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Stakeholder management of the New Zealand red rock lobster (*Jasus edwardsii*) fishery

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ABSTRACT

The history and management of the New Zealand fishery for the rock lobster *Jasus edwardsii* is described. The fishery was essentially open-access to 1979, with limited input controls. Access was strictly limited from 1979 to 1989, but effort increased to a peak in 1985, when the fishery was fully exploited. Early stock assessments suggested over-exploitation. Quotas were introduced in 1990 and catches were reduced from their then mean levels to promote stock rebuilding. Subsequently, the commercial fishing industry has exercised stewardship initiatives to maintain stocks. Operational management procedures have been developed and introduced since 1996. While overall catch is similar to 1990 levels, catch per unit of effort has more than doubled. Successes and challenges for future management are discussed.

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1. Introduction

Two species of palinurid ("spiny" or "rock") lobster are fished in New Zealand. The red rock lobster *Jasus edwardsii* is the major species (2800 t landed in 2013–14; Ministry for Primary Industries, 2014) and the green or packhorse lobster fishery *Sagmariasus verreauxi* is much less important (<40 t in 2014–15). *S. verreauxi* is data-limited and not formally assessed, so in this paper "rock lobster" will apply to *J. edwardsii* only.

We describe history and management of the rock lobster fishery, elucidating lessons learned in a successful fisheries management story. The story involves an open access fishery expanding and depleting the stock, unsuccessful limited entry management and then stock rebuilding after the introduction of property rights-based management that created incentives for the commercial fishery to exercise stewardship; devolution of some management from government to stakeholders; collection of high quality data, including industry-collected data; length-based stock assessments and development of operational management procedures to adjust TACCs as abundance changes within a Quota Management Area (QMA, equals "stock"). We also discuss potential future challenges for the next few decades.

2. Fishery

Rock lobsters occur in relatively shallow waters and are caught in traps or "pots" by small (<10 m) commercial vessels, many of which are beach-launched for day trips. Rock lobsters support the most valuable New Zealand inshore fishery, with NZ $264 million in recent annual exports (Seafood Innovations Ltd., unpublished data) and NZ $1.3 billion in quota value (FishServe, unpublished data). This fishery contributes economically and socially to New Zealand's coastal settlements. Lobster is a taonga (cultural treasure) for Maori people and also supports an important recreational fishery.

The fishery is managed under Individual Transferable Quotas (ITQs), described further below, in nine QMAs (Fig. 1), each

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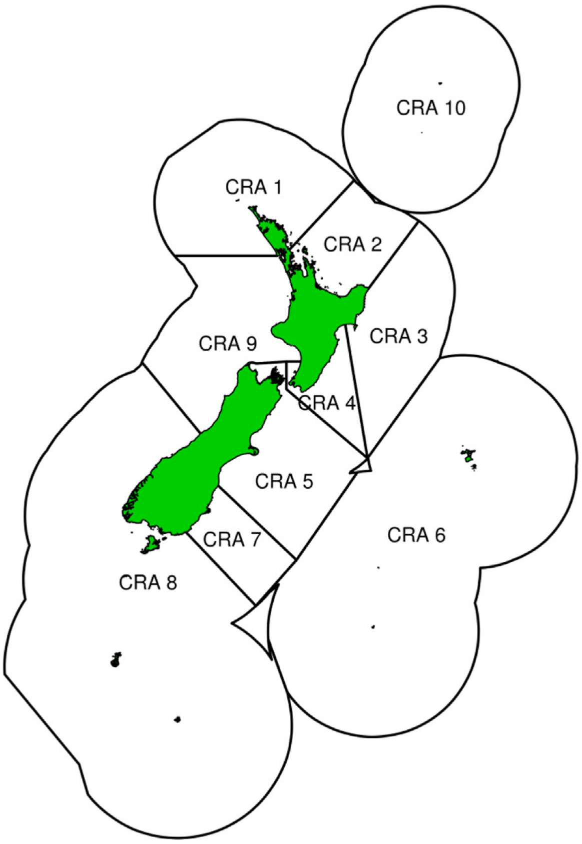

Fig. 1. Quota Management Areas (QMAs) for the New Zealand red rock lobster fishery.

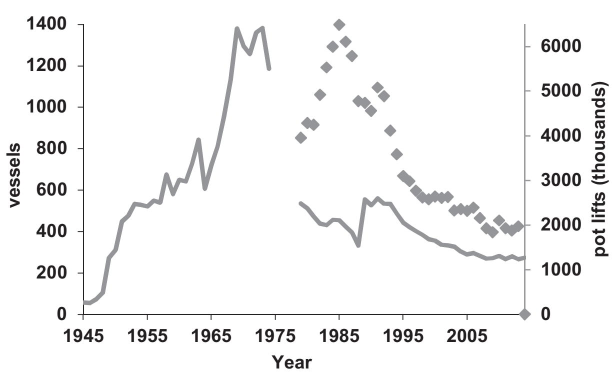

Fig. 2. Total numbers of vessels (solid line) and annual pot lifts (diamonds) in the New Zealand red rock lobster fishery.

with its own Total Allowable Commercial Catch (TACC) and Total Allowable Catch (TAC), within which allowances are made for non-commercial removals. Input controls include minimum legal sizes (MLS) and protection of egg-bearing ("berried") females. Customary Maori fishing is authorised by kaitiaki (Maori guardians) for marae-related activities. The recreational fishery is controlled only by size and berried female restrictions, an individual pot limit and a daily bag limit of six. An illegal fishery thrives on high lobster abundance in most areas and on strong local and restaurant demand (MPI Compliance, unpublished data).

