing the definition of new recruits from 32 mm, with a standard deviation of 2 mm; for example, what would be the effect of an increase in the standard deviation?
- Develop the computer code to include the effects of density-dependent growth and environmental effects.
- Develop and evaluate alternative growth models.
- Re-evaluate the method used to determine length-frequency weights.
- Develop an option for including random effects for certain parameters (e.g., selectivity parameters) in the model.
- Continue development of the spatial model and develop spatial model management procedures.
- Explore new ways to ‘search’ for management procedures (e.g., basic optimisation routines, genetic algorithms).

6.3 CRA 3

This section reports the 2014 stock assessment for *J. edwardsii* for CRA 3 (Haist et al. 2015).

This assessment used a single-stock version of the multi-stock length-based model (MSLM) (Haist et al. 2009).

Catch histories for CRA 3 were agreed by the RLFAWG. Other input data to the model included:

- tag-recapture data from the periods 1975–81 and 1995–2013;
- standardised CPUE from 1979–2013;
- historical catch rate data from 1963–73; and
- length-frequency data from commercial catches (logbook and catch sampling data) from 1989–2013.

Because the predicted growth rates were different for the 1975–81 and 1995–2013 datasets, the RLFAWG agreed that it would be appropriate to fit two growth periods in the model to the two separate tag-recapture datasets. The growth transition matrix for years up to and including 1981 was based on the 1975–81 tagging dataset. The growth transition matrix for years from 1995 onwards was based on the 1995–2013 tagging dataset. The growth transition matrix for the intervening years, 1982–94, was based on an interpolation of the early and later growth transition matrices.

The start date for the model was 1945, with an annual time step through 1978 and then switching to a seasonal time step from 1979 onward: autumn–winter (AW) from April through September and spring–summer (SS) from October through March. The last fishing year was 2013, and projections were made through 2017 (four years). Two selectivity epochs were modelled, with the change made in 1993 to capture regulation shifts for the pot escape gaps. Recruitment deviations were estimated from 1945 through 2011. Maximum vulnerability was assumed to be for males in the SS season. The effect of the introduction of the marine reserve was modelled, beginning in 1999, by excluding 10% of the recruitment. The model was fitted to CPUE, the historical catch rate series, length-frequency data and the two tag-recapture datasets. The puerulus settlement index was evaluated in a separate randomisation trial.

A lognormal prior was specified for *M*, with mean 0.12 and CV of 0.4. A normal prior was specified for the recruitment deviations in log space, with mean 0 and standard deviation 0.4. Normal priors were used for the size at maximum selectivity for each sex, using the current MLS as the mean. Priors for all other parameters were specified as uniform distributions with wide bounds.

Other model options used in the reference base cases were:

- fishing and natural mortality were assumed to be instantaneous, and *F* was determined with 5 Newton-Raphson iterations;
- selectivity was set to the double normal form used in previous assessments;
- the relationship between CPUE and biomass was assumed to be proportional;
- maturity parameters were fixed at the mean of values from the most recent CRA 1 and CRA 3 assessments;
- the growth CV was fixed to 0.5 to stabilise the analysis in one base case;
- the growth shape was fixed to 5 in the other base case;
- the right-hand limb of the selectivity curve was fixed to 200;
- dataset weights were adjusted to attempt to obtain standard deviations of normalised residuals of 1.0 or medians of absolute residuals of 0.67.

The RLFAWG considered results from the mode of the joint posterior distribution (MPD) and the results of 14 sets of MPD sensitivity trials:

- with double the estimated recreational catch
- with the illegal catch ramped down from 2001
- with the illegal catch ramped up from 2001
- not fitted to CPUE
- not fitted to length-frequency data
- not fitted to CR
- not fitted to tags
- with *M* fixed to 0.12
- with growth density-dependence estimated

- with the length-frequency record weights not truncated
- with shape parameter for CPUE versus biomass (*CPUEpow*) estimated
- with Newton-Raphson iterations reduced to 3
- with Newton-Raphson iterations increased to 5 for fixed growth shape or reduced to 4 for fixed growth CV
- with logistic selectivity.

Most base case results showed limited sensitivity to these trials, except when major datasets were removed. Indicator ratios were reasonably stable.

The model was then fitted to the puerulus index time series as well as the other data, with a range of lags from settlement to recruitment to the model at 32 mm TW. For each base case and for each lag, the function value from fitting to the actual data was compared to the distribution of function values obtained when fitting to randomised data (resampled with replacement). This is a test of the signal in the puerulus index: the null hypothesis is that there is no signal; the research hypothesis predicts that the actual-data function value will be in the lower tail of the distribution. For both base cases and at all lags, the null hypothesis had to be accepted.

The assessment was based on Markov chain Monte Carlo (MCMC) simulation results. We started the simulations for each of the two base cases at the MPD, and made a chain of five million, with 1000 samples saved. From the joint posterior distribution of parameter estimates, forward projections were made through 2017. In these projections, catches and their seasonal distributions were assumed to remain constant at their 2013 values. Recruitment was resampled from 2002–11, and the estimates for 2012–13 were overwritten. The most recent 10 years of estimates are considered the best information about likely future recruitments in the short term.

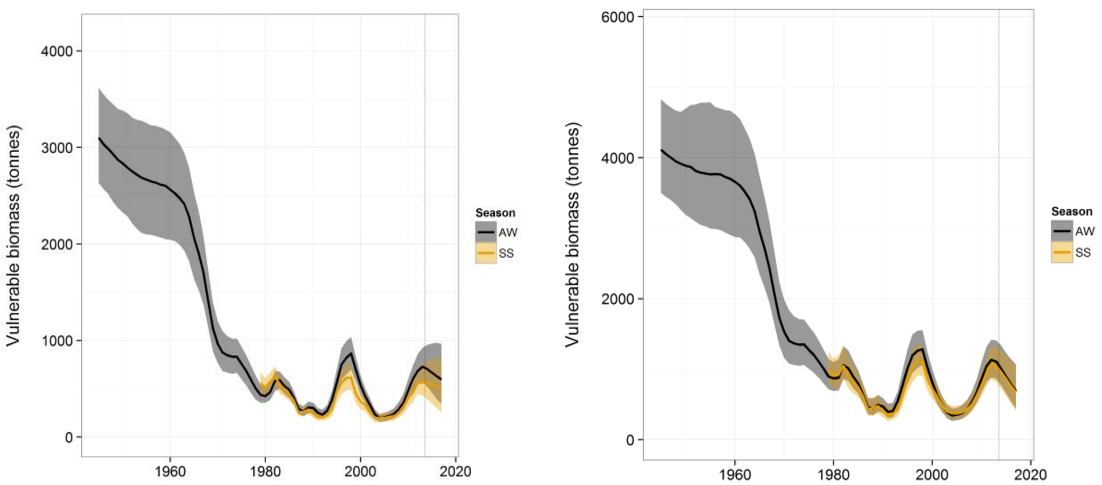


Figure 26: CRA 3: posterior of the trajectory of vulnerable biomass by season, for the fixed growth CV base (left) and the fixed growth shape base case. Shaded areas show the 50% and 90% credibility intervals and the heavy solid line is the median of the posterior distribution. The vertical line shows 2013, the final fishing year of the model reconstruction.

The RLFAWG agreed on a set of indicators. Some of these were based on beginning of season AW vulnerable biomass: the biomass legally and functionally available to the fishery, taking MLS, female maturity, selectivity-at-size and seasonal vulnerability into account. The limit indicator *Bmin* was defined as the nadir of the vulnerable biomass trajectory (using current MLS), 1945–2007. Current biomass, *B2014*, was taken as vulnerable biomass in AW 2014, and projected biomass, *B2017*, was taken from AW 2017.

A biomass indicator associated with MSY or maximum yield, *Bmsy*, was calculated by doing deterministic forward projections for 50 years, using the mean of estimated recruitments from 1979–

2011. This period was chosen to represent the recruitments estimated from adequate data, and represents the best available information about likely long-term average recruitment. The NSL catches (customary and illegal) were held constant at their assumed 2013 values. The SL fishery mortality rate *F* was varied to maximise the annual SL catch, and associated AW biomass was taken as *Bmsy*. MSY was the maximum yield (the sum of AW and SS SL catches) found by searching across a range of multipliers (from 0.1 to 2.5) on the 2013 AW and SS *F* values. This was done for each of the 1000 samples from the joint posterior distribution. If the MSY were still increasing with the highest *F* multiplier, the MSY and *Bmsy* obtained with that multiplier were used. The multiplier, *Fmult*, was also reported as an indicator. The MSY and *Bmsy* calculations were based on the growth parameters estimated from the second (1996–2013) tag dataset.

We also used as indicators the exploitation rate associated with the SL catch from 2013 and 2017: *USL2013* and *USL2017*. For the first time in 2013, MPI requested a total biomass indicator and its comparison with *B0* and a total numbers indicator and its comparison with *N0*.

Some previous assessments used biomass in 1974–79 as a target indicator, *Bref*. This appeared to be based on an early assessment in which biomass in that period appeared relatively stable, whereas the biomass in Figure 26 is decreasing strongly at that time. This assessment therefore reported biomass against *Bref* but the RLFAWG did not consider it a target indicator.

The assessment was based on the medians of posterior distributions of these indicators, the posterior distributions of ratios of these indicators, and probabilities that various propositions were true in the posterior distributions.

The primary diagnostics used to evaluate the convergence of the MCMC were the appearance of the traces, running quantiles and moving means. Some of the growth increment parameters, about which there was limited information in the tag data, were poorly converged. Diagnostic plots of the indicators, however, tended to be more acceptable than those of the estimated parameters.

The posterior trajectory of vulnerable biomass by season from 1976 (Figure 26) shows a nadir near 2004, a strong increase in the 1990s followed by a sharp decrease, then another strong increase in the late 2000s, and variable projections with an decreasing median.

The assessment results are summarised in Table 39. Current biomass (*B2014*) was above *Bmin* in all runs, and the median result was 3.0 to 3.5 times *Bmin*. Current biomass was also above *Bmsy* in all of runs, and the median result was between 3 and 5 times *Bmsy*. Current SL exploitation rate was 16% to 24%. Current and projected spawning stock biomass were estimated at about 1.5 times *SSBmsy*. Total biomass was estimated at more than half *B0*, and total numbers at 76% to 90% of *N0*.

Table 39: Quantities of interest to the assessment from the two base case MCMCs; see text for explanation; all biomass values are in t. [Continued on next page]

	fixed *GCV*			fixed *Gshape*		
Indicator	5%	median	95%	5%	median	95%
Bmin	156.3	194.3	235.7	265.6	334.3	412.9
B2014	524.7	704.1	956.1	765.8	1 001.2	1 335.0
Bref	508.1	633.8	777.3	915.0	1 134.7	1 418.8
B2017	338.2	596.3	964.8	435.7	690.1	1 065.9
Bmsy	173.8	212.8	252.4	173.0	211.7	261.6
MSY	210.2	242.6	282.0	177.1	212.4	253.0
Fmult	4.80	6.02	7.79	5.57	7.34	9.37
SSB2013	1 104.9	1 243.7	1 405.3	2 061.3	2 389.7	2 842.6
SSB2017	1 035.2	1 273.0	1 576.9	1 785.2	2 241.2	2 896.9
SSBmsy	771.5	880.8	1 008.2	1 351.9	1 544.9	1 786.7
CPUE2013	1.782	2.094	2.477	1.467	1.714	2.005
CPUE2017	0.774	1.662	2.799	0.609	1.003	1.517
CPUEmsy	0.233	0.288	0.351	0.156	0.196	0.241
B2014/Bmin	2.89	3.64	4.61	2.45	3.01	3.73
B2014/Bref	0.846	1.119	1.497	0.679	0.886	1.121
B2014/Bmsy	2.609	3.333	4.405	3.820	4.725	5.827
B2017/B2014	0.566	0.846	1.157	0.510	0.686	0.903
B2017/Bref	0.526	0.943	1.500	0.399	0.608	0.898

Table 39 [Continued]:

	fixed *GCV*			fixed *Gshape*		
Indicator	5%	median	95%	5%	median	95%
B2017/Bmsy	1.639	2.797	4.554	2.239	3.234	4.640
SSB2013/SSB0	0.619	0.697	0.804	0.930	1.068	1.254
SSB2017/SSB0	0.582	0.713	0.892	0.803	0.995	1.273
SSB2013/SSBmsy	1.247	1.410	1.610	1.357	1.549	1.800
SSB2017/SSBmsy	1.174	1.433	1.792	1.172	1.449	1.831
SSB2017/SSB2013	0.861	1.019	1.196	0.787	0.930	1.123
USL2013	0.188	0.238	0.305	0.123	0.157	0.202
USL2017	0.180	0.292	0.514	0.163	0.252	0.399
USL2017/USL2013	0.830	1.210	1.965	1.164	1.599	2.244
Btot2013	2 485.0	2 898.7	3 438.1	4 814.6	5 821.1	7 170.6
Btot2013/Btot0	0.417	0.495	0.593	0.560	0.672	0.809
Ntot2013	7 400 000	8 950 000	11 200 000	15 200 000	19 200 000	25 000 000
Ntot2013/Ntot0	0.627	0.756	0.948	0.744	0.909	1.137
P(B2014>Bmin)	1.00			1.00		
P(B2014>Bref)	0.75			0.19		
P(B2014>Bmsy)	1.00			1.00		
P(B2017>Bmin)	1.00			0.99		
P(B2017>Bref)	0.44			0.02		
P(B2017>Bmsy)	1.00			1.00		
P(B2017>B2014	0.21			0.02		
P(SSB2013>SSBmsy)	1.00			1.00		
P(SSB2017>SSBmsy)	1.00			1.00		
P(USL2017>USL2013	0.77			1.00		
P(SSB2013<0.2SSB0)	0.00			0.00		
P(SSB2017<0.2SSB0	0.00			0.00		
P(SSB2013<0.1SSB0)	0.00			0.00		
P(SSB2017<0.1SSB0)	0.00			0.00		

Biomass increased in only a small percentage of projections, and the median decrease was 15–31%. Projected biomass had a large 5% to 95% uncertainty around it. *B2017* was above *Bmin* and *Bmsy* in virtually all runs, and the median result was about 3 times *Bmsy*. Projected CPUE had a median of 1.0 to 1.7 kg/potlift.

These results suggest a stock that is well above *Bmin* and *Bmsy*, with no concerns from spawning stock biomass, total biomass or total numbers. There is a projected decrease at current catch levels, but the stock is projected to stay well above *Bmin* and *Bmsy*. Under current catches and recent recruitments the model predicted a 75% probability of biomass decrease over four years.

The historical track of biomass versus fishing intensity is shown in Figure 27. The phase space in the plot is relative spawning biomass on the abscissa and relative fishing intensity on the ordinate; thus high biomass/low fishing intensity is in the lower right-hand corner, where a stock would be when fishing first began, and low biomass/high intensity is in the upper left-hand corner, where an uncontrolled fishery is likely to go. Specifically, the x-axis is spawning stock biomass *SSB* in year *y* as a proportion of the unfished spawning stock, *SSB0*. *SSB0* is constant for all years of a run, but varies through the 1000 samples from the posterior distribution.

The y-axis is fishing intensity in year *y* as a proportion of the fishing intensity (*Fmsy*) that would have given *MSY* under the fishing patterns in year *y*; fishing patterns include MLS, selectivity, the seasonal catch split and the balance between SL and NSL catches. *Fmsy* varies every year because the fishing patterns change. It was calculated with a 50-year projection for each year in each run, with the NSL catch held constant at that year's value, deterministic recruitment at *R0* and a range of multipliers on the SL catch *F*s estimated for year *y*. The *F* that gave MSY is *Fmsy*, and the multiplier was *Fmult*.

Each point on the figure shows the median of the posterior distributions of biomass ratio and fishing intensity ratio. The vertical line in the figure is the median (line) and 90% interval (shading) of the posterior distribution of *SSBmsy* as a proportion of *SSB0*; this ratio was calculated using the fishing pattern in 2012. The horizontal line in the figure is drawn at 1, the fishing intensity associated with *Fmsy*. The bars at the final year of the plot show the 90% intervals of the posterior distributions of biomass ratio and fishing intensity ratio.

The tracks suggest that fishing intensity exceeded *Fmsy* only in the fixed growth CV base case from 1983–91 and that *SSB* was below *SSBmsy* only in limited periods that vary between the two base cases. The current position of the stock is well above *SSBmsy* and well below *Fmsy*.

Four MCMC sensitivity trials were run for each of the two base case MCMCs:

- with *M* fixed to 0.12, using the covariance matrix was from a run with *M* fixed to 0.20;
- with a uniform prior on *M*; for the fixed growth shape base the covariance matrix was from the base case;
- fitted to the puerulus index with lag of 2 years between settlement and recruitment to the model;
- fitted to a single combined tag data file (this was based on examination of the tag residuals, showing positive for the most recent years).

The major stock assessment conclusions were not challenged by these trials.

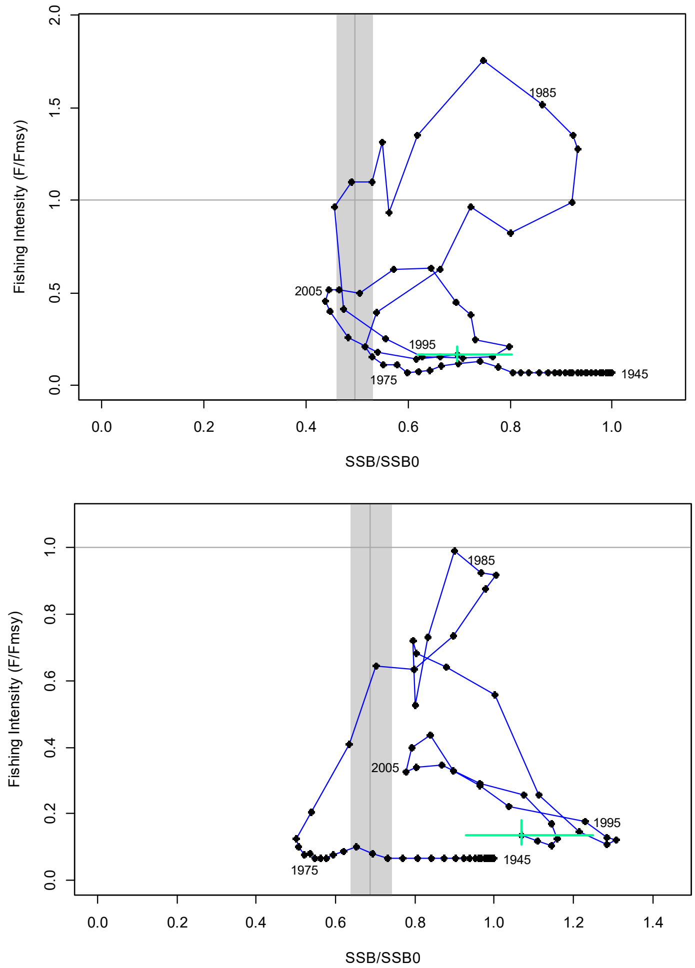


Figure 27: Snail trails from the two CRA 3 base case MCMCs: fixed growth CV at the top.

6.4 CRA 4

This section reports the assessment for CRA 4 conducted in 2016.

Models and model structure

The stock assessment is based on a single-stock version of the multi-stock length-based model (MSLM) (Haist et al. 2009). During the stock assessment workshop, a new single-stock model (Webber, unpublished) was also fitted in parallel and its estimates were verified against the MSLM results. Also during the workshop, multi-stock versions of both models were fitted to four sets of statistical area data on an experimental basis. Only the single-stock MSLM model results are discussed here.

The model was fitted to two series of catch rate indices from different periods, and to size frequency, puerulus settlement and tagging data. The model used an annual time step from 1945 to 1978 and then switched to a seasonal time step with AW and SS from 1979 through 2015. The model had 93 length bins, 31 for each sex group (males, immature and mature females), each 2 mm TW wide, beginning at left-hand edge 30 mm TW.

Significant catches occurred in the historical series for CRA 4. Different MLS regulations existed in the past and pots were not required to have escape gaps. The model incorporated a time series of sex-specific MLS regulations. Data and their sources are listed in Table 40.

Non-commercial catches for CRA 4 are described in Section 1.2.2 (recreational catch), Section 1.3 (Section 111 recreational catches), Section 1.4 (customary catch) and Section 1.5 (illegal catch).

Table 40: Data types and sources for the 2016 assessment for CRA 4. Year codes apply to the first nine months of each fishing year, i.e., 1998–99 is called 1998. MFish – NZ Ministry of Fisheries; NZ RLIC – NZ Rock Lobster Industry Council.

