PRODUCTION COSTS IN DEVELOPING FISHERIES UNDER ITQS: THE NEW ZEALAND KING CLAM FISHERY

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ABSTRACT

Entrepreneurial New Zealand harvesters created a viable diving fishery for King Clams, *Panopea zelandica*, in the 1970's contributing to the development of allocation rights to harvest. Once under the quota management system (QMS), however, allocations for allowable catch do not reflect the harvest potential for this fishery. Expectations for quota value and welfare are reduced by the fishery costs of production combined with the capital needed to develop the fishery. This paper identifies all costs of production in the development of this fishery combined with governance scenarios that address the multiple objectives of quota holders. Choosing the harvest approach to a developing fishery under a quota management scheme has flexibility but it is important to manage the shareholders interests while growing the fishery. The working model will specify the production and cost functions for a hypothetical quota owner/harvester under alternative governance scenarios that contribute to quota owner objectives. The model investigates scenarios to evaluate development approaches to improve quota holdings and promote the fishery over time.

INTRODUCTION

Developing fisheries under New Zealand's individual transferable quota (ITQ) system face a series of challenges to fully utilise the benefits of the fishery while ensuring the stock and habitat are not adversely affected (Fisheries Act, 1996). Owners of New Zealand king clam, *Panopea zelandica*, quota have the choice to pursue the fishery and make it viable or to hold onto quota hoping that others in the fishery or market demand will increase quota value. Some quota owners were endowed, either by catch history through provisional fishing rights, or through the Treaty of Waitangi Deed of Settlement Act (1992) and Maori Fisheries Act (2004). These statutory measures provide 20% of all species quota newly introduced to the New Zealand quota management system and 50% shares in the largest fishing company to Maori interests.

In concert with recent literature on fisheries management systems (Grafton et al, 2005; Beddington et al., 2007), it is the combination of programs that will establish success and sustainability of fisheries. This combination includes secure property rights, information systems, research and a level of internal or stakeholder ownership of management. In addition, fishers require incentives to constructively engage in fisheries management along with strong legal support for predefined harvest strategies. For small, seemingly commercially unimportant species, formal stock assessments may not be feasible. The tools for appropriate management exist, but have not been implemented widely. Management authorities need to develop legally enforceable and tested harvest strategies, coupled with appropriate rights-based incentives.

Self Governance in New Zealand fisheries is not new. Some of the most established fisheries in New Zealand have progressed from fishery industry leadership and cooperation. However, production costs may be stalling fishery development from unequal participation. In addition, the TAC endowed to the fishery by the government may not allow the fishery to develop further (Townsend, 2008). This paper will propose a production function and cost function for a developing fishery for a long-lived and underutilised deepwater king clam fishery. This paper addresses some of the actual costs a developing New Zealand inshore shellfish fishery must sustain in order to prove up the fishery and show viability under the New Zealand quota management system (QMS). Comparisons to existing and developing fisheries are made to determine potential costs to developing and progressing the fishery. To what extent the king clam harvesters should create a self governing body versus trialling the government will be considered as the quota owners are in a position to specify what level of governance they would wish to pursue.

Fishery and Potential Value

The developmental history of the fishery is primarily focused on exploratory fishing beginning in the 1970's. Pioneers of this fishery sought special permits to allow fishing prior to entry to the QMS. The highest annual catch of king clams was 95 mt (metric tons) from Golden Bay in 1989-1990. This level of annual harvest from a single fishery management area created expectations that the fishery has the potential to sustain harvest levels of 100 mt. A moratorium on new species to enter the QMS resulted in a delay and harvesters sought other opportunities. When king clams entered the QMS in 2006, low allowances for total allowable catch (TAC) were given due to the uncertainty of biological parameters and data to support a broader fishery. The quota management area (QMA) that included Golden Bay was allowed 23.1 mt of total allowable commercial catch (TACC).