Fig. 2 shows the history of commercial effort in vessels and pot-lifts and Fig. 3 shows the history of total catch, TACCs and arithmetic mean catch per unit of effort (CPUE) for all of New Zealand since 1979, when verified reporting was first required.

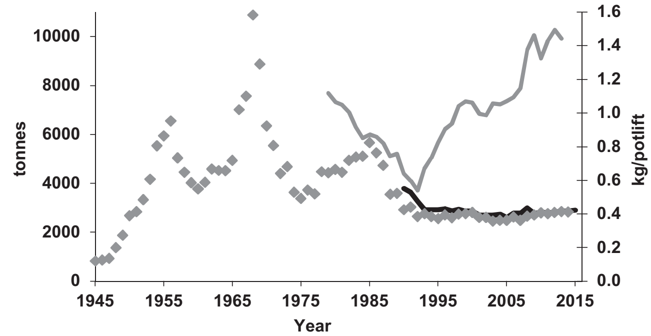

Fig. 3. The history of total commercial catch (diamonds), sum of TACCs (black line) and arithmetic CPUE in the New Zealand red rock lobster fishery.

3. Biology

Females and males move seasonally inshore and offshore as they moult and breed, resulting in spatial and temporal differences in sex ratio, density and size (Bradstock, 1948; MacDiarmid, 1991). Size at maturity generally increases from north to south (Annala et al., 1980; Booth, 1984; MacDiarmid, 1989). Fertilisation is external (MacDiarmid, 1988) and fertility increases with female size (Annala and Bycroft, 1987). Large female rock lobsters may require large males for mating (MacDiarmid and Butler, 1999) and produce eggs of better quality (MacDiarmid, Breen and Kendrick, unpublished data).

Phyllosoma larvae spend 12–24 months offshore (Booth, 1994) and post-larval pueruli are thought to swim actively inshore to settle (Booth and Phillips, 1994). Recruitment around New Zealand (measured on collectors) is spatially variable and some populations may be supported by distant populations (Chiswell and Booth, 2008). There is likely to be some trans-Tasman gene flow (Chiswell et al., 2003).

Tag-recapture experiments and analyses of size-frequency data have investigated growth for over 30 years (e.g. McKoy and Esterman, 1981). Growth varies by size, sex and among stocks (Annala and Bycroft, 1985; McKoy, 1985). Despite early work on total mortality (Annala, 1980), little is known about the natural mortality rate of lobsters in New Zealand.

4. Stocks

J. edwardsii is found on the whole New Zealand coastline, including the Chatham Islands 600 km to the east. Because of the long oceanic larval period (Booth, 1994), stock structure is poorly understood, although it has been studied using fishery and biological data (Booth and Breen, 1992; Bentley and Starr, 2001), larval dispersion and oceanic modelling (Chiswell and Booth, 2008), genetics (Smith et al., 1980; Ovenden and Brasher, 1994; Thomas and Bell, 2012, 2013) and trace element markers (Jack et al., 2011).

When ITQs were introduced in 1990 (see below), TACCs were set for each of nine arbitrary "stocks" (QMAs) that may have no relation to the actual stock structure. Given the long larval life, one would not expect a stock-recruit relation within a QMA. Some of the QMAs have similar abundance trends among the smaller statistical areas within the QMA (e.g. CRA 3; Paul Starr, unpublished data); others are too large to have real coherence (CRA 9) or have strongly opposing trends in abundance within the QMA (CRA 1, CRA 5). The group (CRA 3, CRA 4 and CRA 5) has shown similar trends in recruitment and CPUE over time, so may be related through settlement.

Stock histories and current status differ. The major stocks (CRA 3, CRA 4 and CRA 8) have each been rebuilt from depleted levels using operational management procedures to adjust commercial

Table 1
Some aspects of the New Zealand rock lobster fisheries.

	CRA 1	CRA 2	CRA 3	CRA 4	CRA 5	CRA 6	CRA 7	CRA 8	CRA 9	Total
2015–16 TAC (t)	273.062	416.5	389.95	662	467	370	117.72	1053	115.8	3865
Total non-commercial allowances	142	216.5	129	195	117	10	20	91	55	976
2015–16 TACC (t)	131	200	261	467	350	360	98	962	61	2890
Vessels 2014–15	17	36	27	49	29	38	9	62	6	273
% 2014–15 TACC caught	98%	99%	100%	100%	100%	92%	100%	100%	100%	99%
Last stock assessment	2014	2013	2014	2011	2010	n.a.	2012	2012	2013	
Observer catch sampling?	yes	yes	yes	yes			yes			
Logbooks	yes	yes	yes	yes	yes			yes	yes	
Percentage of vessels doing logs	6%	50%	19%	8%	34%			23%	17%	19%
Voluntary closed season?			yes		yes	yes				
Puerulus time series?			yes	yes	yes		yes	yes		
Stock above reference level?	yes	no	yes	yes	yes	n.a.	yes	yes	yes	
First year of MP	2015	2014	2010	2007	2009		1996	1996	2014	
First year of current MP	2015	2014	2015	2012	2012		2013	2013	2014	

catches (see below); CRA 1, CRA 5 and CRA 9 have maintained good abundance without much intervention until recently; CRA 2 is above B_{MSY} but below an empirical reference point and hence is under a rebuilding regime; CRA 6 may be depleted but has not been assessed and CRA 7 (currently with high CPUE) is volatile because of a small minimum legal size (MLS) and migration to CRA 8 (Street, 1971). All stocks except CRA 6 are currently managed with operational management procedures (Table 1).