Data type	Data source	Begin year	End year
Historical catch rate CR	Annala & King (1983)	1963	1973
CPUE	FSU & CELR	1979	2015
Observer proportions-at-size	MFish and NZ RLIC	1986	2015
Logbook proportions-at-size	NZ RLIC	1997	2015
Tag recovery data	NZ RLIC & MFish	1982	2015
Historical MLS regulations	Annala (1983), MFish	1945	2015
Escape gap regulation changes	Annala (1983), MFish	1945	2015
Puerulus settlement	NIWA	1979	2015

The initial population in 1945 was assumed to be in equilibrium with average recruitment and with no fishing mortality. Each season the number of male, immature female and mature female lobsters within each size class was updated as a result of:

a) **Recruitment:** Each year, new recruits to the model were added equally for each sex for each season, as a normal distribution with a mean size (32 mm) and standard deviation (2 mm), truncated at the smallest size class (30 mm). Recruitment in a specific year was determined by the parameter for base recruitment and a parameter for the deviation from base recruitment. The vector of log recruitment deviations was assumed to be normally distributed with a mean of zero. Recruitment deviations were estimated for 1945 through 2017 when fitting to the puerulus index.

b) **Mortality:** Natural, fishing and handling mortalities were applied to each sex category (male, immature female and mature female) in each size class. Natural mortality was estimated, but was assumed to be constant and independent of sex and length. Fishing mortality was determined from observed catch and model biomass, modified by legal sizes, sex-specific vulnerabilities and selectivity curves. Handling mortality was assumed to be 10% of fish returned to the water until 1990, then reduced to 5%. Two fisheries were modelled: one fishery that operated only on fish above the size limit (SL fishery – including legal commercial and recreational) and one that did not (NSL fishery – all of the illegal fishery plus the Maori customary fishery). It was assumed that size limits and the prohibition on berried females applied only to the SL fishery. Otherwise, the selectivity and vulnerability functions were the same for the SL and NSL fisheries. Relative vulnerability was calculated by assuming (after experimentation) that immature females in the AW had the highest vulnerability and that the vulnerabilities of all other sex categories by season were less. Instantaneous fishing mortality rates for each fishery were calculated using Newton-Raphson iteration (three iterations after experiment) based on catch and model biomass.

c) **Fishery selectivity:** A three-parameter fishery selectivity function was assumed, with parameters describing the shapes of the ascending and descending limbs and the size at which vulnerability is at a maximum. Changes in regulations over time (for instance, changes in escape gap regulations) were modelled by estimating two separate selectivity epochs, pre-1993 and 1993–2010. As in previous assessments for the past decade, the descending limb of the selectivity curve was fixed to prevent underestimation of selection for large lobsters.

d) **Growth and maturity:** For each size class and sex category, a growth transition matrix specified the probability of an individual remaining in the same size class or growing into each of the other size classes. Maturation of females was estimated as a two-parameter logistic curve from the maturity-at-size information in the size-frequency data.

Model fitting

A total negative log likelihood function was minimised using AD Model Builder™. The model was fitted to historical catch rate and standardised CPUE data using lognormal likelihood. Puerulus settlement data were fit with normal-log likelihood. The model was fitted to proportions-at-length with multinomial likelihood and tag-recapture data with robust normal likelihood (after experimentation with normal likelihood). For the CPUE and puerulus likelihoods, CVs for each index value were initially set at the standard error from the GLM analysis. Process error was subsequently added to these CVs. A fixed CV of 0.3 was used for the historical catch rate data. The robust normal likelihood was used for the tagging data. Proportions-at-length, assumed to be representative of the commercial catch, were available from observer catch sampling for all years after 1985 and from voluntary logbooks for some years from 1997. Data were summarised by area/month strata and weighted by the commercial catch taken in each stratum, the number of lobsters measured and the number of days sampled with the size data from each source (research sampling or voluntary logbooks) fitted independently. Seasonal proportions-at-length summed to one for each of males, immature and mature females and the sex ratios by season were fitted using a multinomial likelihood. Randomisation trials were conducted to establish that puerulus settlement data contained a recruitment signal; these established that the puerulus data contributed recruitment information to the model with lags of 1 or 2 years.

Uniform priors with wide bounds were used for most estimated parameters. Informed priors on the growth shape, growth CV and growth observation error were based on a meta-analysis of all rock lobster growth data in 2015 (Webber, unpublished). The CVs of these priors were experimentally increased when the search for a base case was conducted.

Table 41: Parameters estimated and priors used in the base case CRA 4 stock assessment. Prior type abbreviations: U – uniform; N – normal; L – lognormal.

Par	Lower bound	Upper bound	Prior type	Prior mean	Prior std/CV
ln(*R0*)	1	25			
M	0.01	0.35	2	0.12	0.4
*Rdev*s	-2.3	2.3	1	0	0.4
ln(*qCPUE*)	-25	0	0		
ln(*qCR*)	-25	2	0		
ln(*qpuerulus)*	-25	0	0		
size at 50% maturation	30	80	0		
increment at 50 mm TW	1	20	0		
ratio of increments at 80 and 50 mm	0.001	1	0		
growth shape - male	0.1	15	1	4.81	0.38
growth CV - male	0.01	2	1	0.59	0.0076
growth shape - female	0.1	15	1	4.51	0.24
growth CV - female	0.01	2	1	0.82	0.013
growth observation error	0.00001	10	1	1.48	0.015
selectivity left limb	1	50	0		
size at maximum selectivity	30	90	0		
sex-seasonal vulnerability	0.01	1	0		

In the base case, it was assumed that biomass was proportional to CPUE, that growth is not density-dependent and that there is no stock-recruit relationship. Base case explorations involved experimentally weighting the datasets and inspecting the resulting standard deviations of normalised residuals and medians of absolute residuals, experimentally increasing the CVs of the informed growth priors, experimenting with the sex and season for maximum vulnerability, experimenting with fixing the shape of the maturation ogive and exploring other model options such as density-dependence and selectivity curves. Recruitment deviations were estimated for 1945–2017. CPUE process error was decreased for 2014–15 to force a good fit to the 2015 observed CPUE.

Parameters estimated in each model and their priors are provided in Table 41; fixed values used in the assessment are provided in Table 42. CPUE, the historical catch rate, proportions-at-length and tagging data were given relative weights directly by a relative weighting factor.

Table 42: Fixed values used in base case assessment for CRA 4.

Value	CRA 4
shape parameter for CPUE vs biomass	1.0
maturation shape parameter	3.26
minimum std. dev. of growth increment	0.0001
Std dev of historical catch per day	0.30
Handling mortality before 1990	10%
Handling mortality from 1990	5%
Process error for CPUE before 2014	0.25
Process error for CPUE from 2014	0.075
Year of selectivity change	1993
Current male size limit	54
Current female size limit	60
First year for recruitment deviations	1945
Last year for recruitment deviations	2017
Relative weight for length frequencies: male	3.15
Relative weight for length frequencies: immature female	1.0
Relative weight for length frequencies: mature female	1.814
Relative weight for sex proportions	3.09
Relative weight for CPUE	2.8
Relative weight for CR	4
Relative weight for puerulus	0.683
Relative weight for tag-recapture data	1

Model projections

Bayesian estimation procedures were used to estimate the uncertainty in model estimates and short-term projections. This procedure was conducted in the following steps:

1. Model parameters were estimated by AD Model Builder™ using maximum likelihood and the prior probabilities. The point estimates are called MPD (mode of the joint posterior) estimates.
2. Samples from the joint posterior distribution of parameters were generated with Markov chain Monte Carlo (MCMC) simulations using the Hastings-Metropolis algorithm; five million simulations were made, starting from the base case MPD, and 1000 samples were saved. From each sample of the posterior, three-year projections (2016–19) were generated with an assumed current-catch scenario (Table 43).
3. Future annual recruitment was randomly sampled with replacement from the model's estimated recruitments from 2008–17.

Table 43: Catches (t) used in the three-year projections. Projected catches are based on the current TACC for CRA 4, and the current estimates of recreational, customary and illegal catches. SL = commercial + recreational - reported illegal; NSL = reported illegal + unreported illegal + customary.

Commercial	Recreational	Reported illegal	Unreported illegal	Customary	SL	NSL
397	37	0	40	20	434	60

Performance indicators and results

Vulnerable biomass in the assessment model was determined by the MLS, selectivity, relative sex and seasonal vulnerability and berried state for mature females. All mature females were assumed to be berried (and not vulnerable to the fishery) in AW and not berried (thus vulnerable) in SS.

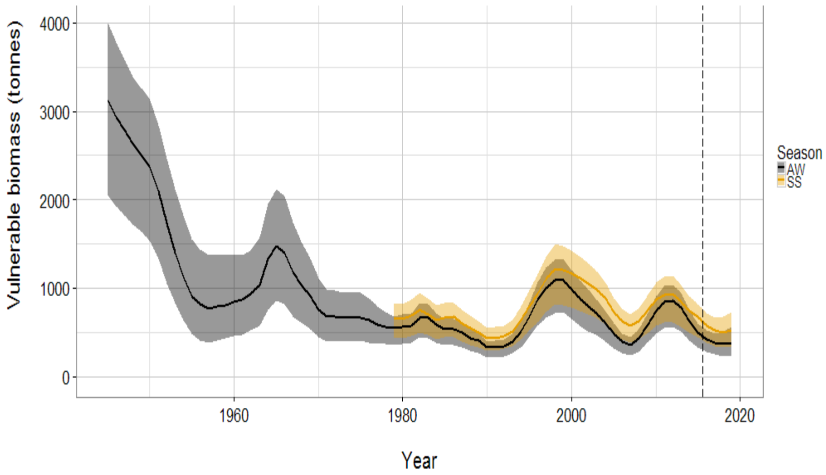


Figure 28: Posterior distribution of the CRA 4 base case MCMC biomass vulnerable trajectory. Before 1979 there was a single time step, shown in AW. For each year the black line represents the median, the shaded area spans the 5th and 95th quantiles.

Results from agreed indicators are summarised in Table 45. Base case results (Table 45) suggested that biomass decreased to a low point in 1991, then increased to a high in 1998 (Figure 28), decreased to 2006 and has increased again. The current vulnerable stock size (AW) is about 0.75 times the reference biomass and the spawning stock biomass is close to SSB_{msy} (Table 45). Projected biomass would decrease at the level of current catches over the next four years (Figure 28).

Table 44: Performance indicators used in the CRA 4 stock assessment. [Continued on next page]

Reference points	Description
Bmin	The lowest beginning AW vulnerable biomass in the series
B2016	Beginning of season AW vulnerable biomass
Bref	Beginning of AW season mean vulnerable biomass for 1979–88
B2019	Projected beginning of season AW 2019 vulnerable biomass
Bmsy	Beginning of season AW vulnerable biomass associated with MSY, calculated by doing deterministic forward projections with recruitment *R0* and current fishing patterns
MSY	Maximum sustainable yield (sum of AW and SS SL catches) found by searching a across a range of multipliers on F.
Fmult	The multiplier that produced *MSY*
SSB2016	spawning stock biomass at start of AW 2016 season
SSB2019	Projected spawning stock biomass at start of AW 2019 season
SSBmsy	Spawning stock biomass at start of AW season associated with *MSY*

CPUE indicators	Description
CPUE2015	CPUE predicted for AW 2015
CPUE2019	CPUE predicted for AW 2019
CPUEmsy	CPUE at *Bmsy*

Performance indicators	Description
B2016 / Bmin	ratio of *B2016* to *Bmin*
B2016 / Bref	ratio of *B2016* to *Bref*
B2016 / Bmsy	ratio of *B2016* to *Bmsy*
B2019 / B2016	ratio of *B2019* to *B2016*
B2019 / Bref	ratio of *B2019* to *Bref*
B2019 / Bmsy	ratio of *B2019* to *Bmsy*
SSB2016/SSB0	ratio of *SSB2016* to *SSB0*
SSB2019/SSB0	ratio of *SSB2019* to *SSB0*
SSB2016/SSBmsy	ratio of *SSB2016* to *SSBmsy*
SSB2019/SSBmsy	ratio of *SSB2019* to *SSBmsy*
SSB2019/SSBcurr	ratio of *SSB2019* to *SSBcurrent*
USL2015	The 2015 exploitation rate for SL catch in AW
USL2019	Projected 2019 exploitation rate for SL catch in AW
USL2019/USL2015	ratio of SL 2019 exploitation rate to 2015 SL exploitation rate
Btot2016	total biomass at start of 2016 AW season
Btot2016/Btot0	*Btot2016* divided by total biomass at the start
Ntot2016	total numbers at start of 2016 AW season
Ntot2016/Ntot0	*Ntot2016* divided by total numbers at the start
minHandMort	minimum tonnage of mortality caused by handling
HandMort2016	2016 tonnage of mortality caused by handling
HandMort2019	2019 tonnage of mortality caused by handling

Table 44 [Continued]:

Probabilities	Description
P(B2016 > Bmin)	probability *B2016* > *Bmin*
P(B2016 > Bref)	probability *B2016* > *Bref*
P(B2016 > Bmsy)	probability *B2016* > *Bmsy*
P(B2019 > Bmin)	probability *B2019* > *Bmin*
P(B2019 > Bref)	probability *B2019* > *Bref*
P(B2019 > Bmsy)	probability *B2019* > *Bmsy*
P(B2019 > B2016)	probability *B2019* > *B2016*
P(SSB2016>SSBmsy)	probability *SSB2016>SSBmsy*
P(SSB2019>SSBmsy)	probability *SSB2019>SSBmsy*
P(USL2019>USL2015)	probability 2019 SL exploitation rate > 2015 SL exploitation rate
P(SSB2016<0.2SSB0)	soft limit: probability *SSB2016* < 20% *SSB0*
P(SSB2019<0.2SSB0	soft limit: probability *SSB2019* < 20% *SSB0*
P(SSB2016<0.1SSB0)	hard limit: probability *SSB2016* < 10% *SSB0*
P(SSB2019<0.1SSB0)	hard limit: probability *SSB2019* < 10% *SSB0*

A series of MCMC sensitivity trials were also made. The assessment results from the base case and sensitivity trials calculated as a series of agreed indicators (Table 44) are shown in Table 45.

The sensitivity trials run were:
- *3-sexlag1*: same as the base but with lag 1 year for puerulus
- *2-sex*: fitted to males and aggregated females with fixed maturation parameters
- *normaltag*: using normal likelihood instead of robust normal for fitting to tags
- *estMat95*: with fixed growth shape and growth CV parameters and the maturation shape parameter estimated
- *fixMat95*: with fixed growth shape and growth CV parameters and the maturation shape parameter fixed.

Indicators based on vulnerable biomass and *Bmsy*
In all trials the median *Bref* was larger than *Bmsy* and *Bmin*. In all trials median current and projected biomass was smaller than *Bref* but larger than *Bmsy*. Projected biomass, using current catches, decreased in the base case but increased in some of the sensitivity trials. Projected biomass remained below *Bref* except in the estMat95 and fixMat95 trials.

Table 45: Assessment results – medians of indicators described in Table 44 from the base case and sensitivity trials; the lower part of the table shows the probabilities that events are true; biomass in t and CPUE in kg/potlift. [Continued on next page]

Indicator	3-sex base	3-sex lag1	2-sex	normaltag	estMat95	fixMat95
Bmin	324.2	307.1	391.4	248.8	270.2	270.2
B_{2016}	416.0	399.3	493.9	316.8	347.1	346.8
Bref	560.9	542.6	672.4	423.1	494.0	493.1
B_{2019}	384.3	412.6	449.5	272.9	509.3	509.6
Bmsy	283.6	269.3	351.1	227.1	305.4	304.8
MSY	638.8	642.2	643.0	620.9	634.8	635.0
Fmult	3.11	3.23	2.97	2.72	2.31	2.33
SSB_{2016}	1 601.2	1 635.8	1 669.2	1 526.4	1 081.1	1 072.8
SSB_{2019}	1 649.3	1 750.3	1 691.1	1 514.4	1 040.5	1 020.7
SSBmsy	1 889.9	1 940.1	2 018.5	1 815.0	1 101.4	1 088.6
$CPUE_{2015}$	0.737	0.741	0.733	0.742	0.747	0.747
$CPUE_{2019}$	0.584	0.646	0.555	0.544	1.028	1.017
CPUEmsy	0.339	0.327	0.353	0.375	0.461	0.459
$B_{2016}/Bmin$	1.295	1.309	1.263	1.279	1.279	1.280
$B_{2016}/Bref$	0.749	0.741	0.735	0.751	0.701	0.700
$B_{2016}/Bmsy$	1.471	1.497	1.414	1.389	1.131	1.137
B_{2019}/B_{2016}	0.942	1.043	0.914	0.884	1.483	1.473
$B_{2019}/Bref$	0.708	0.773	0.669	0.664	1.035	1.030
$B_{2019}/Bmsy$	1.385	1.568	1.282	1.239	1.666	1.668
SSB_{2016}/SSB_0	0.508	0.510	0.508	0.509	0.473	0.475
$SSB2019/SSB_0$	0.518	0.545	0.512	0.503	0.454	0.452
$SSB_{2016}/SSBmsy$	0.850	0.841	0.827	0.835	0.981	0.985
$SSB_{2019}/SSBmsy$	0.867	0.901	0.833	0.827	0.941	0.944
SSB_{2019}/SSB_{2016}	1.021	1.065	1.014	0.989	0.964	0.957
USL_{2015}	0.229	0.236	0.193	0.302	0.285	0.285
USL_{2019}	0.267	0.249	0.229	0.376	0.202	0.202

Table 45 [Continued]:

Indicator	3-sex base	3-sex lag1	2-sex	normaltag	estMat95	fixMat95
USL_{2019}/USL_{2015}	1.134	1.045	1.181	1.209	0.707	0.709
$Btot_{2016}$	4 056.8	4 465.0	4 415.5	4 429.6	2 162.9	2 154.7
$Btot_{2016}/Btot_0$	0.406	0.441	0.415	0.418	0.291	0.293
$Ntot_{2016}$	14 152 350	17 139 950	16 166 500	16 750 850	6 452 725	6 433 990
$Ntot_{2016}/Ntot_0$	0.500	0.584	0.512	0.531	0.393	0.394
minHandMort (t)	14.25	14.42	14.44	14.62	10.99	11.00
$HandMort_{2016}$ (t)	18.14	17.90	18.54	18.95	19.18	19.23
$HandMort_{2019}$ (t)	25.88	24.22	26.78	26.87	16.65	16.70

Indicators based on *SSBmsy*

The historical track of biomass versus fishing intensity is shown in Figure 29. This 'snail trail' shows the median spawning biomass on the x-axis and median fishing intensity on the y-axis; thus high biomass/low fishing intensity is in the lower right-hand corner, where a stock would be when fishing first began, and low biomass/high intensity is in the upper left-hand corner, where an uncontrolled fishery would be likely to go. Specifically, the x-axis is spawning stock biomass *SSB* as a proportion of the unfished spawning stock *SSB0*. Estimated *SSB* changes every year; *SSB0* is constant for all years of a simulation, but varies among the 1000 samples from the posterior distribution.

The y-axis is fishing intensity as a proportion of the fishing intensity that would have given MSY (*Fmsy*) under the fishing patterns in year *y*; fishing patterns include MLS, selectivity, the seasonal catch split and the balance between SL and NSL catches. *Fmsy* varies among years because the fishing patterns change. It was calculated with a 50-year projection for each year in each simulation, with the NSL catch held constant at that year's value, deterministic recruitment at *R0* and a range of multipliers on the SL catch *F*s estimated for year *y*. The *F* (actually *F*s for two seasons) that gave MSY was *Fmsy*, and the multiplier was *Fmult*.

Each point on the figure was plotted as the median of the posterior distributions of biomass ratio and fishing intensity ratio. The vertical line in the figure is the median (line) and 90% interval (shading) of the posterior distribution of *SSBmsy* as a proportion of *SSB0*; this ratio was calculated using the fishing pattern in 2015. The horizontal line in the figure is drawn at 1, the fishing intensity associated with *Fmsy*. The bars at the final year of the plot show the 90% intervals of the posterior distributions of biomass ratio and fishing intensity ratio.

Both current and projected spawning biomass are well above 40% *SSB0*.