The nominal catch limits for king clam set by the Ministry of Fisheries for fishstocks newly introduced into the QMS may not reflect stock abundance but may be set based on catch history or lack of information about appropriate catch. Marchal et al., (2009) investigated New Zealand fleet dynamics, and while examining the allocation of fishing effort, found that harvesters primarily rely on their historical catch experience as indicators for annual catch and profit. Expectations that the fishery would develop similar to the king clam fisheries in British Columbia and Washington State (James, 2008; Oresanz et al., 2000) have quota owners poised for increasing quota values and catch. These expectations are tempered by the reality that the species *P. zelandica* is smaller, darker in colour and less valuable than the northern hemisphere species *Panopea abrupta*, recently renamed *P. generosa* (Vadopalas, et al., 2010).

New Zealand fisheries that are traditionally low in value are not necessarily low because of product limitations and markets but because they are developing and fall off the priority list for research due to prohibitive data collection costs coupled with the inability for the industry to be levied to pay for costs. For this reason, Under section 59 of the Fisheries Act 1996, a quota holder is allowed to hold as much as 45% of quota for deepwater clam. In addition, if a commercial fisher is carrying and operating an automatic location communicator on board a New Zealand fishing vessel that is being used for fishing for deepwater clam, the commercial fisher may use or have underwater breathing apparatus when taking deepwater clam (NZ Commercial Fishing Regulations, 2006).

For developing fisheries to prove up the fishery the cost is nearly prohibitive. Quota holders and those endowed with quota when brought into the QMS may choose to wait for quota to increase in value. Those harvesters who wish to develop the fishery face an uphill battle to kick start the fishery. The live fishery, however, is placed well for potential value. Table 1 is a collection of quota and export values as well as export and port prices for a selection of valuable New Zealand shellfish and fish species taken from Ministry of Fisheries, Statistics New Zealand, Seafood Industry Council and FishServe data sources. New Zealand King Clam is positioned with high export, port prices and deemed values but lacks volume to fully establish fishery value. Quota trades in these fisheries are infrequent but values can be substantial. New Zealand King Clam quota is marketed for $NZ 100,000 per metric ton. In comparison, New Zealand lobster quota costs $200,000 per metric ton.

Table 1: Quota, Export and Wholesale Prices for Selected Invertebrate and Fish Species in New Zealand

2008	QUOTA $NZ m	EXPORT $NZ m	VOLUME mt	PRICE $NZ/kg	PORT PRICE $NZ/kg	DV annual[a] $NZ/kg
King Clam	1.2	0.2	5.1	40.0	20.0	20 / 24
Lobster	634.0	179.5	2640	68.0	38.5	100 / 120
Paua	361.0	46.0	660	70.0	33.0	60 / 72
Scampi	118.4	21204.0	751	28.3	18.7	51.3 / 61.6
Scallop	30.5	2.4	120	19.2	14.4	7.0 / 8.4
Oysters	26.0	16.9	1870	9.0	4.0	8.0 / 9.6
Mussel	39.5	203.5	32720	6.2	0.7	0.12 / 0.12
Roughy[b]	319.2	60.8	5860	10.4	3.0	3.4 / 5.0
Snapper[b]	279.9	32.4	3460	9.4	5.0	8 / 9

[a]DV standard annual deemed values for incremental overcatch in 20% intervals ≤120% and ≥120%
[b]DV annual for ≤110% and ≤120% overcatch for valuable fishstocks with non standard differentials

REGULATIONS AND COSTS FOR NEW ZEALAND QUOTA MANAGEMENT SYSTEM FISHSTOCKS

Once a fishstock enters the QMS, quota owners are provided with legal rights for harvest. However, the Ministry of Fisheries remain in control of consultation, research specification, peer review and can audit special contracts (Harte, 2007). These requirements are the cost drivers in New Zealand fisheries.