5. History of the fishery

Maori arrived in New Zealand in the 10th to 14th centuries (Reed, 1970) and caught lobsters (Leach and Anderson, 1979) using methods described by Best (1929). The first recorded commercial sale was in 1769: on James Cook's first voyage to New Zealand, the Tahitian navigator Tupaia painted a Tolaga Bay Maori selling a lobster to Joseph Banks for a nail (Salmond, 2003).

The post European contact commercial fishery was small until after the Second World War and the modern fishery began in 1945, selling to the domestic market. There was an evolution from "management by regulation" to the present management, which has defined goals and explicit harvest strategies.

Early management (Annala, 1983b; Booth and Breen, 1994; Yandle, 2008) involved transferable licensing of vessels from 1937 and introduction of MLS and other input controls. An attempt to limit vessel numbers through licencing was not effective: vessel numbers increased strongly (Fig. 2); this was abandoned in 1963 and vessel numbers peaked in 1972. Catch peaked in 1956 and then fluctuated. A spike in the 1960s was caused by an uncontrolled boom and bust fishery at the Chatham Islands (Kensler, 1969), accompanied by much waste and area misreporting (Arbuckle, 1971), that reflected the lack of any real fisheries management apart from bureaucratic regulation. Escape gap regulations appeared in 1969 to reduce handling damage of small lobsters.

MLS was first regulated in 1950 (Sorenson, 1970): initially nine inches total length but changed repeatedly for most regions. It became six inches tail length (152 mm) in 1969 (Sorenson, 1970). This MLS was set arbitrarily without reference to yield modelling.

In 1973 and subsequently, industry petitioned government to limit entry and to exclude part-time fishers. Effective limited entry was adopted in 1979 with "Controlled Fishery" Areas. An independent Fisheries Licensing Authority issued licences, which could not be transferred or sold, and there was an obligation to use the Licence or surrender it. There were nine Controlled Fishery Areas, reflecting natural boundaries of fishing practice (Annala, 1983a); licensees could usually fish only in one Area. When ITQs were introduced in 1990 (see below), the same Areas were converted to QMAs.

New fishing permits for lobster fishing were not issued from 1979 and the Ministry[1] established a Policy and Planning Group to facilitate consultation with industry and policy development, which involved managers and researchers and the NZ Fishing Industry Board (FIB), a quasi-governmental agency for coordination and promotion of the fishing industry. Regular consultation with the fishing industry became a feature of management practice and through the FIB industry from all fishery areas could meet with managers and researchers and give advice to the Minister on lobster fishery management.

Limited entry did not limit effort: potlifts increased by 65% from 1979 to 1985 (Fig. 2) while the catch rose by only 28% (Fig. 3). Licensees were required to show landings to maintain their licence, even when returns were low and they had no exit mechanism. By this time, much of the catch was exported as frozen tails to overseas markets, especially the United States.

Difficulties with repeatability and enforcement of the tail length MLS led to introduction of a tail width MLS in 1988, based on morphometric work by Breen et al. (1988), but again without yield analysis. Carapace length was considered unsuitable because of the export market for frozen tails. Despite regional differences in morphology, the Ministry introduced a national tail width for each sex, resulting in functionally increased female MLS for the southern regions and a decrease for the northern regions. Catches in CRA 8 suffered badly from the change, underscoring the high exploitation rates at the time. Most of the stocks now have MLS's of 54 mm for males and 60 mm for females tail width, but the MLS is non-standard in three stocks for mostly historical reasons.

In the 1980s, New Zealand was one of the first countries to manage fisheries through ITQs. Lobster fishers initially resisted ITQs for their fishery and in initial consultation (Yandle, 2008). Many preferred transferable pot entitlements or continued limited entry. Eventually, the industry agreed to adopt ITQs.

At this stage, Maori sued the government, claiming that the issue of ITQs had created and given away property rights and contravened the Treaty of Waitangi, signed in 1840, which guaranteed Maori retention of their fisheries. The courts found in favour of the Maori, who received some of the ITQs; in April 1990 nine rock lobster fishery QMAs were allocated ITQs and the Controlled Fisheries were cancelled. Input controls such as MLS were retained.

ITQ was allocated to each qualifying fisher in proportion to their mean reported catch from mid-1982 through mid-1988. An appeals process was available to fishers who could demonstrate landings not in the database. Because of concerns about the state of the

[1] There have been at least four departmental name changes from 1945; we simply refer to the relevant agency of the time as "the Ministry".

stocks, based on early stock analyses, the sum of ITQs within each QMA was reduced by about 29% from the historical 1982–88 average. Further cuts, averaging 23%, were made over the next three years to encourage rebuilding. Government compensation was paid for a substantial part of the reduction in catch history and for TACC reductions to 1993, but subsequent TACC cuts were not compensated for.