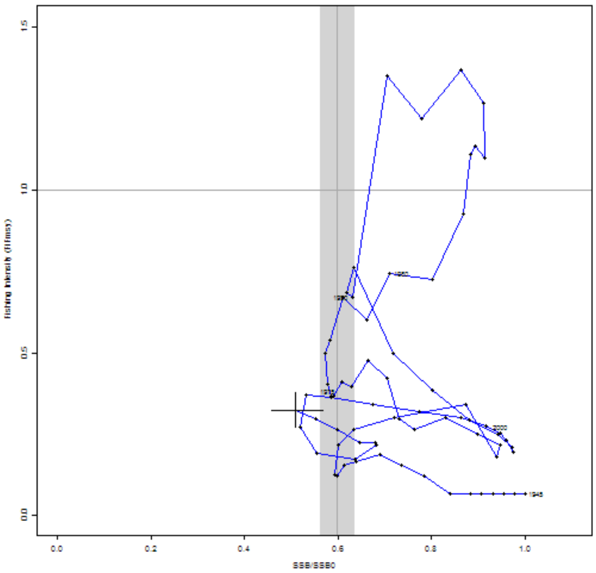


Figure 29: 'Snail trail' showing the median spawning biomass on the x-axis and median fishing intensity on the y-axis.

This year two new models were tested alongside the CRA 4 stock assessment: an experimental CRA 4 sub-area stock assessment and a new rock lobster stock assessment model called Lobster Stock Dynamics (LSD). The experimental CRA 4 sub-area assessment was not completed this year but the approach looks promising and is likely to be a credible approach to investigate in the future. Not only do sub-area models like this provide an understanding of stock status as a whole, they may also provide more disaggregated results that can be used to voluntarily manage fisheries at smaller spatial scales (e.g., apportioning more catch to statistical areas that have the highest abundance or productivity). The new assessment model aimed to emulate the MLSM model (Haist et al. 2009) as closely as possible this year, so few new features were added to the code. The model was written in the state-of-the-art Bayesian programming language, Stan, and several benefits have already been identified. For example, LSD/Stan does not require that the Hessian be positive definite to begin MCMC sampling. Also, Stan uses Hamiltonian Monte Carlo (HMC), which is a much more efficient MCMC sampler and mixes much faster than standard Metropolis-Hastings MCMC samplers. This greatly speeds up the exploration of different model structures and allows for faster Bayesian inference (or more complex models to be explored). Due to its speed, LSD could be an excellent platform for finer-scale spatial modelling in the future.

Future research considerations

- Continued development of the sub-area model
  - More flexible data processing code is needed
  - The new model should have the capability to fit to data that have different spatial or temporal scales (e.g., catch data pre-1979 are by QMA and are only available by statistical area from 1979)
  - The new model should have the capability to specify some parameters as random effects (e.g., natural mortality, selectivity).
- Investigation of methods for collecting growth data for sub-45 mm TW lobsters
- Further exploration of relative weightings of length frequencies
- Improved estimates of non-commercial catch
- More tagging in Statistical Areas 912 and 915.

6.5 CRA 5

This section reports the assessment for CRA 5 conducted in 2015.

Model structure

A single-stock version of the multi-stock length-based model (MSLM) (Haist et al. 2009) was fitted to two series of catch rate indices from different periods, and to size frequency, puerulus settlement and tagging data. The model used an annual time step for 1945–78 and then a seasonal time step (autumn–winter (AW): April to September; and spring–summer (SS): October to March).

Significant catches occurred in the early part of the time series for CRA 5. Different MLS regulations existed at this time and pots were not required to have escape gaps. The model incorporated a time series of sex-specific MLS regulations. Data and sources available to the model are listed in Table 46.

The assessment assumed that recreational catch was equal to survey estimates in 1994, 1996 and an assumed value of 80 t in 2011, fitted to an exponential model driven by the Statistical Area 917 AW CPUE from 1979–2009, and increased linearly from 20% of the 1979 value in 1945 up to the 1979 value (see Section 1.4 for a description of the procedure followed).

The initial population in 1945 was assumed to be in equilibrium with average recruitment and with no fishing mortality. Each season the number of male, immature female and mature female lobsters within each size class is updated as a result of:

a) **Recruitment:** Each year, new recruits were added equally for each sex season, as a normal distribution with a mean size (32 mm) and standard deviation (2 mm), truncated at the smallest size class (30 mm). Recruitment in a specific year was determined by the parameter for base recruitment and a parameter for the deviation from base recruitment. The vector of recruitment deviations was assumed to be normally distributed with a mean of zero with standard deviation of 0.4. It was assumed that stock size has no influence on recruitment because of the long duration of the pelagic larval phase coupled with long-distance movements during this phase.

b) **Mortality:** Natural, fishing and handling mortalities were applied to each sex category (male, immature female and mature female) in each size class. Natural mortality was estimated, but was assumed to be constant and independent of sex and length. Fishing mortality was determined from observed catch and model biomass, modified by legal sizes, sex-specific vulnerabilities and selectivity curves. A constant handling mortality of 10% was applied to all discarded lobsters, independent of size. Two fisheries were modelled: one fishery that operated only on fish above the size limit (SL fishery – consisting of legal commercial and recreational) and one that did not (NSL fishery – all of the illegal fishery plus the Maori customary fishery). It was assumed that size limits and the prohibition on berried females applied only to the SL fishery. Otherwise, the selectivity and vulnerability functions were the same for the SL and NSL fisheries. Relative vulnerability was calculated by assuming that the males in the AW had the highest vulnerability and that the vulnerability of all other sex categories by season are equal to or less than the AW males. Instantaneous fishing mortality rates for each fishery were calculated using Newton-Raphson iteration based on catch and model biomass.

c) **Fishery selectivity:** A three-parameter fishery selectivity function was assumed, with parameters describing the shapes of the ascending and descending limbs and the size at which vulnerability is at a maximum (the right-hand limb was fixed at a high value for the base case and most sensitivity runs to avoid the creation of cryptic biomass). Changes in regulations over time (for instance, changes in escape gap regulations) were modelled by estimating two separate selectivity epoch, pre-1993 and 1993–2014.

d) **Growth and maturity:** For each size class and sex category, a growth transition matrix specified the probability of an individual remaining in the same size class or growing into each of the other size classes. Maturation of females was estimated as a two-parameter logistic curve from the maturity-at-size information in the size-frequency data.

Model fitting

A total negative log likelihood function was minimised using AD Model Builder™. The model was fitted to historical catch rate, standardised CPUE and puerulus settlement data using lognormal likelihood. The model was fitted to proportions-at-length with multinomial likelihood and tag-recapture data with a normal likelihood. For the CPUE and puerulus lognormal likelihoods, CVs for each index value were initially set at the standard error from the GLM analysis. Process error was subsequently added to these CVs so that the overall standard deviation of the standardised (Pearson) residuals was near 1.0. A fixed CV of 0.3 was used for the historical catch rate data. Outliers (defined as lying in the ±0.2% quantiles of the standardised residuals when fitting to the tag data without other model data) were dropped. Proportions-at-length, assumed to be representative of the commercial catch, were available from both observer catch sampling and voluntary logbooks; these were fitted separately. Data were summarised by area/month strata and weighted by the commercial catch taken in each stratum, the number of lobsters measured and the number of days sampled with the size data from each source (research sampling or voluntary logbooks) fitted independently. Seasonal proportions-at-length summed to one for each sex category (males, immature and mature females) and the sex ratios by season were fitted using a multinomial likelihood. Randomisation trials were conducted to establish that puerulus settlement data contained a recruitment signal; these established that the puerulus data contributed recruitment information to the model with a lag of a single year.

Two base case models were accepted by the RLFAWG: both included the puerulus settlement indices but differed by the inclusion/exclusion of density-dependent growth. The RLFAWG was not able to choose between these two models because it was felt that each was equally plausible. The remaining aspects of the base case were the same, with the same weighting assumptions made for each model.

Recruitment deviations were estimated for the entire period: 1945–2015, given that the final 2014 puerulus index applies to 2015 with a one-year lag.

Table 46: Data types and sources for the 2015 assessment for CRA 5. Year codes apply to the first nine months of each fishing year (i.e., 1998–99 is called 1998). MPI – NZ Ministry for Primary Industries; NZRLIC – NZ Rock Lobster Industry Council.

Data type	Data source	Begin year	End year
Historical catch rate CR	Annala & King (1983)	1963	1973
CPUE	FSU & CELR	1979	2014
Observer proportions-at-size	MPI	1989	2010
Logbook proportions-at-size	NZRLIC	1994	2014
Tag recovery data	NZRLIC & MPI	1974	2014
MLS regulations	Annala (1983), MPI	1945	2014
Escape gap regulation changes	Annala (1983), MPI	1945	2014
Puerulus settlement	MPI	1980	2014

Parameters estimated in each model and their priors are provided in Table 47. Fixed parameters and their values are given in Table 48.

CPUE, the historical catch rate, proportions-at-length and tagging data were given relative weights directly by a relative weighting factor. The weights were varied to obtain standard deviations of standardised residuals for each dataset that were close to one.

Table 47: Parameters estimated and priors used in basecase assessments for CRA 5. Prior type abbreviations: U – uniform; N – normal; L – lognormal.

	Prior type	Bounds	Mean	SD	CV
ln(*R0*) (mean recruitment)	U	1–25	–		–
M (natural mortality)	L	0.01–0.35	0.12		0.4
Recruitment deviations	N[1]	-2.3–2.3	0	0.4	
ln(*qCPUE*)	U	-25–0	–		–
ln(*qCR*)	U	-25–2	–		–
ln(*qPuerulus*)	U	-25–0	–		–
Increment at TW=50 (male & female)	U	0.1–20.0	–		–
shape of growth curve (male)	N	0.1–15.0	4.81	0.38	
shape of growth curve (female)	N	0.1–15.0	4.51	0.24	
CV of growth increment (male)	N	0.01–2.0	0.59	.0076	
CV of growth increment (female)	N	0.01–2.0	0.82	.013	
growth observation std.dev. (male & female)	N	0.00001–10.0	1.48	.0015	
TW at 50% probability female maturation	U	30–80	–		–
(TW at 95% probability female maturity) – (TW at 50% probability female maturity)	U	1–60	–		–
density-dependence parameter	U	0–1	–	–	
Relative vulnerability (all sexes and seasons)[2]	U	0–1	–		–
Shape of selectivity left limb (males & females)	U	1–50	–		–
Size at maximum selectivity (males & females)	U	30–80	–		–
Size at maximum selectivity females	U	30–80	–		–

[1] Normal in natural log space = lognormal (bounds equivalent to –10 to 10).
[2] Relative vulnerability of males in autumn–winter was fixed at one.

Table 48: Fixed values used in base case assessment for CRA 5.

Parameter/description	CRA 5
shape parameter for CPUE vs biomass	1
minimum std. dev. of growth increment	0.0001
Std dev of historical catch per day	0.30
Handling mortality	10%
Process error for CPUE	0.25
Year of selectivity change	1993
Current male size limit	54
Current female size limit	60
First year for recruitment deviations	1945
Last year for recruitment deviations	2015
Relative weight for length frequencies	4
Relative weight for CPUE	2.6
Relative weight for CR	4
Relative weight for puerulus	0.3
Relative weight for tag-recapture data	1.0

Model projections

Bayesian estimation procedures were used to estimate the uncertainty in model estimates and short-term projections. This procedure was conducted in the following steps:

a) Model parameters were estimated by AD Model Builder™ using maximum likelihood and the prior probabilities. These point estimates are called MPD (mode of the joint posterior) estimates.

b) Samples from the joint posterior distribution of parameters were generated with Markov chain Monte Carlo (MCMC) simulations using the Hastings-Metropolis algorithm; five million simulations were made, starting from the base case MPD, and 1000 samples were saved. From each sample of the posterior, four-year projections (2015–18) were generated with an agreed catch scenario (Table 49).

c) Future annual recruitment was randomly sampled with replacement from the model's estimated recruitments from 2006–15 (except for the no puerulus sensitivity trial, which resampled from 2003–12).

Table 49: Catches (t) used in the five-year projections. Projected catches are based on the current TACC for CRA 5, and the current estimates of recreational, customary and illegal catches.

Commercial	Recreational	Reported illegal	Unreported illegal	Customary
350	82.8	0	30	10

Vulnerable biomass in the assessment model was determined by the MLS, selectivity, relative sex and seasonal vulnerability and berried state for mature females. All mature females were assumed to be berried (and not vulnerable to the fishery) in AW and not berried (and vulnerable) in SS.

Base case results suggested that biomass decreased to a low level in the late 1980s, remained low through to about 1995, and then increased (Figure 30) to a peak around 2010. The current vulnerable stock size (AW) is about twice the reference biomass and the spawning stock biomass is well above *Bmsy* (Table 51). However, projected biomass would decrease at the level of current catches over the next four years (Figure 30).

Table 50: Performance indicators used in the CRA 5 stock assessment (SL = size limited fishery; AW = autumn–winter season; SS = spring–summer season). [Continued on next page]

Reference points	Description
Bmin	The lowest beginning AW vulnerable biomass in the series
B2015	Beginning of season AW vulnerable biomass for 2015
Bref	Beginning of AW season mean vulnerable biomass for 1979–81
B2018	Projected beginning of season AW vulnerable biomass in 2018
Bmsy	Beginning of season AW vulnerable biomass associated with MSY, calculated by doing deterministic forward projections with recruitment *R0* and current fishing patterns
MSY	Maximum sustainable yield (sum of AW and SS SL catches) found by searching a across a range of multipliers on *F*.
Fmult	The multiplier that produced MSY
SSB2015	Current spawning stock biomass at start of AW season
SSB2018	Projected spawning stock biomass at start of AW season
SSBmsy	Spawning stock biomass at start of AW season associated with MSY

CPUE indicators	Description
CPUE2014	CPUE predicted for AW 2014
CPUE2018proj	CPUE predicted for AW 2018
CPUEmsy	CPUE at *Bmsy*

Performance indicators	Description
B2015 / Bmin	ratio of *B2015* to *Bmin*
B2015/ Bref	ratio of *B2015* to *Bref*
B2015 / Bmsy	ratio of *B2015* to *Bmsy*
B2018 / B2015	ratio of *B2018* to *B2015*
B2018/ Bref	ratio of *B2018* to *Bref*
B2018/ Bmsy	ratio of *B2018* to *Bmsy*
SSB2015/SSB0	ratio of *SSB2015* to *SSB0*
SSB2018/SSB0	ratio of *SSB2018* to *SSB0*
SSB2015/SSBmsy	ratio of *SSB2015* to *SSBmsy*
SSB2018/SSBmsy	ratio of *SSB2018* to *SSBmsy*

Table 50 [Continued]:

Performance indicators	Description
SSB2015/SSB2015	ratio of *SSB2018* to *SSB2015ent*
USL2015	The 2015 exploitation rate for SL catch in AW
USL2018/USL2015	ratio of SL 2018 exploitation rate to 2015 SL exploitation rate
Btot2014	total biomass in 2014
Ntot2014	total numbers in 2014
Btot0	total biomass without fishing
Ntot0	total numbers without fishing

Probabilities	Description
P*(B2015 > Bmin)*	probability *B2015* > *Bmin*
P*(B2015 > Bref)*	probability *B2015* > *Bref*
P*(B2015 > Bmsy)*	probability *B2015* > *Bmsy*
P*(B2018 > Bmin)*	probability *B2018* > *Bmin*
P*(B2018 > Bref)*	probability *B2018* > *Bref*
P*(B2018 > Bmsy)*	probability *B2018* > *Bmsy*
P*(B2018 > B2015)*	probability *B2018* > *B2015*
P*(SSB2015>SSBmsy)*	probability *SSB2015>SSBmsy*
P*(SSB2018>SSBmsy)*	probability *SSB2015>SSBmsy*
P*(USL2018>USL2015)*	probability SL exploitation rate *2018* > SL exploitation rate *2015*
P*(SSB2015<0.2SSB0)*	soft limit CRA 8: probability *SSB2015*< 20% *SSB0*
P*(SSB2018<0.2SSB0*	soft limit CRA 8: probability *SSB2018* < 20% *SSB0*
P*(SSB2015 <0.1SSB0)*	hard limit CRA 8: probability *SSB2015*< 10% *SSB0*
P*(SSB2018<0.1SSB0)*	hard limit CRA 8: probability *SSB2018*< 10% *SSB0*

A series of MCMC sensitivity trials was also made, including exclusion of puerulus data, using an alternative (higher) recreational catch vector, wider CVs on the growth priors, stronger CVs on the CPUE indices (to obtain a better fit), and a descending right-hand limb to the selectivity functions. The assessment results from the base case and sensitivity trials calculated as a series of agreed indicators (Table 50) are shown in Table 51.

(a) Base case without DD

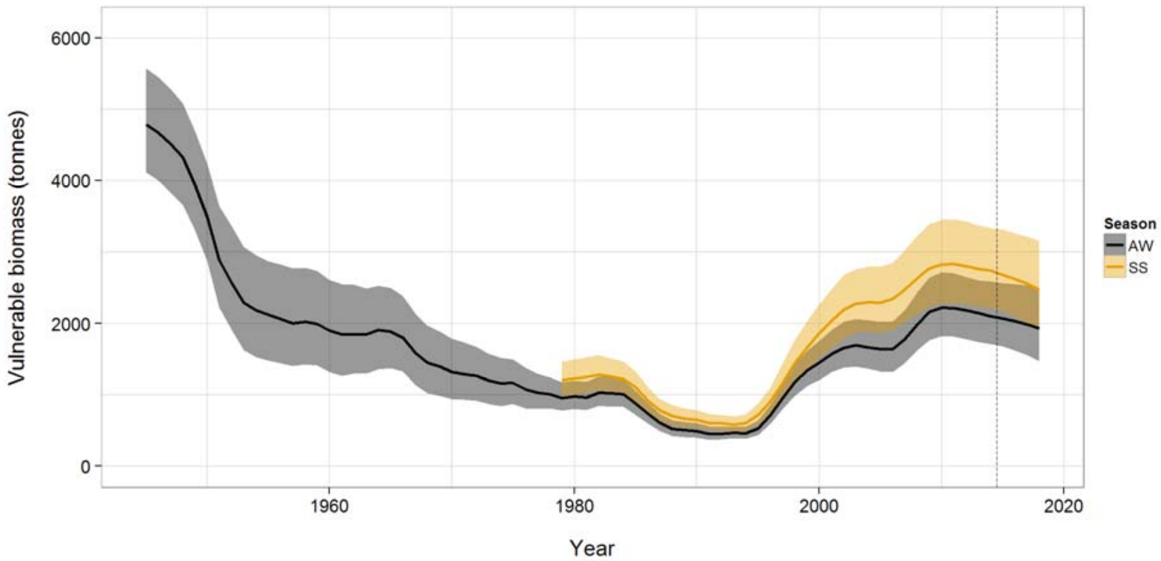


Figure 30: Posterior distributions of the two base case MCMCs biomass vulnerable trajectory (with and without density-dependence [DD]). Before 1979 there was a single time step, shown in AW. The trajectory to the right of the vertical dotted catches are projections based on the catches in Table 49. For each year the horizontal line represents the median and the coloured envelope represent the 5% and 95% quantiles. [Continued on next page]

(b) Base case with DD

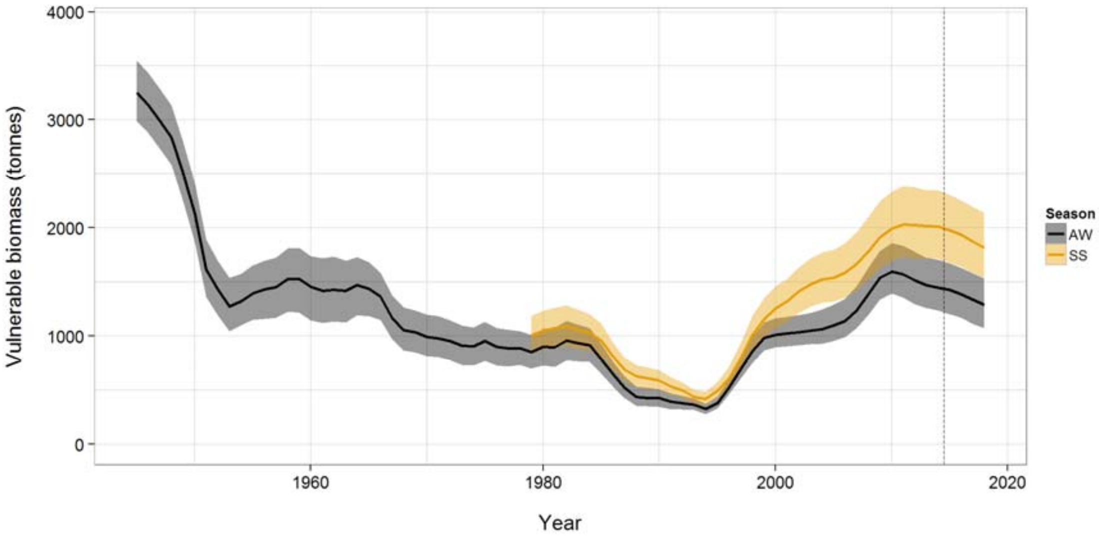


Figure 30 [Continued]: Posterior distributions of the two base case MCMCs biomass vulnerable trajectory (with and without density-dependence [DD]). Before 1979 there was a single time step, shown in AW. The trajectory to the right of the vertical dotted catches are projections based on the catches in Table 49. For each year the horizontal line represents the median and the coloured envelope represent the 5% and 95% quantiles.