Cost Recovery

In New Zealand, cost recovery legislation introduced in 1994, requires that all quota holders in a fishery pay the full costs of compliance, science, management and policy. Stokes, et al. (2006) reviewed the cost recovery regime in New Zealand from 1999 – 2004 as it emphasized integration of service delivery to support annual sustainable decision making from stock assessment data. The Ministry of Fisheries hosts open Research Planning Groups and research is thoroughly reviewed in the

Stock Assessment Working Groups. Research project requests must specify the relative shares of the cost to industry and those to the Government. The industry share specifies which fishstocks bear the costs for research and in what proportions. Quota owners are given a chance to consult on the merits and necessity for the research. As Ministry scientists and research providers propose and advocate the majority of research projects, however, the informal and non-transparent process of estimating project costs relies primarily on the value of the fishery. Ministry overhead costs on research projects rose from 4% to 22% from 2002 to 2004 (Stokes et al., 2006). Fishery values did not rise to in proportion and new fisheries in the QMS would not account for that increase. The combination of extended research contracts (exceeding 25% beyond cost estimates) and growing demands for research targeted at environmental effects from fisheries may account for the increase.

Harte (2008) describes the New Zealand fisheries sector and institutional arrangements for fisheries management including the ever evolving cost recovery regime. A 2006 review of the cost-recovery rules and levy setting process ensured that recovered costs reflected changes in technology or the provision of management services, created incentives for innovation, improved incentives for industry environmental performance, allocated non-specific costs by spreading costs across all quota owners and reduced the complexity of the levy order process. Non-specific costs, allocated by application of the "port price index" cause concern with the industry as the port price index may not be the best measure of stock value. As a result of these concerns, a new model is required as the basis for new cost recovery rules and based on the objective of equity, while seeking efficiency gains. The Government's Fisheries 2030 may have an important impact by informing the objectives of cost recovery and clarifying government and industry roles in service delivery (Seafood New Zealand, 2010).

Cost Levies SeaFIC

Quota registry is taken on by the the Seafood Industry Council (SeaFIC) who hires Commercial Fisheries Services, Ltd. (tradename – FishServe); a privately owned subsidiary to administer ITQ transactions, vessel registrations, quota and annual catch entitlement ACE trading and necessary payments (Campbell, 2006). FishServe manages registry systems and fisheries data management services and has been successful at reducing costs (and establishing other profitable related services (Stokes et al., 2006). Although all data is owned by the Government, it is processed by FishServe. An example of the cost savings to industry can be measured by the 2000/01 contract to the Ministry of Fisheries was $NZ 8.65 million, by 2005/06 and including it's services as an Approved Service Delivery Organisation (ASDO), Ministry Contracts combined with ASDO services account for $NZ 4.98 million (Campbell, 2006). In the same time frame that the Ministry of Fisheries increased science and data management staff from 6 to 13, FishServe decreased staff by one third (82.5 to 55).

Cost Recovered Research

The Ministry of Fisheries subcontracts research data services to the National Institute for Water and Atmospheric Science (NIWA). NIWA holds the data that can be extracted by the Ministry of Fisheries for research. In 2007–08, NIWA's Contestable fisheries research contracts from the Ministry of Fisheries was $NZ 15.1 million (NIWA, 2009). There has been a decreasing trend from Ministry of Fisheries revenue sources since 2006-07 when the high was $NZ 17,183 and most recently published at $NZ 14,121 for the 2008-09 fiscal year. Commercial revenue sources for NIWA have shown an increasing trend suggesting that some of the Ministry of Fisheries specified research may now be captured by direct commercial contracts. The funding stream ranges from $NZ 30,782 in 2005 to a high of $NZ 50,000 in 2007-08 and most recently spending $NZ 47,434 on direct commercial contracted research. This information further supports the trend suggested by Stokes, et al., (2006) as commercial fishing industry organizations show continuing increased spending on direct research projects through SeaFIC from $NZ 300,000 to $NZ 900,000 per year in the review timeframe (1999-2004).

Direct research contracts are less influenced by the government driven TACC. Under Ministry of Fisheries directed research, there is an unspoken but well known trigger TACC level whereby a fishery can fund additional research. A low TACC prohibits sufficient research levies to be collected to pay for research. For example, in the southern blue whiting fishery, the government cannot levy for specified research if the TACC goes below a certain amount. In this case, the required research must use a less costly way to identify fishstock biomass with respect to MSY. A constant or consistent TACC will require less research than a variable TACC that is dependent on the fishing rate (set at a portion of the biomass of the fishery). This type of harvest rule demands consistent updating to check for changes in the stock abundance.