In 1996, ITQs were expressed in shares of the TACC, with shares having a catch weight equivalent that changes proportionally as TACC changes. Shares generate an Annual Catch Entitlement (ACE) in kg; both ITQs and ACE are bought and sold on a free market. Selling ACE is similar to leasing out quota for a year. Fishers must have 3 t of ACE before fishing.

The Minister is legally required to set a TAC that maintains the stock at or above B_{MSY}, and any change in TAC involves statutory consultation with all stakeholders. TAC changes have usually involved changes to TACC only. After the first across-the-board reduction for all QMAs in 1990, TACC changes have been specific for each stock.

ITQs led to a marked reduction in vessel numbers after 1990 as the industry rationalised and older fishers sold out or retired, and effort in potlifts was reduced by the reduced competition for catch (Fig. 2). There was a shift from owner-fishers in 1990 to more corporate ownership of quota and an increasing ownership by Maori companies and collectives. Thus Maori are important in the commercial, recreational and customary fisheries.

In 1991, the National Rock Lobster Management Group (NRLMG) was established comprising representatives from industry, customary, recreational and environmental groups and the Ministry, with access to scientists. The NRLMG developed and oversees a rebuilding plan, is the primary source of advice on lobster fisheries to the Minister and acts as a research planning group. Although not perfect, the NRLMG has been a substantial contributor to the success of transparent lobster management.

The government has charged ITQ owners a "cost recovery" levy on quota for fisheries administration, compliance and research since 1994. The government contributes a "public good" component on behalf of non-commercial fisheries, calculated in proportion to the allowances made in TAC setting, with a default of 25% "public good" for lobster fisheries.

Introduction of cost recovery led to more formal industry organisations. In 1996, industry groups within QMAs became formally organised (CRAMACs, standing for Crayfish (a local name for rock lobsters) Management Advisory Committees). A national body, the New Zealand Rock Lobster Industry Council (NZ RLIC), was formed in 1996, with representation from the CRAMACs and supported by an industry levy on quota share owners. NZ RLIC goals include fair and equitable access for all legitimate lobster fishers including recreational fishers, and maximised economic and social benefits from harvesting.

Data collection and research were originally conducted by the Ministry. In 1995 the research components joined the Crown-owned National Institute for Water and Atmosphere (NIWA). In 1997, research services became contestable (any research provider could bid for them) and NZ RLIC was awarded the lobster research contract for one year. NZ RLIC contracted NIWA and industry scientists and has performed research and stock assessments under contract ever since. NZ RLIC currently subcontracts projects to CRAMACs and to a variety of independent and NIWA scientists and field technicians.

6. Commercial fisher behaviour under ITQs

The lobster industry was already well organised when ITQs were introduced because of the FIB's facilitations. The FIB had also stimulated contact between industry and government scientists and hired its own scientists to collaborate on lobster fishery assessment work (e.g. Breen and Stocker, 1993). Custodial attitudes and collective responsibility were well established.

Having a property right in ITQ encouraged lobster fishermen to look at the stream of future incomes from lobsters, creating an interest in maintaining stocks even at the expense of immediate catches. Industry consistently insists that the stocks be maintained well above B_{MSY}, and have supported many pre-emptive and conservative management actions. For instance, in 1993 the CRA 3 stock was at low abundance. Instead of simply accepting a major TACC cut, industry led the development of a plan that involved recreational and customary Maori fishers and included a 50% TACC reduction, a closed season for all users and a longer commercial closed season, protection of females in winter and an MLS change in winter: these were designed to establish a winter fishery and to reduce losses from illegal fishing and lobster predation. The plan was very successful (Breen and Kendrick, 1997), but the stock later declined because the TACC was not reduced as abundance declined.

In another example, the CRA 5 industry declined a suggested TACC increase arising from a favourable stock assessment (Breen et al., 2002), and chose to retain the original TACC whenever a new stock assessment was made. When the stock showed some decline in 2008, the CRA 5 industry voluntarily commissioned development of a management procedure to arrest further decline (Breen, 2009). Similarly, the CRA 1 industry chose to retain their TACC in 2014 despite management procedure evaluations (Webber and Starr, 2015) showing that a higher TACC was possible.

When the CRA 4 stock was in a steep decline in 2006, CRA 4 industry voluntarily shelved 40% of their ACE to try to stem the decline, and in the following year they voluntarily shelved nearly 60% of their ACE (Breen et al., 2009b). At that time, the recreational fishing organisation announced a voluntary reduction in the bag limit in CRA 4. CRA 3 also adopted voluntary shelving when their stock was declining sharply in 2001.

The custodial attitude of industry is also reflected in voluntary initiatives taken independently of the Ministry or the NRLMG. CRA 5 industry obtained Friend of the Sea certification for their fishery in 2011. CRA 8 industry played a major role from 1995 in developing the Fiordland Marine Guardians, an advisory group appointed by the Minister for the Environment that works with the government to protect the Fiordland marine environment and enhance fishing experiences. The Guardians introduced area-specific fishing rules and provisions to protect sensitive areas of the fiords from a range of threats, including damaging fishing methods such as dredging and lobster potting. CRA 5 industry similarly played a major role in developing Te Korowai o Te Tai ō Marokura (Kaikoura Coastal Marine Guardians), and took pre-emptive action to reduce humpback whale entanglement during the migration season. The NZ RLIC has established a "Whale Safe" program involving observation, reporting, forward warning and measures to avoid or mitigate whale entanglements.