Indicators based on vulnerable biomass (AW) and *Bmsy*

In the base case and for all trials, current and projected biomass levels were larger than *Bref* and *Bmsy* reference levels by substantial amounts for both catch projection scenarios (Table 51). Projected biomass decreased in most runs but remained well above the reference levels in the base case and for all trials.

Table 51: Assessment results – medians of indicators described in Table 50 from the base case and sensitivity trials under catches given in the lower part of the table shows the probabilities that events are true (DD = density-dependence). The last four models were all run without density-dependence. [Continued on next page]

Indicator	Base case: no DD	Base case: with DD	Base case: no DD and no puerulus	Base case: with DD and no puerulus	Alternative recreational catch	Estimate R-H selectivity	Growth prior CV=30%	Double weight to CPUE series
Bmin	438.8	323.9	425.9	319.1	431.6	450.3	370.3	378.0
B2015	2 070.0	1 428.8	2 086.2	1 373.1	2 019.0	2 020.2	1 650.7	1 686.0
Bref	871.0	788.6	841.2	744.7	857.5	903.6	760.2	755.2
B2018	1 935.6	1 290.3	2 250.7	1 257.9	1 844.6	1 869.0	1 548.4	1 594.4
Bmsy	505.2	483.6	503.8	481.9	517.1	568.3	474.6	498.1
MSY	536.6	560.1	545.3	564.5	540.2	591.6	504.2	494.5
Fmult	6.18	4.78	6.30	4.72	5.17	6.01	4.93	4.66
SSB2015	2 926.2	2 250.3	3 022.4	2 195.8	2 867.6	3 556.2	2 406.1	2 541.6
SSB2018	2 669.6	2 018.0	3 139.5	2 016.8	2 574.5	3 313.0	2 218.0	2 335.5
SSBmsy	1 500.4	1 094.2	1 511.8	1 086.8	1 456.2	1 736.2	1 267.6	1 411.4
CPUEcurrent	1.54	1.54	1.54	1.52	1.53	1.49	1.50	1.46
CPUEproj	1.40	1.36	1.68	1.35	1.34	1.33	1.36	1.36
CPUEmsy	0.267	0.362	0.266	0.364	0.291	0.296	0.311	0.318
B2015/Bmin	4.74	4.40	4.90	4.27	4.65	4.47	4.43	4.42
B2015/Bref	2.40	1.82	2.51	1.84	2.36	2.25	2.16	2.22
B2015/Bmsy	4.11	2.94	4.14	2.85	3.89	3.57	3.46	3.41
B2018/B2015	0.92	0.90	1.07	0.92	0.91	0.92	0.93	0.94
B2018/Bref	2.22	1.65	2.69	1.68	2.12	2.05	2.02	2.11
B2018/Bmsy	3.84	2.67	4.46	2.62	3.53	3.27	3.25	3.20
SSB2015/SSB0	0.781	0.970	0.805	0.965	0.751	0.779	0.701	0.702
SSB2018/SSB0	0.707	0.871	0.837	0.888	0.668	0.720	0.649	0.642
SSB2015/SSBmsy	1.96	2.05	2.00	2.02	1.97	2.05	1.89	1.81
SSB2018/SSBmsy	1.78	1.84	2.08	1.86	1.75	1.90	1.74	1.66
SSB2018/SSB2015	0.905	0.897	1.032	0.918	0.889	0.928	0.921	0.916
USL2014	0.113	0.164	0.115	0.170	0.118	0.115	0.142	0.140
USL2018	0.123	0.184	0.106	0.189	0.132	0.127	0.154	0.149
USL2018/USL2014	1.10	1.12	0.93	1.11	1.12	1.11	1.10	1.07
Btot2015	6 986.9	5 193.8	7 448.8	5 109.5	6 835.4	8 463.3	5 558.3	5 952.1
Btot2015/Btot0	0.673	0.668	0.720	0.667	0.645	0.668	0.577	0.588
Ntot2015	16 854 400	12 830 400	19 078 650	12 767 250	16 562 000	18 648 300	13 185 100	14 581 600

Table 51 [Continued]:

Indicator	Base case: no DD	Base case: with DD	Base case: no DD and no puerulus	Base case: with DD and no puerulus	Alternative recreational catch	Estimate R-H selectivity	Growth prior CV=30%	Double weight to CPUE series
Ntot2015/Ntot0	0.832	0.698	0.927	0.699	0.823	0.829	0.771	0.781
P(*B2015>Bmin*)	1	1	1	1	1	1	1	1
P(*B2015>Bref*)	1	1	1	1	1	1	1	1
P(*B2015>Bmsy*)	1	1	1	1	1	1	1	1
P(*B2018>Bmin*)	1	1	1	1	1	1	1	1
P(*B2018>Bref*)	1	0.999	1	1	1	1	1	1
P(*B2018>Bmsy*)	1	1	1	1	1	1	1	1
P(*B2018>B2015*)	0.188	0.026	0.726	0.081	0.133	0.189	0.24	0.281
P(*SSB2015>SSBmsy*)	1	1	1	1	1	1	1	1
P(*SSB2018>SSBmsy*)	1	1	1	1	1	1	1	1
P(*USL2018>USL2014*)	0.822	0.985	0.281	0.956	0.871	0.833	0.788	0.705
P(*SSB2015<0.2SSB0*)	0	0	0	0	0	0	0	0
P(*SSB2018<0.2SSB0*)	0	0	0	0	0	0	0	0
P(*SSB2015<0.1SSB0*)	0	0	0	0	0	0	0	0
P(*SSB2018<0.1SSB0*)	0	0	0	0	0	0	0	0

Indicators based on *SSBmsy*

SSBmsy is biomass of mature females associated with *Bmsy*. The historical track of biomass versus fishing intensity is shown in Figure 31. The phase space in the plot shows biomass on the x-axis and fishing intensity on the y-axis. High biomass/low intensity is in the lower right-hand corner, the location of the stock when fishing first began, and low biomass/high intensity is in the upper left-hand corner, in a period when the fishery was largely uncontrolled. Note that fishing patterns include MLS, selectivity and the seasonal catch split and that *Fmsy* varies in each year because fishing patterns change. The reference *SSBmsy* in Figure 31 has been calculated using the 2014 fishing pattern.

In 1945, the fishery was near the lower right-hand corner of the plot, in the high biomass/low fishing the intensity region. It climbed towards the low biomass/high intensity region, reaching highest fishing intensity in 1985 and lowest biomass in 1989–91. After 1991, the fishery moved quite steadily back towards lower fishing intensity and higher biomass. The current biomass on this scale is near that of 1951, and current fishing intensity is near that of 1952.

Two alternative base case models were investigated for CRA 5: one that assumed that growth was faster at low abundance (density-dependent growth) and another that assumed a constant average growth rate regardless of abundance. The model that assumed density-dependent growth had lower productivity and smaller average biomass than the model without density-dependence. However, biomass at the end of 2015–16 was estimated by both models to be well above all reference points (*Bmin, Bmsy* and *Bref*), with a nearly certain expectation that biomass would remain above these reference points at the end of the next four years. However, both models predict with a high probability (about 90%) that biomass will have declined by the end of the four-year projection period.

Future research considerations

- For the new growth analysis:
    - Investigate potential seasonal effects such as seasonal patterns in growth and the probability of recapture
    - Modify the ‘Q’ matrix (matrix of similarities between areas) to determine how much assumptions about similarities matter
    - Further work with alternative error distributions would be useful
    - Explore the utility of contamination models.
- Recreational catch estimates are highly uncertain and improving them should be a high priority for the future. Estimates of illegal catch are also large and uncertain.
- CPUE is used as a continuous series from 1979 to 2014, yet there have been substantial technological changes over that time; the potential effects of changes in CPUE should be investigated by breaking the series in one or two places – e.g., around 1992 or 1993, when the

species was introduced into the Quota Management System and when GPS began to be widely used.
- Plot the expected growth increment as a function of %*SSB0*, in order to determine the effect of density-dependence.
- There are few data available to estimate *a50* for females in the first epoch; therefore, examine alternative approaches other than estimating it – e.g., setting the value to the same as that estimated for the second epoch.
- Estimates of the size-at-maturity are uncertain; consider conducting a maturity ogive meta-analysis using all rock lobster data.
- Examine the effect of returning large females in influencing sex ratios.
- Examine the sensitivity of the model to the assumption of 10% mortality for rock lobsters returned to the sea.

(a) Base case without DD **(b) Base case with DD**

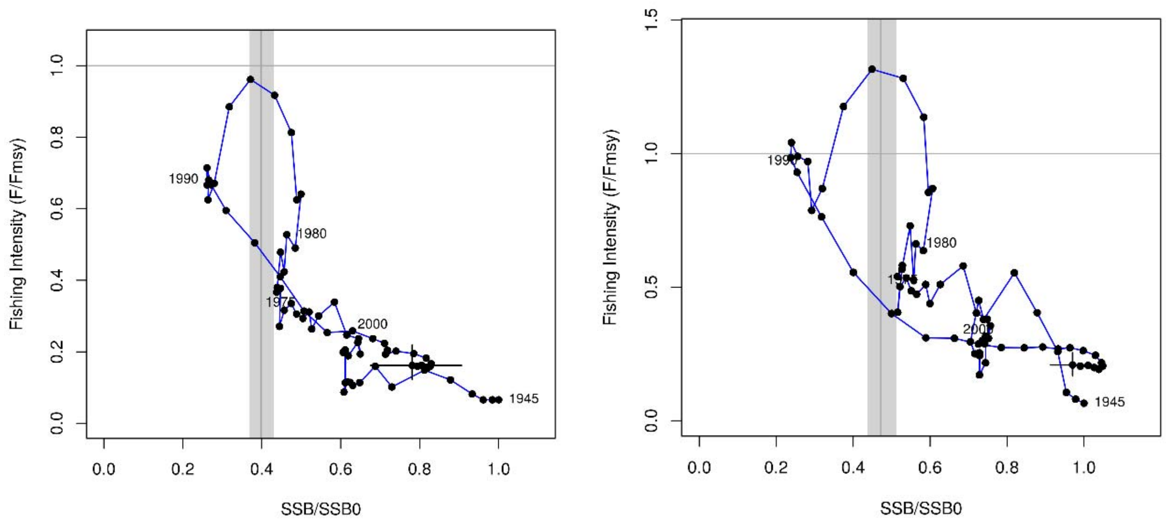


Figure 31: Phase plots that summarise the history of the CRA 5 fishery for the two base cases. The x-axis is the spawning biomass (*SSB*) as a proportion of B0 (*SSB0*); the y-axis is the ratio of the fishing intensity (F) relative to *Fmsy*. Each point is the median of the posterior distributions, and the bars associated with 2009 show the 90% confidence intervals. The vertical reference line shows *SSBmsy* as a proportion of *SSB0*, with the grey band indicating the 90% confidence interval. The horizontal reference line is *Fmsy*.

6.6 CRA 6

The most recent stock assessment for CRA 6 was done in 1996, using catches and abundance indices current up to the 1995–96 fishing year. The status of this stock is uncertain. Catches were less than the TACC 1990–91 to 2004–05, but have been within 10 t of the TACC since then. CPUE showed a declining trend from 1979–80 to 1997–98, but has then increased in two stages to levels higher than seen in the early 1990s. These observations suggest a stable or increasing standing stock after an initial fishing down period. However, size-frequency distributions in the lobster catch had not changed when they were examined in the mid-1990s, with a continuing high frequency of large lobsters. Large lobsters would have been expected to disappear from a stock declining under fishing pressure. This apparent discrepancy could be caused by immigration of large lobsters into the area being fished. The models investigated assume a constant level of annual productivity that is independent of the standing stock.

Commercial removals in the 2012−13 fishing year (356 t) were within the range of estimates for MCY (300−380 t), and close to the current TACC (360 t). The current TAC (370 t) lies within the range of the estimated MCY.

Alternative methods have been used to assess the CHI stock. These include a simple depletion analysis, presented to the RLFAWG in previous years, and a production model, which appeared to fit the observed data well. Both models assume a constant level of annual productivity that is independent of the standing stock and thus will not be affected by changes to the level of the standing stock. B_0 was estimated by both models to be about 20 000 t.

6.7 CRA 7 and CRA 8

This section describes stock assessments for CRA 7 and CRA 8 conducted in 2015.

Model structure

A two-stock version of the multi-stock length-based model (MSLM) (Haist et al. 2009) was fitted to data from CRA 7 and CRA 8: seasonal standardised CPUE from 1979–2014, older catch rate data (CR), length frequencies from observer and voluntary (logbook) catch sampling, and tag-recapture data. Puerulus settlement data are available from Halfmoon Bay, Chalky Inlet and Jackson Bay for different periods, but they showed differing trends. Because the puerulus indices appeared to have limited predictive power in the 2012 assessment, they were not used. The model used an annual time step from 1963 through 1978 and then switched to a seasonal time step with autumn–winter (AW, April through September) and spring–summer (SS, October through March) from 1979 through 2014. The model had 93 length bins, 31 for each sex group (males, immature and mature females), each 2 mm TW wide, beginning at left-hand edge 30 mm TW.

Significant catches occurred in the historical series for both CRA 7 and CRA 8 before the beginning of the model and the reconstruction assumed that the population began from an exploited state. MLS and escape gap regulations in place at the beginning of the reconstruction differed from the current ones. To accommodate these differences, the model incorporated stock-specific time series of MLS regulations by sex and modelled escape gap regulation changes by estimating separate selectivity functions before 1993. The model simulated the return of large legal lobsters to the sea in CRA 8, where this practice is prevalent. Smaller males are retained in preference to larger males, and the model used annual fitted retention curves from 2000 onwards to simulate this in the fishing dynamics. Data and their sources are listed in Table 52.

Historical and recent recreational catch surveys were examined and the stock assessment assumed that recreational catch was constant from 1979 (see Section 1.2) and that it increased linearly from 20% of the 1979 value in 1945 up to the 1979 value.

Table 52: Data types and sources for the 2015 assessment for CRA 7 and CRA 8. Year codes are from the first nine months of each fishing year, i.e., 1998–99 is called 1998. N/A – not applicable or not used; MPI – NZ Ministry for Primary Industries; NZ RLIC – NZ Rock Lobster Industry Council; FSU: Fisheries Statistics Unit; CELR: catch and effort landing returns; NIWA: National Institute of Water and Atmosphere.

		CRA 7		CRA 8	
Data type	Data source	Begin year	End year	Begin year	End year
CPUE	FSU & CELR	1979	2014	1979	2014
Older catch rate (CR)	Annala & King (1983)	1963	1973	1963	1973
Observer proportions-at-size	MPI and NZ RLIC	1988	2014	1987	2010
Logbook proportions-at-size	NZ RLIC	N/A	N/A	1993	2014
Tag recovery data	NZ RLIC & MFish	1965	2013	1966	2011
Historical MLS regulations	Annala (1983), MPI	1974	2014	1974	2014
Escape gap regulation changes	Annala (1983), MPI	1974	2014	1974	2014
Puerulus settlement (not used)	NIWA	1990	2014	1980	2014
Retention	NZ RLIC	N/A	N/A	2000	2014

The initial populations in 1963 were assumed to be in equilibrium with estimated exploitation rates for each stock. Each season, numbers of male, immature female and mature female lobsters in each size class were updated as a result of:

a) **Recruitment:** Each year, new recruits to the model were added equally for each sex for each season for each stock, as a normal distribution with a mean size (32 mm) and standard deviation

(2 mm), truncated at the smallest size class (30 mm). Recruitment in a specific year was determined by the parameters for base recruitment and parameters for the deviations from base recruitment; all recruitment parameters were stock-specific. The vector of recruitment deviations in natural log space was assumed to be normally distributed with a mean of zero. Recruitment deviations were estimated for 1963 through 2012. It was assumed that stock size has no influence on recruitment because of the long duration of the pelagic larval phase coupled with long-distance movements during this phase.

b) **Mortality:** Natural, fishing and handling mortalities were applied to each sex category in each size class. Natural mortality was assumed to be constant and independent of sex and length; a value was estimated for each stock. Fishing mortality was determined from observed catch and model biomass in each stock, modified by legal sizes, sex-specific vulnerabilities and selectivity curves in each stock and, for CRA 8, retention curves for 2000 and later. Handling mortality was assumed to be 10% for fish returned to the water. Two fisheries were modelled for each stock: one that operated only on fish above the size limit, excluding berried females (SL fishery – including legal commercial and recreational) and one that did not respect size limits and restrictions on berried females (NSL fishery – all of the illegal fishery plus the Maori customary fishery). Selectivity and vulnerability functions were otherwise the same for the SL and NSL fisheries. Vulnerability in each stock by sex category and season was estimated relative to males in AW, which were assumed to have the highest vulnerability. Instantaneous fishing mortality rates for each fishery were calculated using Newton-Raphson iterations (four iterations) based on catch and model biomass.

c) **Fishery selectivity:** A three-parameter fishery selectivity function was assumed, with parameters for each stock describing the shapes of the ascending and descending limbs and the size at maximum selectivity. Changes in MLS and escape gap regulations were accommodated for CRA 8 only (in CRA 7 there have been no MLS changes) by estimating selectivity in two separate epochs, pre-1993 and 1993–2014. As in all recent stock assessments the descending limb of the selectivity curve was fixed to prevent underestimation of selectivity of large lobsters.

d) **Growth and maturation:** For each size class and sex category in each stock, a growth transition matrix specified the probability of an individual remaining in the same size class or growing into each of the other size classes. The growth parameters for shape, CV and observation error were estimated with priors based on exploratory fits using only the growth model (Webber, unpublished data); these stabilised the estimation considerably. Maturation of females was estimated as a two-parameter logistic curve from the maturity-at-size information in the size-frequency data. Maturation parameters were estimated as common parameters for both stocks (all other estimated parameters were stock-specific).

e) **Movements between stocks:** For each year from 1985–2014, the model estimated the proportion of fish of sizes 45–60 mm TW that moved each season from CRA 7 to CRA 8. Mean movement was assumed for all other years.

Model fitting:
A total negative log likelihood function was minimised using AD Model Builder™. The model was fitted to standardised CPUE and CR using lognormal likelihood, to proportions-at-length with multinomial likelihood and to tag-recapture data with normal likelihood after removal of outliers based on tag-only fits. For the CPUE lognormal likelihoods, CVs for each index value were initially set at the standard error from the GLM analysis. Process error was subsequently added to these CVs.

Proportions-at-length, assumed to be representative of the commercial catch, were available (see Table 52) from observer catch sampling and voluntary logbooks: data were summarised by area/month strata and weighted by the commercial catch taken in each stratum, the number of lobsters measured and the number of days sampled. Size data from each source were fitted separately. Seasonal proportions-at-length summed to one across each sex category. These data were weighted within the model using the method of Francis (2011).

In the base case, it was assumed that biomass was proportional to CPUE, that growth was not density-dependent but for CRA 8 had changed between the pre-1993 and 1993 onwards periods, there was no stock-recruit relationship and there was migration between CRA 7 and CRA 8, involving fish 45–60 mm TW. Base case explorations involved experimentally weighting the datasets and inspecting the resulting standard deviations of normalised residuals and medians of absolute residuals, exploring the effect of the start year (1963 was chosen), exploring the effect of excluding SS length-frequency data from CRA 7 (it was not excluded), and changing the prior on *M* (a prior with a smaller CV was chosen).

Parameters estimated in the base case and their priors are provided in Table 53. Fixed parameters and their values are given in Table 54.

Table 53: Parameters estimated and priors used in the base case assessments for CRA 7 and CRA 8. Prior type abbreviations: U – uniform; N – normal; L – lognormal.