The Ministry of Fisheries Guide to Biological Reference Points (Ministry of Fisheries, 2010) suggests that new fisheries can operate using fishery policies to guide total allowable catch (TAC) setting and remain under statutory requirements of the Fisheries Act (1996) toward achieving maximum sustainable yield (MSY). The biological reference points for new fisheries are identified as the maximum constant yield (MCY). For new fisheries MCY is defined as: $MCY = 0.25\, F_{0.1}\, B_0$ where $F_{0.1}$

is the value of instantaneous fishing mortality rate F, where the slope of the curve showing yield per recruit vs F is 10% of the slope at the origin. B_0 represents the initial biomass of the population. Developing fisheries may have insufficient biological and fishery data to conduct a yield per recruit analysis so $F_{0.1}$ can be initially set to the estimate of natural mortality, M. In addition, harvest strategy standards from the Ministry of Fisheries (2007) specify that the target biomass that new fisheries can aim and oscillate about is identified as ½ B_{MSY} or 20% B_0. New and developing fisheries are expected to be managed cautiously and the fishing mortality rate should not exceed $F_{MSY.}$ Where F_{MSY} is not known, an estimate of natural mortality, M can be used as it is likely to be less than F_{MSY}.

Recently introduced and developing fisheries in the QMS result from bycatch in established fisheries or emerging markets for underutilised species. Total allowable catch are set at nominal levels when distribution, abundance and reproductive potential of fisheries resources is unknown. Legislative requirements require sufficient research to ensure the level of fishing will be sustainable. Research is expensive and requires substantial investments from fishery quota owners. Stokes et al., (2006) describes efforts by the industry to reduce costs, provide constructive input to research development and evaluation and industry directed research as significant but limited. The industry approach to research provision is sometimes to beneficial and sometimes captured by other research providers that are part of the Ministry of Fisheries research review process. Industry driven research through direct contract to explore new fisheries is infrequent because of the uncertain benefits from engaging in expensive research programmes. Through special permits, exploratory fishing can investigative research and minimize costs and provide a mechanism to carry out fishing activities not authorised by the 1996 Fisheries Act and develop policy guidance for fishstocks with limited information.

REVIEW OF NEW ZEALAND AND BRITISH COLUMBIA FISHERIES INDUSTRY GOVERNANCE COSTS

Industry drivers for self governance have historically developed in response to the high costs of Ministry of Fisheries services and commitment of the fishing industry to pursue fishery viability. Quota owners formed commercial fishing industry organisations to specify increasingly precise fishing areas and monitoring programmes to control harvest (Clement et al., 2008). These commercial seafood organisations (CSOs) show that collective action is needed to take on key functions of fishery management. In addition to developing sophisticated business plans, CSOs monitor harvest, address fleet dynamics, contract and manage research providers. Quota owners utilise the commodity levy to fund fisheries management and research as well as innovative forms of enhancement, policy, harvest strategy and compliance. Whether these devolved approaches decrease the cost requirements for research or just provide better research accountability is unknown.

New Zealand actively promoted the devolution of responsibility for fishery management services to industry in 1990. The Orange Roughy Management Company (now The Deepwater Group, DWG) developed an offshore deepwater fishery and coordinated quota owner membership to fund these efforts. This cooperation led to management of several sub-quotas within quota management areas (QMAs) to prevent localised depletion (Clement, et al., 2008). The Deepwater Group has also become active in developing research, including deepwater acoustic surveys and design, due to industry dissatisfaction with the results of traditional stock assessment methods. DWG commission substantial research, seek expert professional advice and actively participate in the Ministry of Fisheries research processes, funding these activities through industry-initiated levies or voluntary contributions. Further, the hoki fisheries east-west management split arrangements, benthic protected areas, and catch monitoring programmes have become an integral part of DWG self-governance.