Industry began to collect their own data after ITQs were adopted. A voluntary logbook program was established to collect length frequencies, with government and FIB scientists' advice, in CRA 8 in the early 1990s and in CRA 2 soon afterwards. Participants sample a small, but representative, fraction of their catch. This program has expanded to several other stocks, and in CRA 8 and CRA 5 it has replaced the original government observer catch sampling (Table 1). Data from the two sources are comparable (Starr and Vignaux, 1997) and the voluntary logbook data are considered more representative. Industry pioneered development of electronic data capture. Tag-recapture programs, a valuable source of growth information, are dependent on industry reporting of the recapture data.

CRA 5 and CRA 8 industry have developed puerulus collection independently of the government-contracted work. The industry in CRA 8 has commissioned two projects to enhance the quality of lobsters reaching the market: one examined the annual physiological changes during moult stages; the second explored the effects of handling, holding, transport and packing for export. These resulted in best practice guidelines for the whole supply chain from the point of capture to the point of export. The NZ RLIC has commissioned gene-flow work from Victoria University of Wellington to assist in understanding recruitment sources (Thomas and Bell, 2013).

Industry initiatives tried to obtain the best value from the limited catches in the early 1990s, when stocks were depleted but export prices were rising. Live exports, which had been pioneered in New Zealand in the late 1970s, became the norm and now comprise nearly the whole New Zealand export. Live exports also caused fishers to measure lobsters quickly, handle them carefully and return discards to the sea promptly. Previously, lobsters were often left lying on board in the sun or rain before sorting, with likely high discard mortality. Some fishers formed their own processing and export companies, and after 1990 did much market development, initially in Japan and then in China (Elenio, 2014).

The size range of lobsters caught has increased as stocks have rebuilt. There is currently a strong size/price differential, with small lobsters commanding a premium, and a large lobster can be much less valuable than two smaller lobsters with the same combined weight. A fisher can legally return large lobsters and catch smaller lobsters worth much more later. Such legal "high-grading" is a feature of the CRA 8 and CRA 9 fisheries, where up to 40% of the legal catch by weight is returned. Retention-at-size can be predicted from CPUE (Starr et al., 2013) and are used within the stock assessment model.

High-grading affects CPUE. The Ministry attempts to capture the weight of lobsters returned on the mandatory reporting forms, but there are difficulties in estimating the returned weight at sea give low buy-in from fishers. Retention is reported well in the catch sampling, but overall reporting is poor and unlikely to improve in the short term.

7. Stock assessment

The earliest stock assessments, in the late 1970s (Saila et al., 1979), comprised surplus-production modelling of catches and CPUE from the North and South Islands combined, excluding the Chatham Islands (CRA 6 in Fig. 1), using commercial catch and effort data. A yield-per-recruit (YPR) analysis of the Gisborne stock was also conducted by Saila et al. (1979). Surplus production analyses were the primary approach through the 1980s through the mid-1990s (e.g. Annala and Esterman, 1986; Fogarty and Murawski, 1986; Breen and Stocker, 1993; Polacheck et al., 1993). These analyses suggested that fishing pressure on the North and South Islands stock was too high: Polacheck et al. (1993) concluded that the stock was "highly depleted" at 16–17% of unfished abundance. As these assessments matured, they included estimates of recreational and illegal catches and applied the model to smaller stock units than the North and South Islands (Breen and Kendrick, 1994). YPR was also a continuing basis for stock assessment in this period (e.g. Annala and Breen, 1989; Breen and Anderson, 1993), and tended to suggest growth and perhaps egg overfishing. Bio-economic modelling was conducted by the FIB in 1979 (cited in Annala 1983a). Breen et al. (1994) suggested there was little or no economic surplus in 1987. These analyses, primitive by today's standards, were the basis for reductions in TACCs in 1990–93 from the historical mean catches.

In the mid-1990s, length-based modelling began, originally based on the model for rock lobster fisheries off Tasmania (Punt and Kennedy, 1997). Early length-based models used an annual time step and were fitted only to CPUE and length-frequency data (e.g. Starr et al., 1999).

Tagging programs to estimate growth were established in the major QMAs in the mid-1990s, replicating earlier work to measure growth and movements in CRA 3 and CRA 8 (e.g. Annala, 1981; McKoy, 1983).

CPUE, the primary indicator of relative stock abundance, is based on data consistently reported since 1979. There are no fishery-independent abundance data for rock lobster. The standardisation procedure of Maunder and Starr (1995) accounts for shifts in fishing patterns. Starr (2012) found that the CPUE signal is independent of data stratification.

The length-based assessment model was improved in the early 2000s by using a six-month annual time step to accommodate regulation and biological changes within a year (Bentley et al., 2001), allowing the model to estimate seasonal vulnerability. Growth in the assessment model is modelled using a transition matrix based on a continuous growth model, and can address changes in growth rate, such as seen in CRA 3 (Breen et al., 2009a). Tagging data, used to estimate growth, were incorporated into the integrated model. The model was completely rewritten in 2006 (Haist et al., 2009), with better data weighting approaches and options for density-dependent growth and marine reserves; it allowed for simultaneous assessment of adjacent QMAs by estimating movement between QMAs.