Parameter	Prior type	Number of parameters	Bounds	Mean	SD	CV
ln(*R0*) (mean recruitment)	U	2	1–25	–	–	–
M (natural mortality)	L	2	0.01–0.35	0.12	–	0.10
Initial exploitation rate	U	2	0.00–0.99	–	–	–
Recruitment deviations	N [1]	100	-2.3–2.3	0	0.4	
ln(*qCPUE*)	U	2	-25–0	–	–	–
ln(*qCR*)	U	2	-25-2.0	–	–	–
Increment at TW=50 (male & female)	U	6	1–20	–	–	–
ratio of TW=80 increment at TW=50 (male & female)	U	6	0.001–1.000	–	–	–
shape of growth curve (male)	N	2	0.1–15.0	4.812	0.384	–
shape of growth curve (female)	N	2	0.1–15.0	4.508	0.236	
growth CV (male)	N	2	0.01–5.0	0.587	0.0076	
growth CV (female)	N	2	0.01–5.0	0.820	0.0131	
growth observation error (male and female)	N	1	1E-5-10.0	1.482	0.0152	
TW at 50% probability female maturation	U	1	30–80	–	–	–
difference between TWs at 95% and 50% probability female maturation	U	1	3–60	–	–	–
Relative vulnerability (all sexes and seasons)	U	8	0.01–1.0	–	–	–
Shape of selectivity left limb (males & females)	U	6	1–50	–	–	–
Size at maximum selectivity (males & females)	U	6	30–70	–	–	–
Movement parameters	U	30	0.00–0.50	–	–	–

[1] Normal in natural log space = lognormal (bounds equivalent to –10 to 10).

Table 54: Fixed values used in base case assessment for CRA 7 and CRA 8.

Value	CRA 7	CRA 8
Shape parameter for CPUE vs biomass	1.0	1.0
Minimum std. dev. of growth increment	0.001	0.001
Handling mortality	10%	10%
Process error for CPUE	0.25	0.25
process error for CR	0.3	0.3
Year of selectivity change	1993	1993
Current male size limit (mm TW)	47	54
Current female size limit (mm TW)	49	57
First year for recruitment deviations	1963	1963
Last year for recruitment deviations	2012	2012
Relative weight for male length frequencies	0.227	1.849
Relative weight for immature female LFs	0.239	5.145
Relative weight for mature female LFs	0.422	1.272
relative weight for proportion-at-sex	3.645	3.645
Relative weight for CPUE	1.251	1.251
relative weight for CR	1.062	1.062
Relative weight for tag-recapture data*	1	1
length-weight intercept (male)	3.39E-6	3.39E-6
length-weight intercept (female)	1.04E-5	1.04E-5
length-weight slope (male)	2.9665	2.9665
length-weight slope (female)	2.6323	2.6323

* For CRA 7 the weight for tag-recapture data was increased by doubling the dataset.

Model projections

Bayesian estimation procedures were used to estimate the uncertainty in model estimates and short-term projections. This procedure was conducted in the following steps:

1. Model parameters were estimated by AD Model Builder™ using maximum likelihood and the prior probabilities. The point estimates are called the MPD (mode of the joint posterior) estimates.
2. Samples from the joint posterior distribution of parameters were generated with Markov chain Monte Carlo (MCMC) simulations using the Hastings-Metropolis algorithm; five million simulations were made starting from the base case MPD and 1000 samples were saved.
3. From each sample of the posterior, four-year projections (2015–18) were generated using the 2014 catches, with annual recruitment randomly sampled from the model's estimated recruitments from 2003–12, and with annual movement resampled from the estimated values.

Performance indicators and results

The definition of the 'current fishing pattern', used to calculate MSY statistics, was modified to include the retention pattern. That is, for CRA 8 the estimated 2015 retention pattern was included in the definition of *Fmsy* (for other CRA QMAs retention is assumed to be 1, so does not influence *Fmsy*). This is somewhat anomalous because fishing at *Fmsy* would result in lower biomass and it would be expected that there would be full retention of all legal rock lobster. The alternative, to ignore retention in the definition of *Fmsy*, is also problematic because it results in the conclusion that the current fishing intensity exceeds *Fmsy* (which is not the case because greater than 40% of the biomass of legal rock lobster is returned to the sea). The retention pattern was not included in the definitions of 'vulnerable biomass', used to calculate *Bmsy* and *Bref*, because that would also lead to inconsistency between the retention pattern used to define those reference levels and the retention pattern expected at the biomass levels.

Vulnerable biomass in the assessment model was determined by the MLS, selectivity, relative sex and seasonal vulnerability and berried state for mature females. All mature females were assumed to be berried (ovigerous) and not legally available to the fishery in AW and not berried, thus vulnerable, in SS.

Agreed indicators are summarised in Table 55.

For CRA 7, base case results (Figure 32 and Table 56) suggested that AW biomass decreased to a low point in 1997, increased to a high in the late 2000s, decreased and then increased again. *B2015* was about twice *Bref*. Median projected biomass was 8% less than current biomass at the level of current catches over the next four years, but indicators remained above reference levels. Neither current nor projected biomass was anywhere near the soft limit. Note that MSY from CRA 7 was estimated as a high proportion of *Bmsy*, thus that fishing intensity *Fmsy* is very high.

For CRA 8, base case results (Figure 33 and Table 57) suggested that AW biomass decreased to a low point in 1990, remained relatively low until 2000, then increased strongly and has remained relatively high. *B2015* was well above *Bmsy* and 35% above *Bref* (mean biomass for 1979–81). Biomass was projected to remain about the same in four years at the current level of catches and was projected to remain well above both *Bref* and *Bmsy*. Spawning biomass was a high proportion (43%) of the unfished level. Neither current nor projected biomass was anywhere near the soft limit.

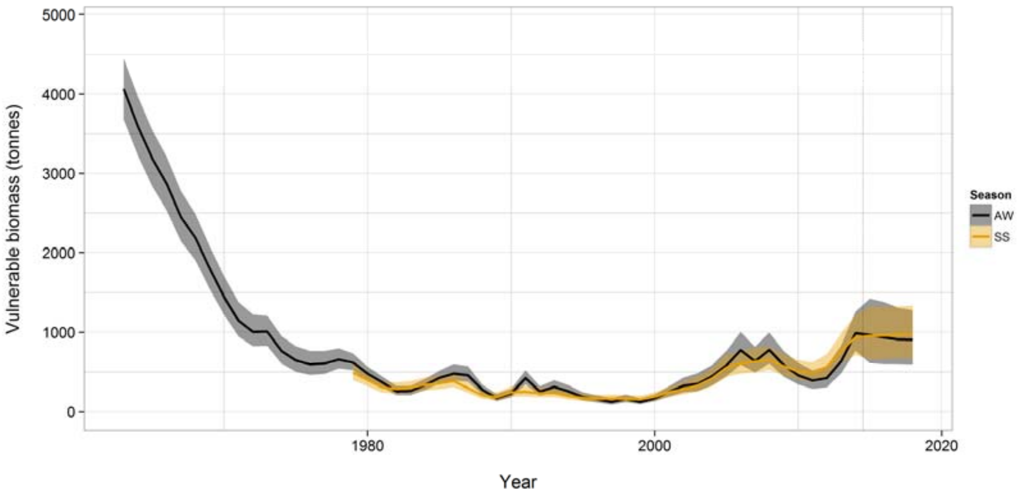


Figure 32: Posterior distribution of the CRA 7 base case MCMC vulnerable biomass trajectory. Before 1979 there was a single time step, shown in AW. The shaded areas span the 5th and 95th quantiles.

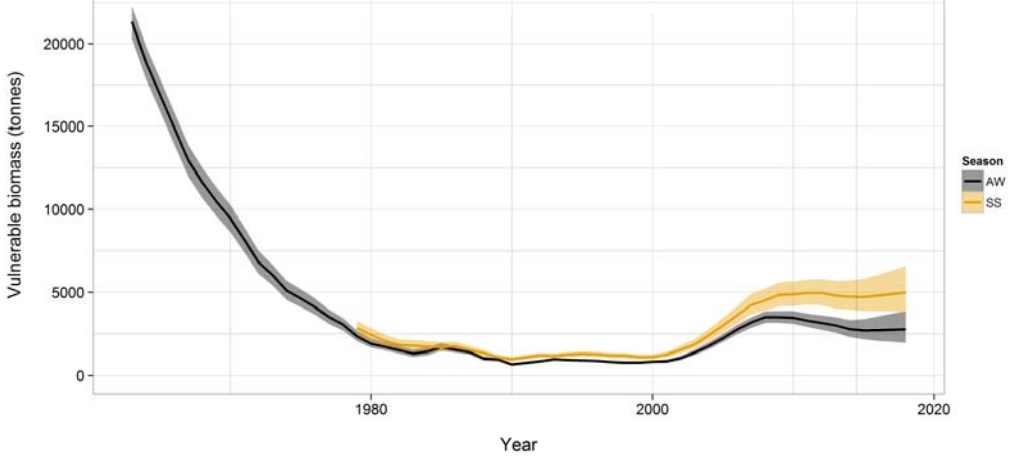


Figure 33: Posterior distribution of the CRA 8 base case MCMC vulnerable biomass trajectory. Before 1979 there was a single time step, shown in AW. The shaded areas span the 5th and 95th quantiles.

Table 55: Performance indicators used in the CRA 7 and CRA 8 stock assessments. [Continued on next page]

Reference points	Description
Bmin	The lowest beginning AW vulnerable biomass in the series
B2015	Beginning of season AW vulnerable biomass for 2015
Bref	Beginning of AW season mean vulnerable biomass for 1979–81
B2018	Projected beginning of season AW vulnerable biomass in 2018
Bmsy	Beginning of season AW vulnerable biomass associated with MSY, calculated by doing deterministic forward projections with recruitment *R0* and current fishing patterns
MSY	Maximum sustainable yield (sum of AW and SS SL catches) found by searching a across a range of multipliers on *F*.
Fmult	The multiplier that produced MSY
SSB2015	Current spawning stock biomass at start of AW season
SSB2018	Projected spawning stock biomass at start of AW season
SSBmsy	Spawning stock biomass at start of AW season associated with MSY

CPUE indicators	Description
CPUE2014	CPUE predicted for AW 2014
CPUE2018proj	CPUE predicted for AW 2018
CPUEmsy	CPUE at *Bmsy*

Performance indicators	Description
B2015 / Bmin	ratio of *B2015* to *Bmin*
B2015/ Bref	ratio of *B2015* to *Bref*
B2015 / Bmsy	ratio of *B2015* to *Bmsy*
B2018 / B2015	ratio of *B2018* to *B2015*
B2018/ Bref	ratio of *B2018* to *Bref*
B2018/ Bmsy	ratio of *B2018* to *Bmsy*

Table 55 [Continued]:

Performance indicators	Description
SSB2015/SSB0	ratio of *SSB2015* to *SSB0*
SSB2018/SSB0	ratio of *SSB2018* to *SSB0*
SSB2015/SSBmsy	ratio of *SSB2015* to *SSBmsy*
SSB2018/SSBmsy	ratio of *SSB2018* to *SSBmsy*
SSB2015/SSB2015	ratio of *SSB2018* to *SSBcurrent*
USL2015	The 2015 exploitation rate for SL catch in AW
USL2018	2018 exploitation rate for SL catch in AW
USL2018/USL2015	ratio of SL 2018 exploitation rate to 2015 SL exploitation rate
Btot2014	total biomass in 2014
Ntot2014	total numbers in 2014
Btot0	total biomass without fishing
Ntot0	total numbers without fishing

Probabilities	Description
P*(B2015 > Bmin)*	probability *B2015* > *Bmin*
P*(B2015 > Bref)*	probability *B2015* > *Bref*
P*(B2015 > Bmsy)*	probability *B2015* > *Bmsy*
P*(B2018 > Bmin)*	probability *B2018* > *Bmin*
P*(B2018 > Bref)*	probability *B2018* > *Bref*
P*(B2018 > Bmsy)*	probability *B2018* > *Bmsy*
P*(B2018 > B2015)*	probability *B2018* > *B2015*
P*(SSB2015>SSBmsy)*	probability *SSB2015>SSBmsy*
P*(SSB2018>SSBmsy)*	probability *SSB2015>SSBmsy*
P*(USL2018>USL2015)*	probability SL exploitation rate *2018* > SL exploitation rate *2015*
P*(SSB2015<0.2SSB0)*	soft limit CRA 8: probability *SSB2015*< 20% *SSB0*
P*(SSB2018<0.2SSB0*	soft limit CRA 8: probability *SSB2018* < 20% *SSB0*
P*(SSB2015 <0.1SSB0)*	hard limit CRA 8: probability *SSB2015*< 10% *SSB0*
P*(SSB2018<0.1SSB0)*	hard limit CRA 8: probability *SSB2018*< 10% *SSB0*
P(*B2015* <50%*Bref*)	soft limit CRA 7: probability *B2015* < 50% *Bref*
P(*B2015* <25%*Bref*)	hard limit CRA 7: probability *B2015* < 25% *Bref*
P(*B2018*<50%*Bref*)	soft limit (CRA 7): probability *B2015* < 50% *Bref*
P(*B2018*<25%*Bref*)	hard limit (CRA 7): probability *B2015* < 25% *Bref*

MCMC sensitivity trials were also made:

- *d-d*: estimating growth density-dependence, and using a single tag data file for CRA 8 instead of two (as in the base case);
- *wideG*: using priors on the growth parameters for shape, CV and observation error with CVs that were 30% of the mean;
- *noMoves*: with no estimated movements from CRA 7 to CRA 8;
- *rawLFs*: using the calculated weights on length-frequency records, instead of truncating them between 1 and 10;
- *wideM*: with the CV of the prior on *M* 0.40 instead of 0.10.

Results from the base case and sensitivity trials are compared in Table 56 for CRA 7 and Table 57 for CRA 8.

Table 56: Assessment results: median and probability indicators for CRA 7 from the base case MCMC and sensitivity trials; biomass in t and CPUE in kg/pot. [Continued on next page]

	Base median	d-d median	wideG prior median	noMoves median	rawLFs median	wideM prior median
Bmin	114.7	118.3	102.8	125.9	113.2	104.1
B2015	965.7	994.4	755.1	931.2	940.3	962.3
Bref	489.2	510.3	443.3	455.7	477.6	453.1
B2018	905.3	858.7	604.3	1 118.5	891.1	916.8
Bmsy	241.1	268.0	265.5	770.9	232.0	223.4
MSY	192.1	208.6	248.7	219.5	187.9	183.6
Fmult	15.2	15.2	15.2	3.25	15.2	15.2
SSB2014	413.5	419.6	464.1	505.7	400.1	427.3
SSB2018	575.1	567.0	541.1	723.0	568.2	636.2
SSBmsy	43.1	50.2	74.9	660.8	39.4	43.3
CPUE2014	2.121	2.172	2.088	1.911	2.112	2.254
CPUE2018	1.900	1.724	1.360	2.658	1.966	2.206
CPUEmsy	0.375	0.412	0.463	1.700	0.367	0.387
B2015/Bmin	8.440	8.251	7.282	7.386	8.374	9.263
B2015/Bref	1.974	1.940	1.712	2.050	1.956	2.130

Table 56 [Continued]:

	Base median	d-d median	wideG prior median	noMoves median	rawLFs median	wideM prior median
B2015/Bmsy	4.002	3.719	2.873	1.220	4.042	4.345
B2018/B2015	0.925	0.851	0.789	1.202	0.946	0.948
B2018/Bref	1.833	1.677	1.384	2.463	1.861	2.021
B2018/Bmsy	3.697	3.180	2.300	1.465	3.831	4.126
SSB2014/SSB0	0.167	0.178	0.222	0.191	0.161	0.134
SSB2018/SSB0	0.234	0.244	0.257	0.273	0.229	0.195
SSB2014/SSBmsy	9.577	8.266	6.209	0.760	10.149	10.084
SSB2018/SSBmsy	13.307	10.982	7.276	1.087	14.416	14.905
SSB2018/SSB2014	1.384	1.346	1.153	1.423	1.411	1.513
USL2014	0.048	0.046	0.053	0.060	0.050	0.052
USL2018	0.076	0.080	0.113	0.061	0.077	0.075
USL2018/USL2014	1.575	1.758	2.129	1.030	1.500	1.424
Btot2014	2 445.7	2 723.1	3 561.0	1 777.7	2 315.2	2 343.9
Btot2014/Btot0	0.320	0.369	0.540	0.232	0.304	0.254
Ntot2014	7.7E+06	9.0E+06	1.4E+07	4.4E+06	7.3E+06	7.3E+06
Ntot2014/Ntot0	0.661	0.681	0.815	0.468	0.648	0.581
P(B2015>Bmin)	1.000	1.000	1.000	1.000	1.000	1.000
P(B2015>Bref)	0.998	0.999	0.994	1.000	0.998	1.000
P(B2015>Bmsy)	1.000	1.000	1.000	0.934	1.000	0.997
P(B2018>Bmin)	1.000	1.000	1.000	1.000	1.000	1.000
P(B2018>Bref)	0.991	0.981	0.911	1.000	0.996	0.998
P(B2018>Bmsy)	1.000	1.000	1.000	0.993	1.000	0.997
P(B2018>B2015	0.236	0.101	0.104	0.999	0.327	0.300
P(SSB2014>SSBmsy)	1.000	1.000	1.000	0.007	1.000	0.968
P(SSB2018>SSBmsy)	1.000	1.000	1.000	0.747	1.000	0.982
P(USL2018>USL2014	0.993	0.999	1.000	0.615	0.994	0.987
P(SSB2014<0.2SSB0)	0.919	0.716	0.233	0.674	0.948	0.992
P(SSB2018<0.2SSB0	0.213	0.182	0.069	0.002	0.240	0.536
P(SSB2014<0.1SSB0)	0.000	0.000	0.000	0.000	0.000	0.274
P(SSB2018<0.1SSB0)	0.000	0.000	0.000	0.000	0.000	0.120

Table 57: Assessment results: median and probability indicators for CRA 8 from base case MCMC and sensitivity trials; biomass in t and CPUE in kg/pot. [Continued on next page]

	Base median	d-d median	wideG prior median	noMoves median	rawLFs median	wideM prior median
Bmin	658.2	674.2	550.9	651.5	635.9	601.8
B2015	2 698.1	2 529.9	2 362.5	2 624.9	2 175.2	2 506.1
Bref	1 983.4	1 873.9	1 687.1	2 024.7	1 902.7	1 781.7
B2018	2 770.6	2 383.3	2 971.5	2 334.1	2 004.4	2 674.3
Bmsy	1 464.9	1 170.9	1 393.0	1 494.3	1 410.9	1 949.5
MSY	1 091.3	1 072.6	1 104.79	1 117.5	1 015.5	1 047.2
Fmult	1.59	2	1.6	1.57	1.23	1.17
SSB2014	5 043.3	4 815.6	4 631.9	4 974.7	4 974.5	5 525.7
SSB2018	5 321.6	4 868.4	5 345.3	5 003.0	4 950.2	6 176.7
SSBmsy	3 103.6	2 364.0	2 937.370	3 093.9	3 399.4	4 878.0
CPUE2014	2.504	2.468	2.524	2.441	2.173	2.494
CPUE2018	2.539	2.181	3.391	2.075	1.879	2.654
CPUEmsy	1.147	0.867	1.325	1.159	1.185	1.774
B2015/Bmin	4.104	3.772	4.289	3.990	3.399	4.148
B2015/Bref	1.352	1.358	1.389	1.288	1.140	1.404
B2015/Bmsy	1.834	2.161	1.701	1.746	1.536	1.317
B2018/B2015	1.024	0.935	1.257	0.895	0.926	1.071
B2018/Bref	1.399	1.269	1.747	1.159	1.055	1.505
B2018/Bmsy	1.889	2.043	2.140	1.571	1.425	1.421
SSB2014/SSB0	0.438	0.774	0.391	0.432	0.393	0.253
SSB2018/SSB0	0.462	0.789	0.450	0.436	0.391	0.285
SSB2014/SSBmsy	1.620	2.028	1.572	1.611	1.462	1.132
SSB2018/SSBmsy	1.711	2.060	1.812	1.622	1.453	1.270
SSB2018/SSB2014	1.055	1.019	1.152	1.003	0.994	1.115
USL2014	0.181	0.187	0.218	0.183	0.217	0.196
USL2018	0.182	0.211	0.169	0.216	0.251	0.188
USL2018/USL2014	1.002	1.137	0.8	1.184	1.168	0.962
Btot2014	9 749.9	9 689.3	8 030.890	1 0038.7	9 020.7	9 729.8
Btot2014/Btot0	0.269	0.403	2.3E-01	0.273	0.235	0.157
Ntot2014	1.6E+07	1.7E+07	1.2E+07	1.8E+07	1.5E+07	1.5E+07
Ntot2014/Ntot0	0.415	0.405	0.352	0.423	0.372	0.294
P(B2015>Bmin)	1.000	1.000	1.000	1.000	1.000	1.000
P(B2015>Bref)	0.995	0.999	0.997	0.975	0.862	0.990
P(B2015>Bmsy)	1.000	1.000	1.000	1.000	1.000	0.954
P(B2018>Bmin)	1.000	1.000	1.000	1.000	1.000	1.000

Table 57 [Continued]:

	Base median	d-d median	wideG prior median	noMoves median	rawLFs median	wideM prior median
P(B2018>Bref)	0.942	0.916	0.999	0.724	0.602	0.961
P(B2018>Bmsy)	0.998	1.000	1.000	0.961	0.944	0.932
P(B2018>B2015	0.575	0.203	0.974	0.241	0.275	0.711
P(SSB2014>SSBmsy)	1.000	1.000	1.000	1.000	1.000	0.855
P(SSB2018>SSBmsy)	1.000	1.000	1.000	1.000	1.000	0.970
P(USL2018>USL2014	0.510	0.893	0.045	0.804	0.824	0.395
P(SSB2014<0.2SSB0)	0.000	0.000	0.000	0.000	0.000	0.056
P(SSB2018<0.2SSB0	0.000	0.000	0.000	0.000	0.000	0.017
P(SSB2014<0.1SSB0)	0.000	0.000	0.000	0.000	0.000	0.000
P(SSB2018<0.1SSB0)	0.000	0.000	0.000	0.000	0.000	0.000

Indicators based on vulnerable biomass (AW) and *Bmsy*

For both stocks, median current and projected biomass were above medians of *Bref* and *Bmsy*. Projected biomass decreased in 76% of runs for CRA 7 and decreased in 42% of runs for CRA 8 but remained well above the reference levels in both stocks.