The Rock Lobster Industry Council (NRLIC) has historically managed research services directly contracting research and controlling contract costs and delivery (Sykes, 2006). The NRLIC has maximized the value of that fishery by lowering harvesting costs (fishing abundant lobster populations), collaborating in research projects and increasing quota value since its entry to the QMS in 1990 (Starr, 2010). Decision rules now trigger management responses with successful fishery reductions of 20% and a 25% increase in quota value. Despite Ministry of Fishery assumptions that harvest targets should be maximized, the NRLIC and the National Rock Lobster Management Group support goals based on raising catch per unit effort (CPUE), and target “stability and abundance” in fishery assessment models.

The Challenger Scallop Enhancement Company has made comprehensive efforts to embrace self-management by enhancing scallop recruitment and optimising catches by harvesting in spatial rotation (Mincher, 2008). Challenger shareholding is based on scallop quota ownership. Civil contracts raise proportional levies to maintain and operate capital equipment. Seeded scallops made up 70% to 90% of the scallops harvested by Challenger’s quota owners. Commodity levies provide funding for cooperative benefits and avoid free-rider problems by requiring all producers to pay an agreed levy under a commodity levy order. Challenger quota holders agree to a levy rate sufficient to fund an annual business plan and budget. This traditional government-led co-management approach has resulted from Challenger Scallop Enhancement Company leadership (Harte, 2008). Challenger is also responsible for purchasing and providing services for the monitoring of natural biotoxins. The Southern Scallop fishery biotoxin management plan provides for the collection of water and shellfish samples required for analysis by Challenger and its subcontractors. Challenger directly purchases analysis services from approved laboratories with cost savings from direct programme management and by an improved peak harvest sampling regime. The Bluff Oyster Management Company has incorporated Challenger's rotational fishing policy and shared arrangements with scallop fisheries.

In recent years, the Paua Industry Council fishery has taken a collaborative research approach where industry divers provide both the fishery dependent and fishery independent research necessary for stock assessments. In addition, the paua fishery has initiated and carried out reseeding projects as enhancement to their fisheries (Cooper et al., 2006), created the Paua Industry Council's fine scale management areas, enhancement and diver monitoring programmes. In a newly developing fishery, Aotearoa Fisheries Limited's Crabco has used special permits and direct research programmes to demonstrate the viability of the deepwater crab fishery. CrabCo Limited is a joint venture company between Aotearoa Fisheries Limited, New Zealand Longline Limited, Live Fish New Zealand and Te Ohu Kai Moana Trustee Limited. CrabCo was established to develop the deepwater crab fisheries – *Chaceon sp.*, king crabs and spider crabs, around New Zealand and initiated research for future exploitation of deepwater crab species introduced into the QMS in 2006 (Soboil and Craig, 2008). Though special permits, investigations concentrate on developing satisfactory harvesting arrangements (Te Ohu, 2009). NZ Geoduc Ltd is exploring the potential of this recently introduced inshore clam species. Harvest must be supported by extensive and expensive ongoing sanitation testing. Valuable feedback has been received from markets on the care needed in harvesting, handling, transport, and acceptable size ranges and colour.

The British Columbia Underwater Harvesters Association (UHA) and Department of Fisheries and Oceans Canada (DFO) co-manage the North Pacific geoduc fishery (James, 2008). The UHA and DFO signed a five year 2008-2012 Joint Project Agreement (JPA) requiring an annual work plan of commercial geoduck fishery science, management and enforcement programs (DFO 2009). In 2008, the total Department costs of managing the geoduck fishery was estimated to be $659,048, with a portion contributed directly by the UHA to cover a portion of Fisheries Management salaries. Other UHA funded projects include surveys for stock assessment , monitors and a coastwide dockside monitoring program. The total cost to the UHA of these programs in 2008 was estimated at $1,114,025. The UHA also funds and conducts enhancement activities (seeding juvenile geoducks). In addition, the UHA contributes to a coast-wide Paralytic shellfish poison, PSP/biotoxin sampling program. The value of this program was approximately $265,000 in 2008 (DFO, 2009). Table 2 first column provides a representative example of costs to manage select New Zealand and British Columbia fisheries (source data: Ministry of Fisheries, SeaFIC, R. Tilney and M. Soboil personal communication). Government and industry levies as well as industry internal governance costs are provided for deepwater finfish and crab.