NZ RLIC holds the research contract from the Ministry. The work is done by a group of independent scientists who work collegially as equals. This unusual arrangement has led to a continually evolving approach for stock assessment and management. Innovations include development of management procedures (described below), accommodating flexibility in growth, integrating puerulus settlement indices into the stock assessment (with variable success), fitting to the sex ratio data and modelling the discard behaviour of fishers based on logbook data.

All New Zealand fisheries research is done in an open peer-reviewed process under the supervision of government scientists: every step of the stock assessment is reviewed by an expert working group. The government periodically engages international experts to review the stock assessment.

Several important elements remain missing from the lobster stock assessment. Poor reporting of legal discards leads to underestimation of recent CPUE and biomass. The effects of technology and economics on CPUE, and effects of contraction of the fishery because of reduced effort and higher biomass levels, are not understood and may also distort CPUE. Growth rates between settlement as puerulus and recruitment to the fishery are unknown.

New Zealand legislation tends to support B_{MSY} or unfished biomass reference points, but these cause problems for lobster fisheries because of poorly documented early catches and the large number of egg-bearing females below the size limit in the more northern QMAs. B_{MSY} reference points are reported from stock assessments, but have limited utility because of high associated fishing intensity. The NRLMG and stakeholders have agreed to use historical periods to define reference biomass levels that are higher than B_{MSY}. Periods are chosen when the stock was relatively stable, catch rates were acceptable and subsequent biomass declined and then recovered. Regulation changes since the selected historical period are handled by calculating the reference-period biomass using current selectivity estimates and regulations.

8. Management procedures

Because stocks fluctuate naturally, TACCs cannot be set and left in place indefinitely. Although the 1993CRA 3 stakeholder plan combined with good recruitment rebuilt the depleted stock quickly (Breen and Kendrick, 1997), there was no simple mechanism to reduce catches as the stock declined again, beginning in the late

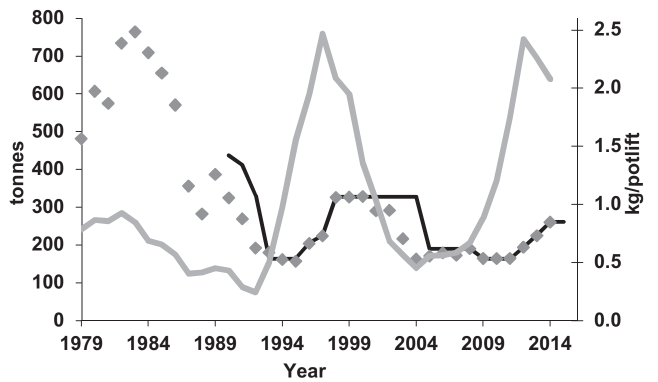

Fig. 4. CRA 3: Commercial catch (grey diamonds), TACC (black line) and standardised CPUE (grey line).

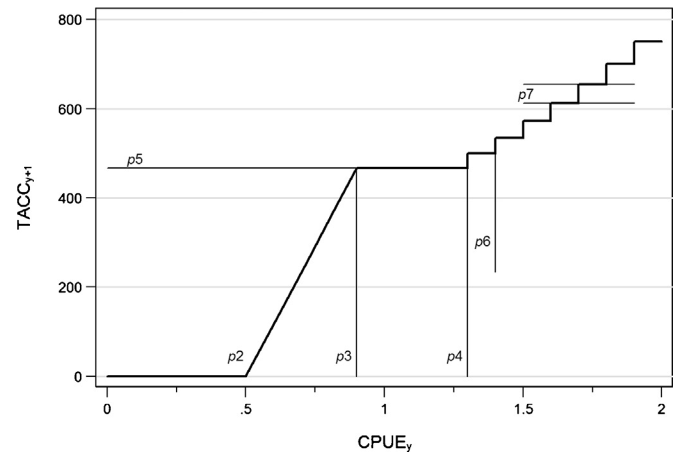

Fig. 5. A generalised plateau harvest control rule; parameters: p2 indicates the *x*-intercept, p3 and p4 the CPUE values at the left and right edges of the plateau, p5 the plateau height, p6 the upper step width and p7 the step height.

1990s. Comparison of TACC changes and CPUE for CRA 3 (Fig. 4) from this period shows that increases and decreases in TACC were out of phase with trends in CPUE. CRA 3 industry decreased the catch voluntarily by shelving quota until the Ministry responded.

Operational management procedures (MPs; Butterworth and Punt, 1999) were first used in New Zealand in 1996 (Starr et al., 1997). They are now a major part of New Zealand rock lobster fishery management (Bentley et al., 2003; Breen et al., in press) and are also used to manage South African rock lobster fisheries (Johnston and Butterworth, 2005; Johnston et al., 2014). Bentley and Stokes (2009) discuss the paradigm shift in management represented by MPs.

New Zealand lobster fishery MPs use standardised CPUE as input and specify a TACC. Additional inputs such as larval settlement indices have been investigated (Bentley et al., 2005), but have not been used. Industry is interested in using a pre-recruit index. The input CPUE is calculated from the October through September year so that the most recent data can be included when CPUE is standardised.