Indicators based on *SSBmsy*

The historical track of biomass versus fishing intensity is shown in Figure 34 for the CRA 7 stock. The phase space in the plot shows biomass on the x-axis and fishing intensity on the y-axis. High biomass/low intensity is in the lower right-hand corner, the location of the stock when fishing first began, and low biomass/high intensity is in the upper left-hand corner, in a period when the fishery was largely uncontrolled. *Fmsy* varies among runs because of parameter variations and among years because of variation in fishing patterns, which include MLS, selectivity and the seasonal catch split. Figure 34 was calculated using the 2014 fishing pattern.

Fmsy was calculated with a 50-year projection for each year in each run, with the NSL catch held constant at that year's value, deterministic recruitment at *R0* and a range of multipliers on the SL catch *F*s estimated for year *y*. The *F* (actually separate *F*s for two seasons) that gives MSY is *Fmsy* and the multiplier is *Fmult*. Each point on the figure was plotted as the median of the posterior distributions of biomass ratio and fishing intensity ratio.

Figure 34 suggests that for CRA 7, *SSBmsy* was estimated as a very small fraction of *SSB0*, and that, while the fishery has driven the stock to low levels of *SSB0* in the past, the stock has never gone below *SSBmsy* and has recovered to 20% of *SSB0* over the past decade. As noted above, the fishing intensity associated with MSY was very high, and similarly the fishery has never exceeded *Fmsy*. The figure suggests that fishing intensity is now lower than in 1963 and far below its peak in 1979.

For CRA 8, Figure 35 shows declining biomass after 1963 and increasing fishing intensity after 1975. After 1970, until 2005, fishing intensity exceeded *Fmsy*. *SSB* was below *SSBmsy* from 1979 until 2009. The current position of the stock is relatively good, well above *SSBmsy* and with fishing intensity well below *Fmsy*.

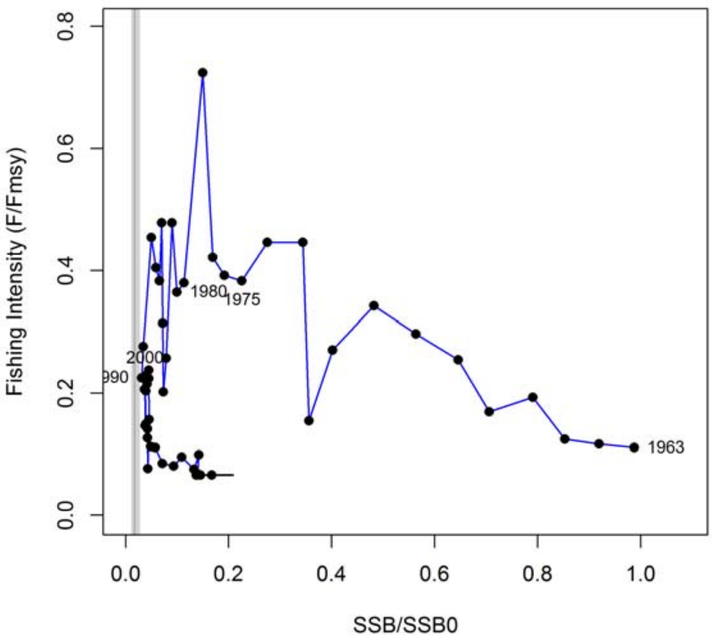


Figure 34: Phase plot (base case MCMC) for CRA 7, showing median spawning stock biomass for each year on the x-axis and median fishing intensity for each year on the y-axis; thus, high biomass/low fishing intensity is in the lower right-hand corner, where a stock would be when fishing first began, and low biomass/high intensity is in the upper left-hand corner, where an uncontrolled fishery would be likely to go. Specifically, the x-axis is spawning stock biomass *SSB* as a proportion of the unfished spawning stock *SSB0*. *SSB0* is constant for all years of a simulation, but varies among the 1000 samples from the posterior distribution. The y-axis is fishing intensity as a proportion of the fishing intensity that would have given *MSY* (*Fmsy*) under the fishing patterns in year y; fishing patterns include MLS, selectivity, the seasonal catch split, retention curves and the balance between SL and NSL catches. *Fmsy* varies among years because the fishing patterns change. It was calculated with a 50-year projection for each year in each simulation, with the NSL catch held constant at that year's value, deterministic recruitment at R0 and a range of multipliers on the SL catch *F*s estimated for year y. The *F* (actually *F*s for two seasons) that gave *MSY* was *Fmsy*, and the multiplier was *Fmult*. Each point on the figure was plotted as the median of the posterior distributions of biomass ratio and fishing intensity ratio. The vertical line in the figure is the median (line) and 90% interval (shading) of the posterior distribution of *SSBmsy* as a proportion of *SSB0*; this ratio was calculated using the fishing pattern in 2013. The horizontal line in the figure is drawn at 1, the fishing intensity associated with *Fmsy*. The bars at the final year of the plot show the 90% intervals of the posterior distributions of biomass ratio and fishing intensity ratio.

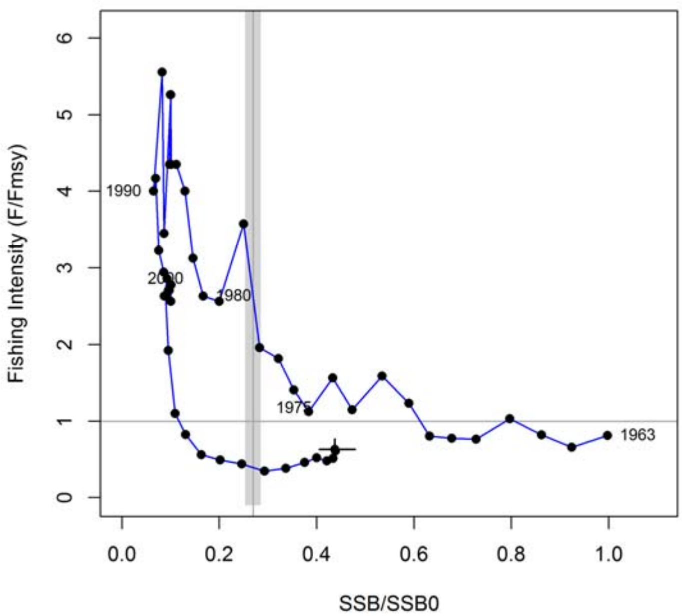


Figure 35: Phase plot for CRA 8; see the caption for Figure 34.

Future research considerations

- For the new growth analysis:
  - o Investigate potential seasonal effects such as seasonal patterns in growth and the probability of recapture
  - o Modify the 'Q' matrix (matrix of similarities between areas) to determine how much assumptions about similarities matter
  - o Further work with alternative error distributions would be useful
  - o Explore the utility of contamination models.
- The uncertainty of the length-frequency datasets needs further investigation (by, for example, bootstrapping to obtain appropriate estimates of uncertainty).
- Further work is needed on the influence of returning a high proportion of large lobsters to the sea on the calculation and interpretation of reference points.
- Examine the sensitivity of the model to the assumption of 10% mortality for lobsters returned to the sea.

6.8 CRA 9

A management procedure for CRA 9, based on a Fox surplus-production stock assessment model and MPEs, was used for the 2014–15 fishing year. However, an audit of the CRA 9 CPUE data in 2015 suggested that the CRA 9 CPUE index was not a reliable indicator of abundance in CRA 9 because of the small number of vessels fishing in recent years (six or fewer), problems with reporting and the large size of the CRA 9 area, in which changes in fished area could affect CPUE substantially. The NRLMG (National Rock Lobster Management Group) agreed to reject the CRA 9 management procedure. There is currently no accepted stock assessment for CRA 9.

7. STATUS OF THE STOCKS

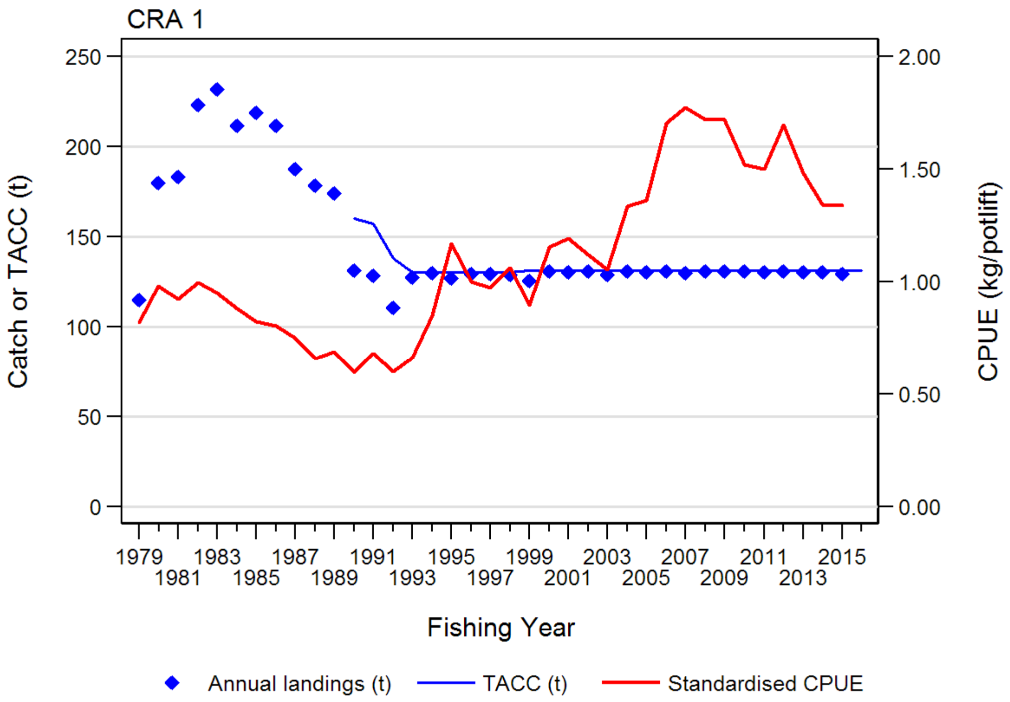
For the purposes of stock assessment and management, rock lobsters are assumed to constitute separate Fishstocks within each CRA Quota Management Area. There is likely to be some degree of relationship and/or exchange between Fishstocks in these CRA areas, either as a result of migration, larval dispersal or both.

7.1 *Jasus edwardsii*

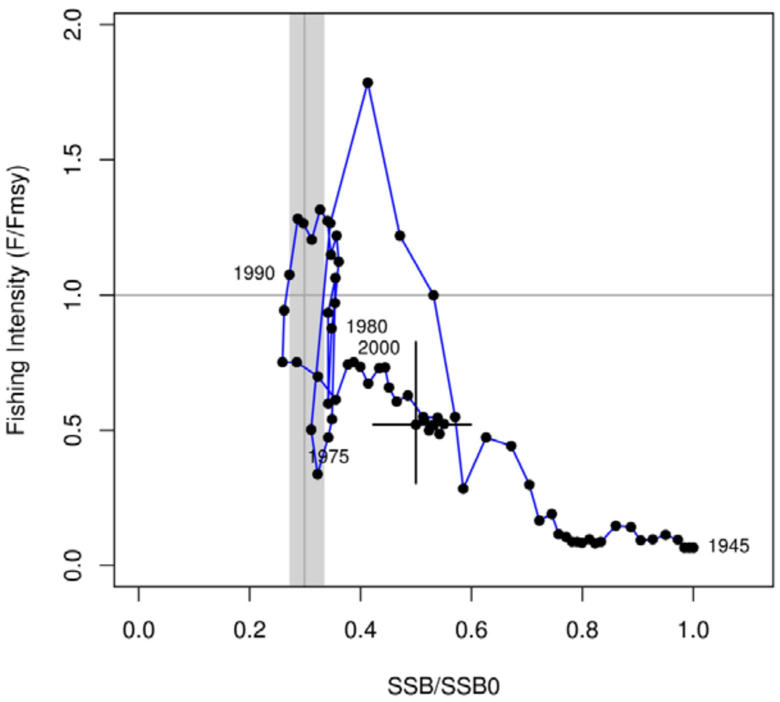
- **CRA 1 Northland**

Stock Status	
Year of Most Recent Assessment/Evaluation	Assessment 2014; MP update 2016
Assessment Runs Presented	2014 assessment: base case and 5 MCMC sensitivities; 2016: MP evaluated
Reference Points	Target: *Bref*: mean of beginning AW vulnerable biomass for the period 1979–88 Limit: reported against B_{MIN}: minimum AW vulnerable biomass, 1945–2013 Soft limit: 20% SSB_0 (default) Hard limit: 10% SSB_0 (default)
Status in relation to Target	Biomass in 2014 was 173% of B_{REF} ; MP update suggests biomass in 2016 is only slightly lower Virtually Certain (> 99%) that B_{2014} and B_{2016} > B_{ref}
Status in relation to Limits	Exceptionally Unlikely (< 1%) that B_{2014} and B_{2016} < B_{min} Exceptionally Unlikely (< 1%) that B_{2014} and B_{2016} < soft and hard limits
Status in relation to Overfishing	Overfishing is Exceptionally Unlikely (< 1%) to be occurring

Historical Stock Status Trajectory and Current Status



Annual landings, TACC and standardised CPUE for CRA 1 from 1979 to 2016.



Snail trail summary of the CRA 1 base case model. The line tracks the median values for each axis from the MCMC posteriors and the cross marks the 90% credibility interval on both axes for the final model year (2013). The vertical line in the figure is the median (line) and 90% interval (shading) of the posterior distribution of *SSBmsy*. This ratio was calculated using the fishing pattern in 2013. The horizontal line in the figure is drawn at 1, the fishing intensity associated with *Fmsy*.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	AW biomass decreased to a low point in the early 1970s, remained low until the mid-1990s, and has increased since then.
Recent Trend in Fishing	Size-limited and non-size-limited exploitation have declined since

Intensity or Proxy	the early 1990s.	
Other Abundance Indices	Catch rates (CR) not fitted (1963–73)	
Trends in Other Relevant Indicators or Variables	-	
Projections and Prognosis		
Stock Projections or Prognosis	Offset CPUE decreased from 1.58 kg/potlift in 2014 to 1.43 kg/potlift in 2016.	
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Exceptionally Unlikely (< 1%) that $B_{2017} < B_{min}$ Soft Limit: Exceptionally Unlikely that (< 1%) $B_{2017} < 0.2SSB0$ Hard Limit: Exceptionally Unlikely that (< 1%) $B_{2017} < 0.1SSB0$	
Probability of Current Catch or TACC causing Overfishing to continue or to commence	Exceptionally Unlikely (< 1%)	
Assessment Methodology		
Assessment Type	Level 1 – Full Quantitative Stock Assessment	
Assessment Method	Bayesian length-based model with MCMC posteriors (MLSM, Haist et al. 2009)	
Assessment Dates	Latest assessment: 2014	Next assessment: 2019
Overall assessment quality rank	1 – High Quality	
Main data inputs	- CPUE - Length-frequency data - Tagging data	1 – High Quality (all)
Data not used (rank)	N/A	
Changes to Model Structure and Assumptions	- Latest version of MLSM - Added informed priors to selectivity parameters	
Major Sources of Uncertainty	- Non-commercial catch (the levels of illegal and recreational catches)	

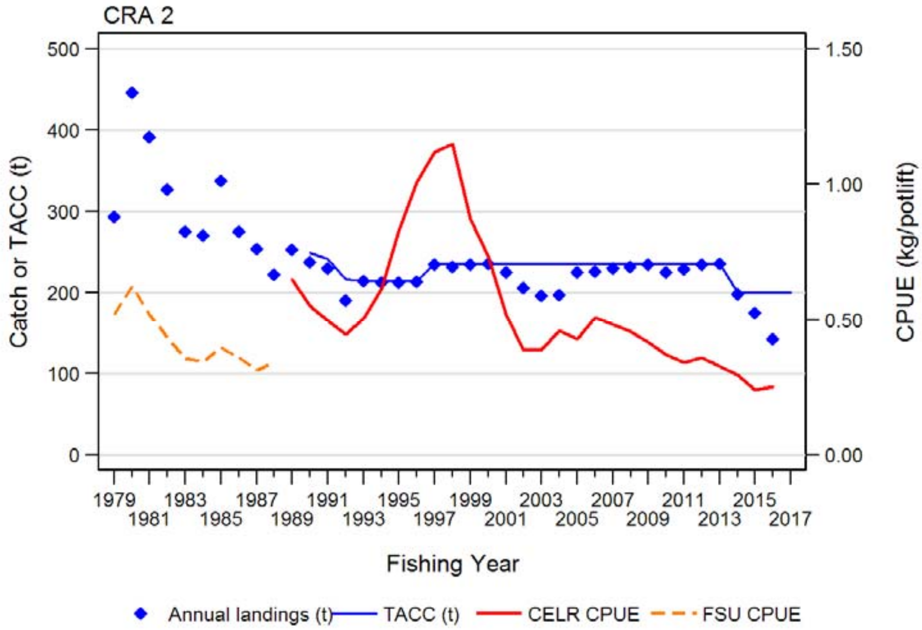
Qualifying Comments
Model could not predict the sex ratios during the spring–summer (SS). Spatial heterogeneity of the observations throughout the statistical areas may not be representative of the population.

Fishery Interactions
-

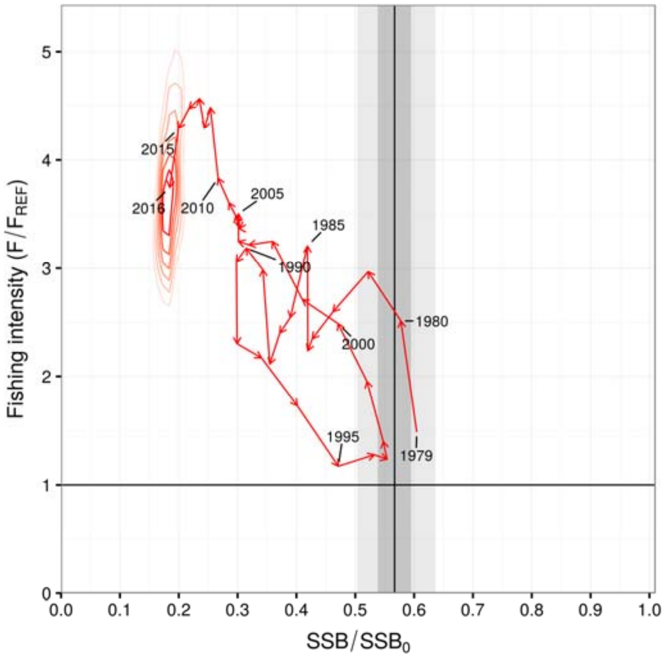
- **CRA 2 Bay of Plenty**

Stock Status	
Year of Most Recent Assessment/Evaluation	Assessment 2017; MP to be revised
Assessment Runs Presented	2017 assessment: base case and 3 sensitivity runs
Reference Points	Target: B_{REF}: mean of beginning AW vulnerable biomass for the period 1979–81 Soft limit: 20% SSB_0 (default) Hard limit: 10% SSB_0 (default) Overfishing threshold: F_{REF}
Status in relation to Target	Biomass in 2017 was 21% of B_{REF} Exceptionally Unlikely (< 1%) that B_{2017} is above B_{REF}
Status in relation to Limits	Likely (> 60%) that B_{2017} is below the Soft Limit Very Unlikely (< 10%) that B_{2017} is below the Hard limit
Status in relation to Overfishing	Overfishing is Virtually Certain (> 99%) to be occurring

Historical Stock Status Trajectory and Current Status



Annual landings, TACC, and two standardised CPUE series for CRA 2 from 1979 to 2016. The CELR CPUE series has been standardised with month, area, and vessel explanatory variables, using vessels at least five years in the fishery. The FSU CPUE series has been standardised with month and area variables.



Phase plot for CRA 2. Median values are plotted up to the final (2016) year. The contour density for the final year of the plot (2016) shows the posterior distributions of the two ratios. See Figure 25 caption for detailed explanation of this plot.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	AW biomass declined from a peak in the mid-1990s, which was near B_{REF} to near 20% B_{REF} in 2017. There was a short period of increasing biomass to 2007, followed by a steady decline to 2017.
Recent Trend in Fishing Intensity or Proxy	Fishing intensity dropped after 2013, but remains well above F_{REF}.

Other Abundance Indices	-
Trends in Other Relevant Indicators or Variables	-
Projections and Prognosis	
Stock Projections or Prognosis	2016–17 offset-year CPUE is likely to decline from the 2015–16 level
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Soft Limit: Likely (> 60%) Hard Limit: Unknown
Probability of Current Catch or TACC causing Overfishing to continue or commence	Virtually Certain (> 99%) to continue

Assessment Methodology and Evaluation		
Assessment Type	Level 1 – Full Quantitative Stock Assessment	
Assessment Method	Bayesian length-based model	
Assessment dates	Latest assessment: 2017	Next assessment: 2022
Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	- FSU CPUE data 1979–88 - CELR CPUE data: 1989–2016 - Length-frequency data - Tag-recapture data	1 – High Quality (all)
Data not used (rank)	N/A	
Changes to Model Structure and Assumptions	- start model in 1979 instead of 1945 - standardised CELR CPUE with vessel explanatory variable - separate FSU and CELR CPUE series - no density-dependence - only fit to first tag-recapture event - each sex category weighted by the number of size samples	
Major Sources of Uncertainty	- non-commercial catch - lack of size-frequency data before 1993 - lack of puerulus index	

Qualifying Comments
-

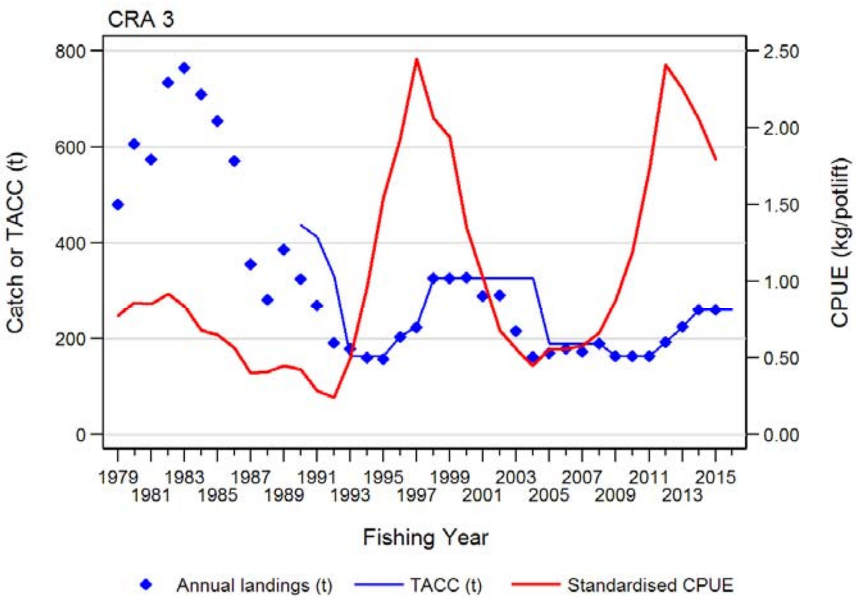
Fishery Interactions
Potting is the main method of targeting rock lobster and is thought to have little direct effect on non-target species. For all QMAs, the most frequently reported incidental species caught are, in decreasing order of catch across all stocks: octopus, conger eel, blue cod, trumpeter, sea perch, red cod, butterfish and leatherjackets. However, these compose less than 10% of the rock lobster catch.

- **CRA 3 Gisborne**

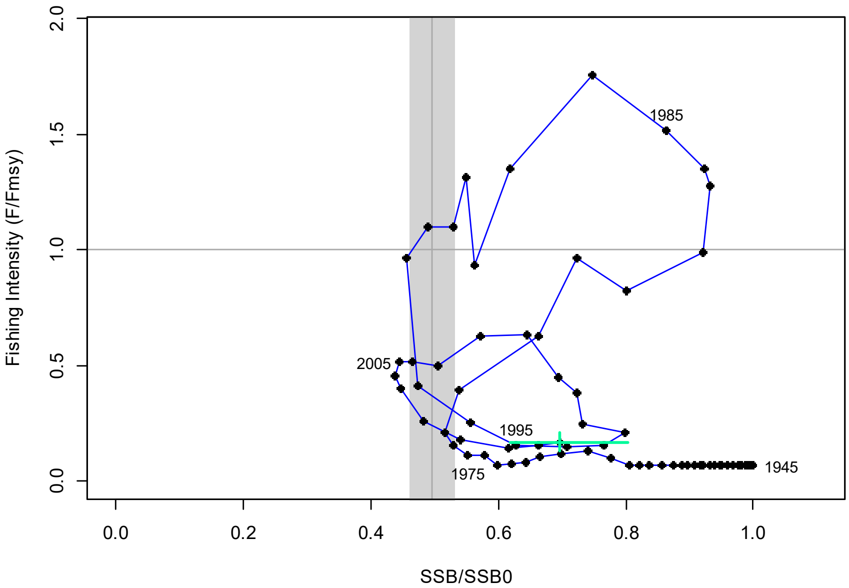
Stock Status	
Year of Most Recent Assessment/Evaluation	Assessment 2014; MP update 2016
Assessment Runs Presented	2014 assessment: two base case MCMCs and four MCMC sensitivity trials from each base case; 2016: MP evaluated
Reference Points	Target: reported against B_{MSY}: autumn–winter (AW) vulnerable biomass associated with MSY (maximum size-limited catch summed across AW and SS) Limit: reported against B_{MIN}: minimum AW vulnerable biomass, 1945–2013

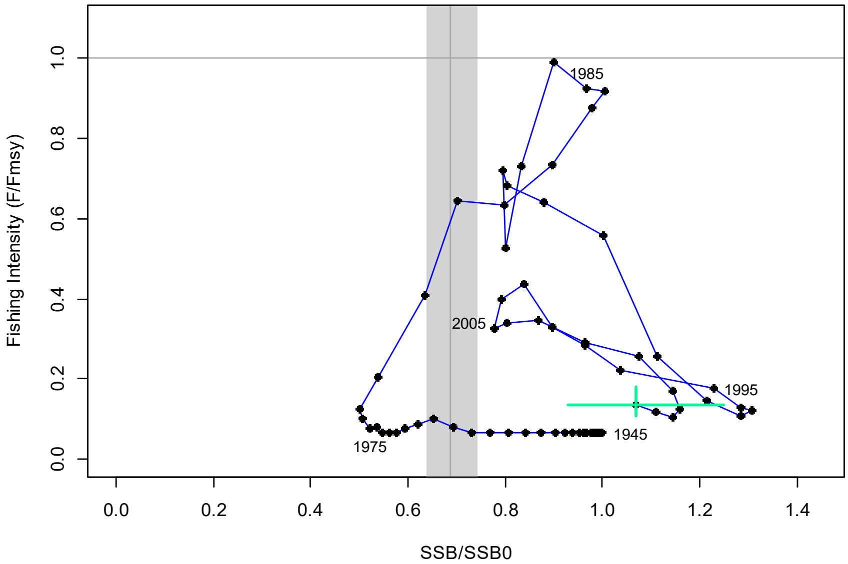
	Soft limit: 20% SSB_0 (default) Hard limit: 10% SSB_0 (default)
Status in relation to Target	Biomass in 2014 was 333% or 473% of B_{MSY} for the two base cases; MP update suggests biomass in 2016 is lower B_{2014} and B_{2016} Virtually Certain (> 99%) to be above B_{MSY}
Status in relation to Limits	Exceptionally Unlikely (< 1%) that B_{2014} and B_{2016} are below B_{MIN} Exceptionally Unlikely (< 1%) that B_{2014} and B_{2016} are below soft and hard limits
Status in relation to Overfishing	Overfishing is Exceptionally Unlikely (< 1%) to be occurring

Historical Stock Status Trajectory and Current Status



Annual landings, TACC and standardised CPUE for CRA 3 from 1979 to 2016.





CRA 3: Snail trails from the two base case MCMCs: fixed growth CV at the top. The vertical line in the figure is the median (line) and 90% interval (shading) of the posterior distribution of *SSBmsy* as a proportion of *SSB₀*; this ratio was calculated using the fishing pattern in 2012. The horizontal line in the figure is drawn at 1, the fishing intensity associated with *Fmsy*. The bars at the final year of the plot show the 90% intervals of the posterior distributions of biomass ratio and fishing intensity ratio.

Fishery and Stock Trends		
Recent Trend in Biomass or Proxy	Biomass declined steadily from 1997 to 2003 and then increased strongly after 2009. CPUE shows the same pattern and is now near its 1997 peak.	
Recent Trend in Fishing Mortality or Proxy	Size-limited and non-size-limited exploitation rates have declined since 2002.	
Other Abundance Indices	Puerulus not fitted in base case	
Trends in Other Relevant Indicators or Variables	-	
Projections and Prognosis		
Stock Projections or Prognosis	Offset-year CPUE decreased from 2.21 kg/potlift in 2014 to 1.72 kg/potlift in 2016 (but the data for 2016 is actually the 2015–16 offset year, so is incomplete).	
Probability of Current Catch or TACC causing decline below Limits	Exceptionally Unlikely (< 1%)	
Probability of Current Catch or TACC causing Overfishing to continue or commence	Unlikely (< 40%)	
Assessment Methodology		
Assessment Type	Level 1 – Full Quantitative Stock Assessment	
Assessment Method	Bayesian multi-stock length-based model (MLSM, Haist et al. 2009)	
Assessment Dates	Latest assessment: 2014	Next assessment: 2019
Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	- CPUE - Length frequency - Tagging data	1 – High Quality (all)
Data not used (rank)	- Puerulus not fitted in base case	

Changes to Model Structure and Assumptions	- Latest version of MLSM
Major Sources of Uncertainty	- Temporal changes in growth rate

Qualifying Comments
-

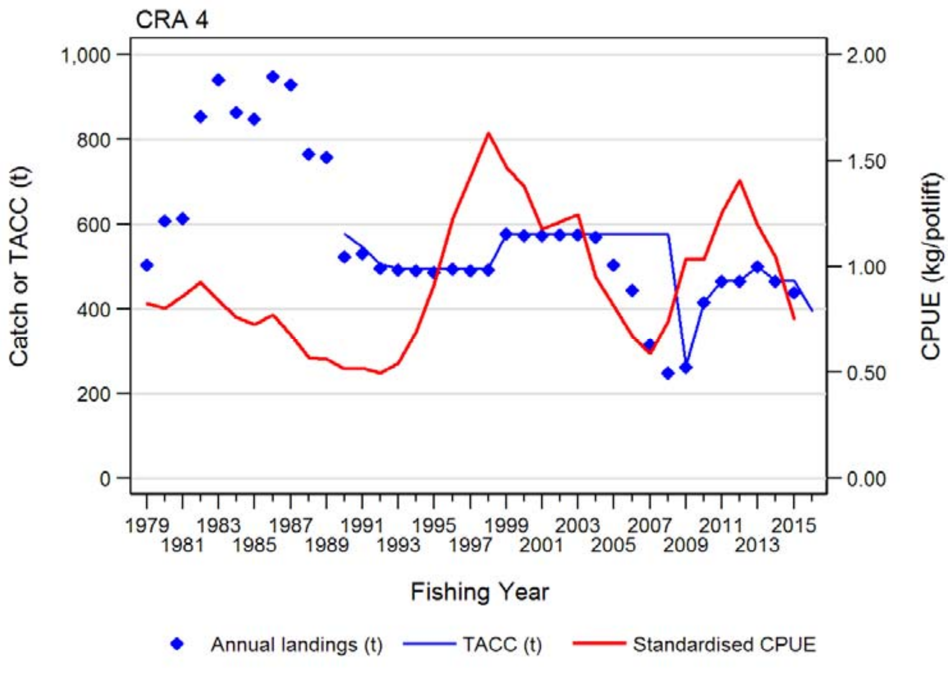
Recent developments in stock status
CPUE increased strongly from 2009 and the current level is near the 1997 peak.

Fishery Interactions
Potting is the main method of targeting rock lobster and is thought to have little direct effect on non-target species.

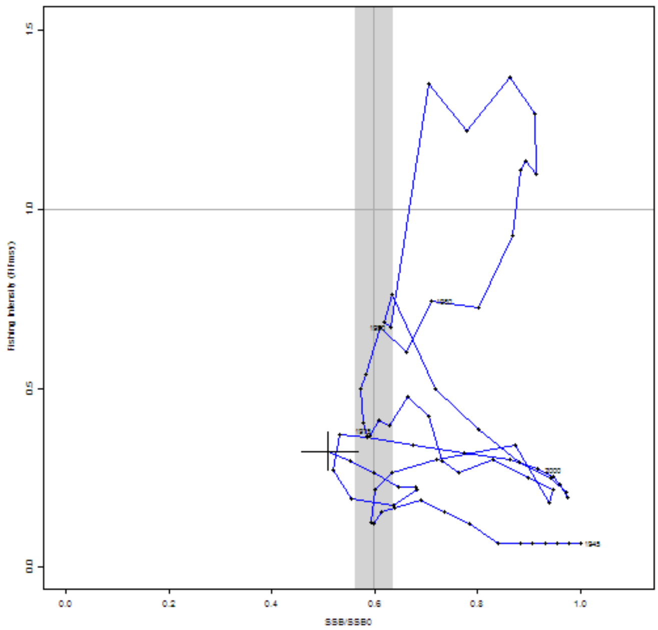
- **CRA 4 Wellington – Hawke's Bay**

Stock Status	
Year of Most Recent Assessment/Evaluation	Assessment 2016
Assessment Runs Presented	Base case
Reference Point	Target: *Bref*: mean of beginning AW vulnerable biomass for the period 1979–88 Soft limit: 20% SSB_0 (default) Hard limit: 10% SSB_0 (default) Overfishing threshold: F_{MSY}
Status in relation to Target	Biomass in 2016 was 75% of B_{REF} Very Unlikely (< 10%) to be above B_{REF}
Status in relation to Limits	Exceptionally Unlikely (< 1%) to be below the soft and hard limits
Status in relation to Overfishing	Overfishing is Likely (> 60%) to be occurring

Historical Stock Status Trajectory and Current Status



Annual landings, TACC and standardised CPUE for CRA 4 from 1979 to 2016.



Snail trail summary of the CRA 4 base case model. The line tracks the median values for each axis from the MCMC posteriors and the cross marks the 90% credibility interval on both axes for the final model year (2016). The vertical line in the figure is the median (line) and 90% interval (shading) of the posterior distribution of *SSBmsy*. This ratio was calculated using the fishing pattern in 2015. The horizontal line in the figure is drawn at 1, the fishing intensity associated with *Fmsy*.

Fishery and Stock Trends		
Recent Trend in Biomass or Proxy	Biomass has been decreasing since 2012.	
Recent Trend in Fishing Intensity or Proxy	Fishing intensity has been increasing since 2012.	
Other Abundance Indices	-	
Trends in Other Relevant Indicators or Variables	-	
Projections and Prognosis		
Stock Projections or Prognosis	Biomass is projected to decrease over the next three years at the level of the 2016 TACC (397 t)	
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Likely (> 60%)	
Probability of Current Catch or TACC causing Overfishing to continue or commence	Likely (> 60%)	
Assessment Methodology		
Assessment Type	Level 1 – Full Quantitative Stock Assessment	
Assessment Method	Bayesian length based model	
Assessment Dates	Latest assessment: 2016	Next assessment: 2021
Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	CPUE, length frequency, tagging data, puerulus settlement indices	1– High Quality
Data not used (rank)	N/A	
Changes to Model Structure and Assumptions	- informed priors on some growth parameters, fitting LFs separately by sex and estimating sex ratios; change to estimate	

	of handling mortality
Major Sources of Uncertainty	- level of non-commercial catches, including recreational and illegal catches, modelling of growth, estimation of productivity, vulnerability of immature females; estimated recent recruitment.

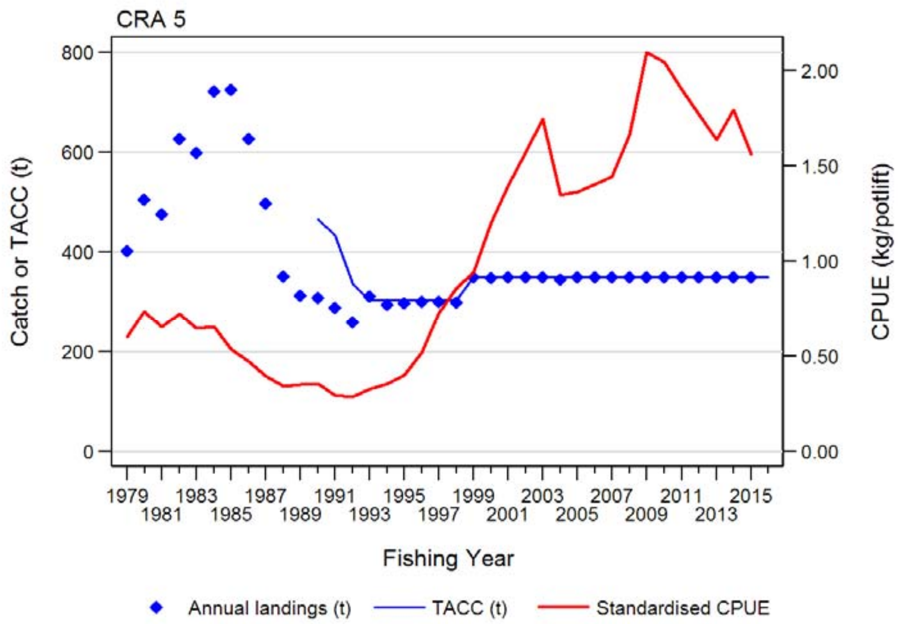
Qualifying Comments
-

Fishery Interactions
Potting is the main method of targeting rock lobster and is thought to have little direct effect on non-target species. For all QMAs, the most frequently reported incidental species caught are, in decreasing order of catch across all stocks: octopus, conger eel, blue cod, trumpeter, sea perch, red cod, butterfish and leatherjackets. However, these compose less than 10% by weight of the rock lobster catch.

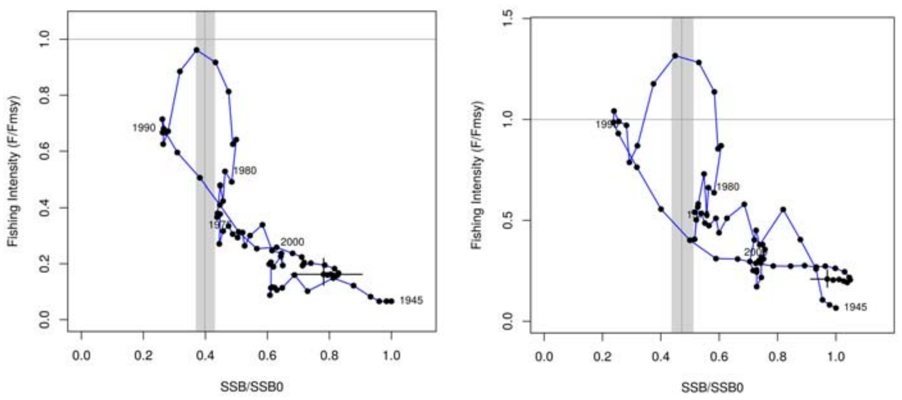
- **CRA 5 Canterbury – Marlborough**

Stock Status	
Year of Most Recent Assessment/Evaluation	Assessment 2015; MP update 2016
Assessment Runs Presented	2015 assessment: two base cases; 2016: MP evaluated
Reference Points	Target: *Bref*: mean of beginning AW vulnerable biomass for the period 1979–81 Soft limit: 20% SSB_0 (default) Hard limit: 10% SSB_0 (default) Overfishing threshold: F_{MSY}
Status in relation to Target	Biomass in 2015 was 182% or 240% *Bref* for the two base cases; MP update suggests biomass in 2016 is only slightly lower B_{2015} and B_{2016} Virtually Certain (> 99%) to be above *Bref*
Status in relation to Limits	B_{2015} and B_{2016} Exceptionally Unlikely (< 1%) to be below the soft and hard limits
Status in relation to Overfishing	Overfishing is Very Unlikely (< 10%) to be occurring

Historical Stock Status Trajectory and Current Status



Annual landings, TACC and standardised CPUE for CRA 5 from 1979 to 2016.