The first MP was used to rebuild the depleted CRA 8 stock and to manage the volatile CRA 7 stock (Starr et al., 1997). Industry requested a mechanism that would decrease ITQs and then increase them again when the depleted stock had rebuilt. In the CRA 4 fishery, industry adopted an MP to reduce their catches voluntarily (Breen et al., 2009b) and a voluntary MP for CRA 5 was designed to maintain high abundance (Breen, 2009). Eight of the nine QMAs are now managed with MPs (Breen et al., in press). CRA 6 has not been assessed and therefore cannot be managed with an MP. For each stock the MP is revisited, in conjunction with a stock assessment, on a roughly five-year cycle (Table 1).

The earliest MP used both CPUE and its recent slope, compared with a rebuilding trajectory, to set the TACC (Starr et al., 1997). Breen et al. (2003) found the long-term behaviour of that MP to be unstable. Later MPs involved a simple line describing TACC as a function of CPUE, curved or straight. Such rules would generate a TACC change every year, so they were buffered by minimum and maximum change thresholds, and sometimes by a "latent year" that prohibited TACC changes in consecutive years.

These early MPs were criticised because they changed the TACC too often and by too much, or because they failed to respond quickly enough to CPUE declines. Industry requested MPs with more stability, and the CRA 8 industry conceived the "plateau rule" (Fig. 5) after their stock had rebuilt. The steep initial slope is designed to decrease TACC quickly at low CPUE to halt any decline, the plateau leaves the TACC alone over a range of CPUE, and an upper slope or steps allow increased catch at high abundance. This MP form sacrifices some potential catch for higher catch stability, but the industry accepts the tradeoff. The evolution has been towards more responsive MPs when CPUE is low or declining and more stable MPs when CPUE is near its desired average level.

MPs are evaluated using an operating model based on a length-based stock assessment model (Haist et al., 2009), with specified variation in recruitment and observation error for CPUE. Non-commercial catches are simulated from empirical data. For stocks with high-grading, the retention curve is projected from CPUE each year. Each of many MPs is tested with one 20-year projection from each sample of the base case joint posterior. Each MP is also tested using the joint posteriors from three to six robustness trials, which are alternative models that explore critical uncertainties.

For each MP, indicators are summarised for resource conservation (how often the stock fell below a reference level), yield (average and minimum commercial and recreational catches), abundance (average and minimum CPUE) and stability (the frequency and size of TACC changes). Sets of alternative MPs show strong tradeoffs between average abundance and average yield, between yield and stability at higher catch levels, between average abundance and safety, etc.

After the MPs failing to meet minimum conservation criteria have been rejected, the remaining candidates will deliver the Minister's statutory obligation to maintain the stock above B_{MSY}. Thus, the choice of MP from these alternatives should lie with stakeholders (industry, customary, recreational and environmental groups), not with the Ministry or scientists. Stakeholders are consulted early in the assessment and MP evaluation process: what are their goals for the fishery, which of yield, stability and abundance do they value most, what tradeoffs do they want to make? The NRLMG chooses a short list of candidate MPs that appear to deliver what the stakeholders have requested.

Choosing among a large set of MPs uses several techniques. "Screening" simply sets arbitrary thresholds (after looking at summaries) for MP performance on selected indicators and rejects MPs with performance outside the thresholds. The "choice frontier" (Bentley et al., 2003) summarizes the joint performance of a set of MPs with respect to two key indicators. For instance, TACC variability may vary considerably for a given level of mean catch (Fig. 6), and the "best" MPs (for these two indicators) lie along the lower edge of the joint distribution. The utility function approach has also been considered (Bentley et al., 2003), but has not been used.

Stock rebuilding brought about by MPs has been strong. Overall, arithmetic CPUE has increased by 60% (Fig. 3) since the first MP was used. In CRA 8, the current CPUE is nearly five times the pre-MP level; in CRA 7 nearly ten times; in CRA 3 and CRA 4 roughly twice over shorter timespans. Current catches are beneath pre-MP levels

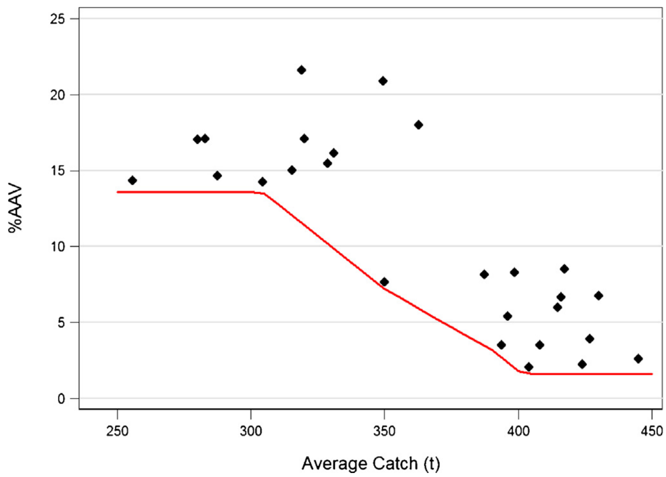

Fig. 6. An example of a trade-off between the management objectives yield (average catch) and stability (average annual variation in TACC). Each point represents the median result from one management procedure; the solid line indicates the choice frontier: the lowest variation for a given level of average catch.

in CRA 7 and just above in CRA 8; they are 50–60% higher in CRA 3 and CRA 4.

As well as in stock rebuilding, success of these MPs is also in making stakeholders think strategically about management goals (Bentley and Stokes, 2009). Notably, a series of Ministers, in whose hands the TACC decisions always lie, have chosen to accept NRLMG recommendations based on MP results throughout their short New Zealand history.