Phase plots for the two base case runs (without and with density-dependence).

Fishery and Stock Trends		
Recent Trend in Biomass or Proxy	CPUE has decreased since 2009, the highest level observed in the 36-year series, but remains at high levels.	
Recent Trend in Fishing Intensity or Proxy	Fishing mortality has remained well below the overfishing threshold in recent years.	
Other Abundance Indices	-	
Trends in Other Relevant Indicators or Variables	-	
Projections and Prognosis		
Stock Projections or Prognosis	Biomass is expected to decrease from 2015–18 but will remain above all reference levels for either of the two base case results.	
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Very Unlikely (< 10%)	
Probability of Current Catch or TACC causing Overfishing to continue or to commence	Very Unlikely (< 10%)	
Assessment Methodology		
Assessment Type	Level 1 – Full Quantitative Stock Assessment	
Assessment Method	Bayesian length based model	
Assessment Dates	Latest assessment: 2015	Next assessment: 2020
Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	CPUE, length frequency, tagging data, puerulus data	1 – High Quality
Data not used (rank)	N/A	
Changes to Model Structure and Assumptions	- new growth priors - addition of a density-dependence parameter	
Major Sources of Uncertainty	- level of non-commercial catches, illegal catches, validity of the assumption of constant catchability since 1979 in the CPUE series.	

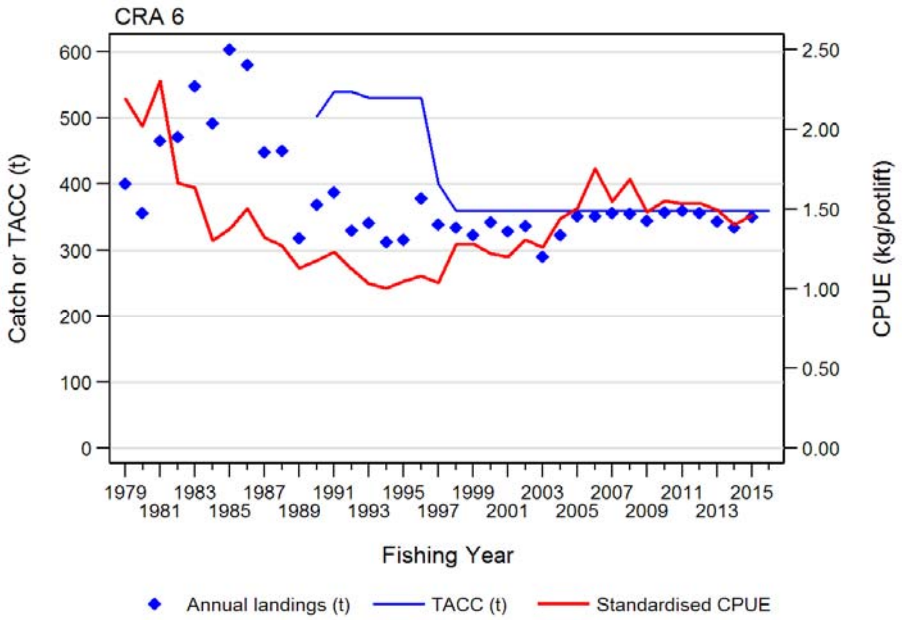
Qualifying Comments
-

Fishery Interactions
Potting is the main method of targeting rock lobster and is thought to have very little direct effect on non-target species. For all QMAs, the most frequently reported incidental species caught are, in decreasing order of catch across all stocks: octopus, conger eel, blue cod, trumpeter, sea perch, red cod, butterfish and leatherjackets. However, these generally compose less than 10% of the rock lobster catch.

- **CRA 6 Chatham Islands**

Stock Status	
Year of Most Recent Assessment/Evaluation	Assessment 1996; CPUE updated to 2015
Assessment Runs Presented	Base case
Reference Points	Target: Not established Soft limit: 20% SSB_0 (default) Hard limit: 10% SSB_0 (default) Overfishing threshold: F_{MSY}
Status in relation to Target	Unknown
Status in relation to Limits	Unknown
Status in relation to Overfishing	Unknown

Historical Stock Status Trajectory and Current Status



Annual landings, TACC and standardised CPUE for CRA 6 from 1979 to 2016.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	CPUE has declined slightly over the last 3 years.
Recent Trend in Fishing Intensity or Proxy	Unknown
Other Abundance Indices	-
Trends in Other Relevant Indicators or Variables	-

Projections and Prognosis	
Stock Projections or Prognosis	Unknown

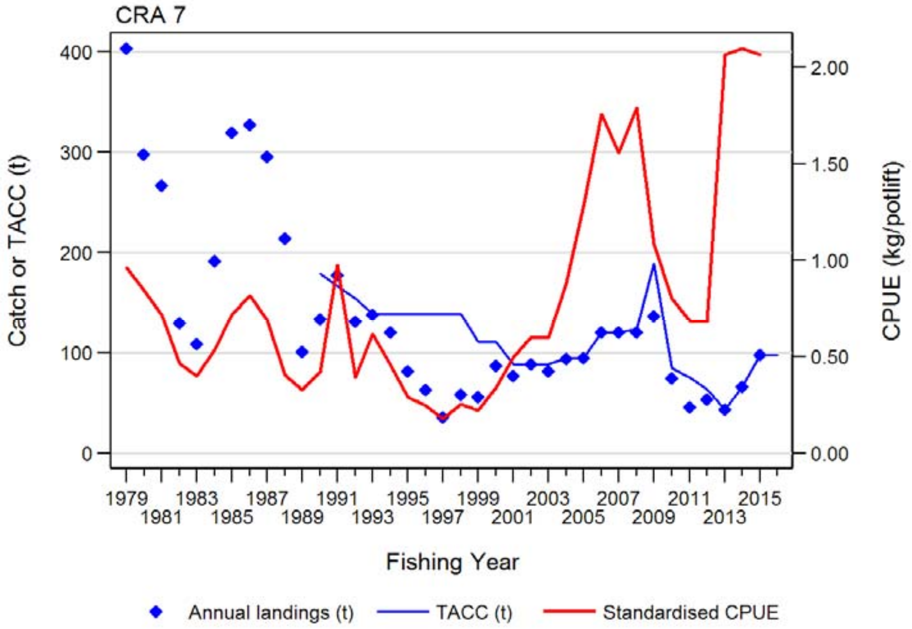
Probability of Current Catch or TACC causing Biomass to remain or to decline below Limits	Soft Limit: Unknown Hard Limit: Unknown	
Probability of Current Catch or TACC causing Overfishing to continue or commence	Unknown	
Assessment Methodology and Evaluation		
Assessment Type	Level 1 – Full Quantitative Stock Assessment	
Assessment Method	Production model	
Assessment dates	1996	Next assessment: Unknown
Overall assessment quality rank	Unknown: assessment out of date	
Main data inputs (rank)	CPUE	1 – High Quality
Data not used (rank)	N/A	
Changes to Model Structure and Assumptions	-	
Major Sources of Uncertainty	Catch rates are 50% higher than when the production model was fitted in 1996.	

Qualifying Comments
-

Fishery Interactions
Potting is the main method of targeting rock lobster and is thought to have little direct effect on non-target species. For all QMAs, the most frequently reported incidental species caught are, in decreasing order of catch across all stocks: octopus, conger eel, blue cod, trumpeter, sea perch, red cod, butterfish and leatherjackets. However, these compose less than 10% of the rock lobster catch.

- **CRA 7 Otago**

Stock Status	
Year of Most Recent Assessment/Evaluation	Assessment 2015; MP update 2016
Assessment Runs Presented	2015 assessment: MCMC base case; 2016: MP evaluated
Reference Point	Target: *Bref*: mean of beginning AW vulnerable biomass for the period 1979–81 Soft limit: ½*B_{REF} (default) Hard limit: ¼*B_{REF} (default) Overfishing threshold: F_{MSY}
Status in relation to Target	CPUE is at a relatively high level. B_{2015} Very Likely (> 90%) to be above B_{REF}; MP update suggests biomass in 2016 is even higher
Status in relation to Limits	B_{2015} and B_{2016} Unlikely (< 40%) to be below soft or hard limits
Status in relation to Overfishing	Overfishing is Very Unlikely (< 10%) to be occurring

Historical Stock Status Trajectory and Current Status		
 **Annual landings, TACC and standardised CPUE for CRA 7 from 1979 to 2016.**		
Fishery and Stock Trends		
Recent Trend in Biomass or Proxy	Biomass levels have increased since the mid-2000s to a level well above the reference period.	
Recent Trend in Fishing Intensity or Proxy	Stable over the past decade	
Other Abundance Indices	-	
Trends in Other Relevant Indicators or Variables	-	
Projections and Prognosis		
Stock Projections or Prognosis	Four-year projections from 2015 suggest median biomass will decline by 8% but will remain well above reference levels.	
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Unlikely (< 40%)	
Probability of Current Catch or TACC causing Overfishing to continue or to commence	Very Unlikely (< 10%)	
Assessment Methodology		
Assessment Type	Level 1 – Full Quantitative Stock Assessment	
Assessment Method	Bayesian length based model	
Assessment Dates	Latest assessment: 2015	Next assessment: 2020
Overall assessment quality rank	1– High Quality	
Main data inputs (rank)	CPUE, historic catch rate, length frequency, tagging data	1– High Quality
Data not used (rank)	Puerulus indices	3 – Low quality: three indices in CRA 7 and CRA 8, with conflicting trends

Changes to Model Structure and Assumptions	Average movement used for years without movement estimated; Francis (2011) weights for composition data; change in tag-recapture likelihood; no density-dependent growth.
Major Sources of Uncertainty	Variation in length-frequency data, uncertain movement patterns out of CRA 7 (with potential change over time), lack of mature females.

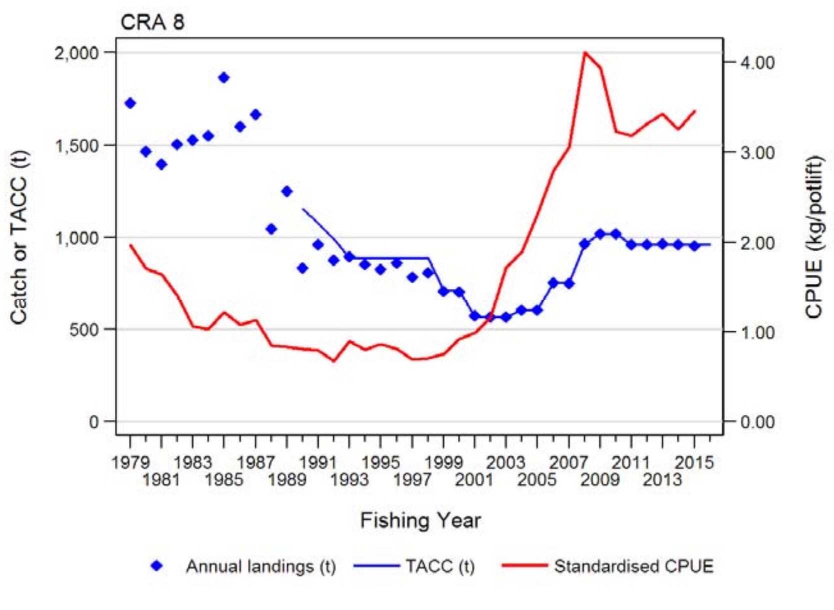
Qualifying Comments
-

Fishery Interactions
Potting is the main method of targeting rock lobster and is thought to have little direct effect on non-target species. Across all QMAs, the most frequently reported incidental species caught are, in decreasing order of catch: octopus, conger eel, blue cod, trumpeter, sea perch, red cod, butterfish and leatherjackets. However, these compose less than 10% of the rock lobster catch.

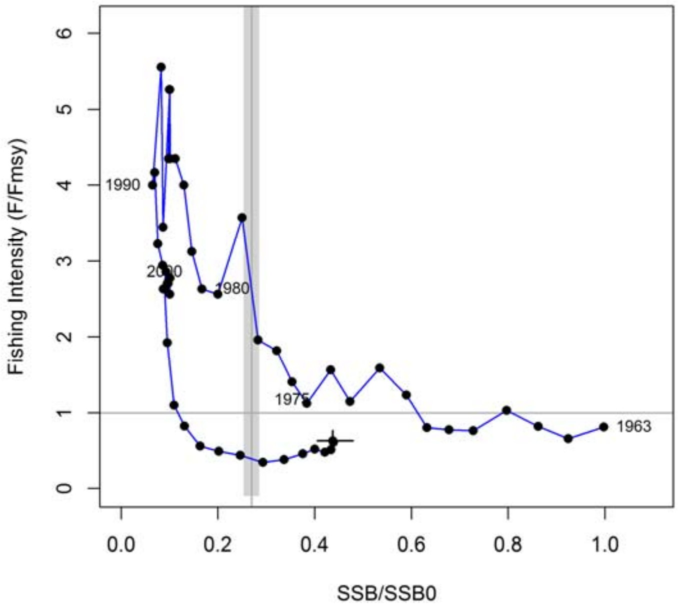
- **CRA 8 Southern**

Stock Status	
Year of Most Recent Assessment/Evaluation	Assessment 2015; MP update 2016
Assessment Runs Presented	2015 assessment: MCMC base case; 2016: MP evaluated
Reference Point	Target: *Bref*: mean of beginning AW vulnerable biomass for the period 1979–81 Soft limit: 20% SSB_0 (default) Hard limit: 10% SSB_0 (default) Overfishing threshold: F_{MSY}
Status in relation to Target	CPUE is at a level well above the levels during the reference period; MP update suggests biomass in 2016 is similar B_{2015} and B_{2016} Virtually Certain (> 99%) to be above B_{REF}
Status in relation to Limits	B_{2015} and B_{2016} Exceptionally Unlikely (< 1%) to be below the soft and hard limits
Status in relation to Overfishing	Overfishing is Very Unlikely (< 10%) to be occurring

Historical Stock Status Trajectory and Current Status



Annual landings, TACC and standardised CPUE for CRA 8 from 1979 to 2016



Phase plot that summarises the history of the CRA 8 fishery.

Fishery and Stock Trends		
Recent Trend in Biomass or Proxy	Biomass has been increasing steadily in recent years.	
Recent Trend in Fishing Intensity or Proxy	Relatively stable and well below *Fmsy*	
Other Abundance Indices	-	
Trends in Other Relevant Indicators or Variables	-	
Projections and Prognosis		
Stock Projections or Prognosis	2015 projections suggest the stock will remain near its current level.	
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Exceptionally Unlikely (< 1%)	
Probability of Current Catch or TACC causing Overfishing to continue or commence	Very Unlikely (< 10%)	
Assessment Methodology and Evaluation		
Assessment Type	Level 1 – Full Quantitative Stock Assessment	
Assessment Method	Bayesian length based model	
Assessment Dates	Latest assessment: 2015	Next assessment: 2020
Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	CPUE, historic catch rate, length frequency, tagging data	1 – High Quality
Data not used (rank)	Puerulus indices	3 – Low quality: three indices in CRA 7 and CRA 8, with conflicting trends
Changes to Model Structure and Assumptions	- Francis (2011) weights for composition data; change in tag-recapture likelihood.	
Major Sources of Uncertainty	- Effect of returning a high proportion of large lobsters to the sea (including for the calculation of reference points); assumption of constant catchability over the entire CPUE time series.	

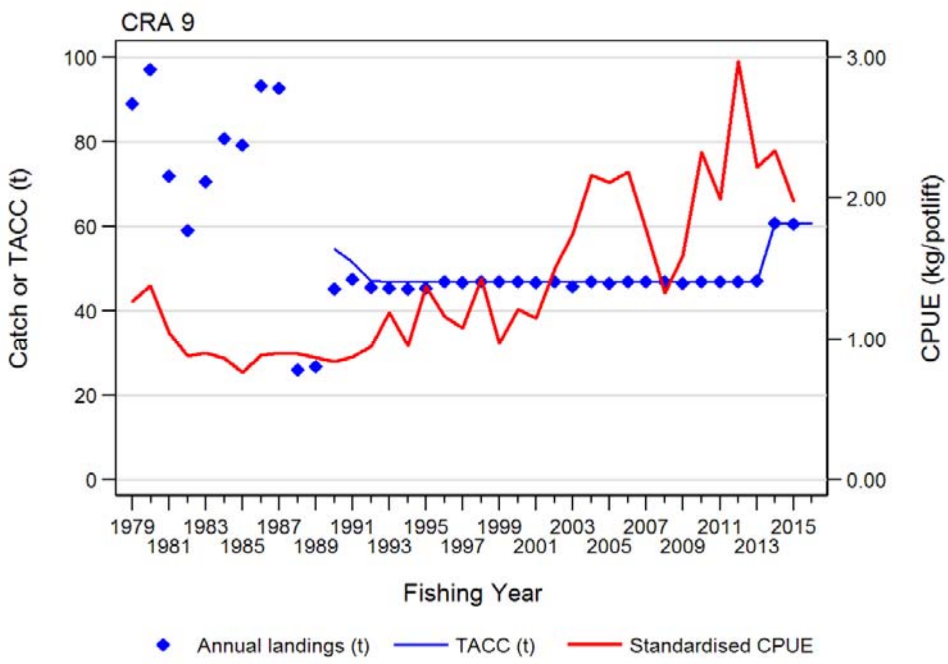
Qualifying Comments
-

Fishery Interactions
Potting is the main method of targeting rock lobster and is thought to have little direct effect on non-target species. Across all QMAs, the most frequently reported incidental species caught are, in decreasing order of catch: octopus, conger eel, blue cod, trumpeter, sea perch, red cod, butterfish and leatherjackets. However, these compose less than 10% of the rock lobster catch.

- **CRA 9 Westland–Taranaki**

Stock Status	
Year of Most Recent Assessment/Evaluation	Stock assessment and MP suspended in 2015; CPUE updated to 2015
Assessment Runs Presented	-
Reference Points	Target: Not yet established Soft limit: 20% *K* (default) Hard limit: 10% *K* (default) Overfishing threshold: F_{MSY}
Status in relation to Target	Unknown
Status in relation to Limits	Unknown
Status in relation to Overfishing	Unknown

Historical Stock Status Trajectory and Current Status



Annual landings, TACC and standardised CPUE for CRA 9 from 1979 to 2016.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	CPUE has risen steadily since the early 1990s.
Recent Trend in Fishing Intensity or Proxy	Size data from commercial fisheries suggests low exploitation rates in all statistical areas.
Other Abundance Indices	-
Trends in Other Relevant Indicators or Variables	-

Projections and Prognosis		
Stock Projections or Prognosis	-	
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Unknown	
Probability of Current Catch or TACC causing Overfishing to continue or to commence	Unknown	
Assessment Methodology		
Assessment Type	N/A	
Assessment Method	N/A	
Assessment Dates	Latest assessment: 2013	Next assessment: Unknown
Overall quality assessment rank	3 – Low Quality: assessment and MP rejected	
Main data inputs (rank)	Catch and CPUE	1 – High Quality
Data not used (rank)	-	
Changes to Model Structure and Assumptions	-	
Major Sources of Uncertainty	Catch and CPUE data from small number of participants	

Qualifying Comments
Not a true assessment; the production model was used as an operating model for Management Procedure Evaluations.

Fishery Interactions
Potting is the main method of targeting rock lobster and is thought to have little direct effect on non-target species. For all QMAs, the most frequently reported incidental species caught are, in decreasing order of catch across all stocks: octopus, conger eel, blue cod, trumpeter, sea perch, red cod, butterfish and leatherjackets. However, these compose less than 10% of the rock lobster catch.

7.2 *Sagmariasus verreauxi*, PHC stock

The status of this stock is unknown.

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