A challenge for designing MPs to rebuild stocks is to estimate and manage the abundance of lobsters of sizes that are retained rather than the total stock of lobsters that are legally available. The latter stock includes many large, currently low-value lobsters, and industry is demanding MPs that manage the abundance of the smaller high-value lobsters so that economic return can be optimised.

9. Discussion

9.1. Successes

Despite stringent limited entry during the Controlled Fishery, 1979–89, stocks were generally not healthy in 1990 when ITQs began. Limited entry does not limit effort: those with licences were free to increase their fishing effort and to invest in technology that increases efficiency of effort. In general, limited entry creates incentives that act against the management goals (Wilen, 1988; Grimm et al., 2012). Although analyses were available in the late 1980s that the New Zealand stock was depleted and a better economic performance could be obtained from a rebuilt stock (e.g. Fogarty and Murawski, 1986), only crude mechanisms were available to reduce effort: removing licences, restricting pot numbers or having long closed seasons.

Managers could control catch directly when ITQs were introduced in 1990, and they reduced catches to initiate rebuilding. Incentives for fishers changed: the race for fish was immediately reduced wherever the stock could support the new TACCs. Economic rationalisation and efficiency were seen in the sharp decrease in vessels immediately after 1990 (Fig. 2).

Yandle (2008) suggested that "ITQs can provide a form of property rights that provide incentives for the ITQ owners to enhance and conserve the resource, as well as participate in fisheries management". This happened in New Zealand: owners have proven to be conservative co-managers of their stocks who take pre-emptive action when abundance declines, who collect fishery data and engage actively in research and management, and who develop initiatives to protect their marine environment.

ITQ management was insufficient to achieve and maintain rebuilt stocks. The history of CRA 3 (Fig. 4) illustrates that stocks fluctuate naturally and that TACCs cannot always be set and then left in place for long periods. Periodic stock assessments allow TACC changes when necessary, but only in the year of the stock assessment, and it may be five years or longer between assessments because of limited scientific resources. MPs provide a mechanism for rapid response to changes in stock abundance and were instrumental in rebuilding CRA 3, CRA 4, CRA 7 and CRA 8, allowing catches to be taken with much less effort (Figs. 2 and 3) and increased economic returns.

The unique stock assessment arrangement for lobsters has also been a success. Collaborative assessments and MP evaluations made by independent scientists have high levels of innovation and internal peer-review, especially when new scientists become involved. The integrated length-based model has been a successful platform for operating models to test MPs (see Punt et al., 2013 for a review of length-based models).

A solid strength of the New Zealand system is in the open Working Group process that peer-reviews work in progress, making useful suggestions for directions of and changes to the work as it unfolds. Although the contractor, NZ RLIC, has an interest in the outcome, the brief to scientists is to do good science; there has been no interference from the industry on this goal.

9.2. Challenges

ITQs are a property right for which owners have paid a high price. The property right is undermined when lobster habitat is lost to no-take marine reserves, despite the claim that spill-over compensates for the loss of access (Costello, 2014), also by mataitai reserves for customary Maori fishing and recreational-only reserves. Government has refused compensation because "there is no sustainability concern" when habitat is protected from harvest by the commercial fishery. However, because there is little spill-over effect from marine reserves (Buxton et al., 2014) and the fishery has to increase effort outside the new reserves, the cumulated amount of habitat protected erodes the commercial property right and reduces incentives.

To date, MPs explicitly and management actions generally have focussed on commercial fishing. The recreational fishery is thought to be increasing, and surveys show that recreational catch is non-trivial (Wynne-Jones et al., 2014; CRAMAC5, unpublished data). The Ministry cannot estimate the illegal catch. These fisheries are not managed; recreational fishing is not even licenced. Recreational stakeholders have contributed to stock rebuilding in CRA 3 and CRA 4, and are an important contributor to the NRLMG, but commercial fishers are beginning to resent TACC reductions to maintain or rebuild stocks when the benefits might be reduced by the unmanaged sectors. The lack of government policy and strategy in this area will need to be addressed.

Attitudes have changed as many owner/fishers have been replaced by non-fishing corporate ITQ owners. Non-owning fishers do not experience the incentives associated with ITQs, while corporate owners may tend to focus on the short-term profitability of their investment. CRAMACs are working to educate new owners and to ensure that stewardship and custodial attitude are retained.

The NRLMG, a strong contributor to the evolution of management by stakeholders, is not without difficulties. Environment and conservation organisations no longer attend. Changing Ministry representatives and changing government policies also pose challenges. Although it has facilitated stakeholder management, there has been no statutory recognition or formal devolution of responsibility to the NRLMG: a Minister could go back to central government control at any time. On various aspects of management, such as compliance, protection of habitat from fishing, and non-commercial management, the NRLMG has not been a successful advisor to government because these issues go far beyond lobster fishery management.

The current market is concentrated in China, with minor markets in other Asian countries. High dependence on a single destination poses obvious risks to the industry and a rapid readjustment would be required if the present single market were suddenly to soften.

Finally, New Zealand lobster fisheries face the same environmental challenges as other near-shore fisheries elsewhere: sea temperature increases (e.g. Nursey-Bray et al., 2012) and other anthropogenic changes such as siltation, nutrient run-off, invasive species, agriculture and forestry chemicals.

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