Table 2. King Clam Expected Management and Research Costs Using New Zealand and British Columbia Examples

King Clam Expected Management Costs	Expected Costs $NZ	King Clam Expected Research Requirements	Expected Costs $NZ
Government Levy[a]	30.3/mo/mt		
SeaFIC Commodity Levy[b]	10.5/mo	Validation of Biological Parameters	38K
NZ Roughy/Oreo Sub Area Catch Monitoring	30K/yr	Distribution and Abundance Estimates	125K
NZ Hoki E-W Catch Split Monitoring	40K/yr	Estimation of growth and age	62K
NZ Crew Monitoring/Compliance VMPs	45K/yr	Stock Characterisation	65K
NZ Crew Fish Sampling	28K/yr	Fishery Monitoring	25K
NZ Paua Enhancement Levy	1K/mt/yr	Stock Assessment	125K
British Columbia Geoduc Fishery	54K/yr	Benthic effects of fishing/Habitat Surveys	33K
DW Crab – 3 Year Research Programme	100-200K/yr		
Monitoring	35K/yr		
Observers	40K/yr		
Harvest	3.5K/day		
Processing	5.5/kg		
Marketing	3% revenue		

[a]TACC for PZL7 is 23.1 mt. All other QMAs for PZL: TACC less than 1.2 mt
[b]SeaFIC Commodity Levy is 0.525% of port price at $NZ20

BIOLOGICAL RESEARCH COSTS FOR INSHORE SPATIALLY DISTRIBUTED DEVELOPING FISHERIES

Determining the appropriate level of research commitment for a fishery can be challenging. Basic life history information essential for stock assessment in developing fisheries such as aging, maturity and fecundity are lacking in newly exploited species. In New Zealand, however, Ministry of Fisheries biological reference point requirements (as described above) identify the level of biological scientific research sufficient to inform fishery management on suitable TAC levels. Table 2 second column provides a recent sample of the expected research drivers and research costs a developing fishery would be required to undertake to provide scientific evidence for fishery harvest.

Fisheries management decisions are primarily made on quantitative stock assessments. Stock assessments rely on estimates of stock abundance or biomass. Sufficient research to estimate fishstock biomass and the ability to cost recover research from quota holders is a continuing point of contention in New Zealand fisheries. Bentley and Stokes (2009) addressed the prohibitive cost of data collection on some smaller value fisheries and included these costs into a utility function expressly using cost efficiency cost as a performance measure. Further, Stokes et al., (2006) specify two essential recommendations for the cost recovery regime for fisheries research services. The first is that public good marine research utilise public funds rather than relying on solely on industry. The second is that Ministry of Fisheries research planning processes be improved to link fisheries management and research, and that required research should not depend on research provider influence.

For research purposes, characterising groupings of commercially fished species based on known life history traits can fill in information gaps that developing fisheries with little data requirements (King and McFarlane, 2003). Fishery groupings by life history characteristics can show susceptibility and vulnerability to changes in abundance and environment as a result of decadal scale climactic changes and harvest. Applications to developing fisheries can allow for experimental management tools that provide information on exploitation rates on population attributes and abundance trends. This type of information can direct research programmes in the pursuit of building a developing fishery. In addition, data poor fisheries can benefit science with harvester involvement and support (Starr, 2010).

Inshore Shellfish

Most research on fished species in New Zealand focuses on measuring aspects of population dynamics to mange toward MSY. This approach assumes that the carrying capacity of the ecosystem is relatively constant, so that if fishing is reduced then the stock should increase toward a pre-fishing state (Morrisson et al., 2009). In New Zealand, fishing has not been the only stressor on fished populations, and fishery closures will not necessarily lead to a recovered population. Additional stressors including sedimentation, eutrophication, pollution and dredging effects have been operating on marine systems through sheep, cattle, dairy, forestry, viticulture, cropping and coastal development. As king clams are inshore species distributed at 10-30 meter depth contour lines, they are susceptible to land use effects and water quality.

The New Zealand Food and Safety Authority (NZFSA) oversees shellfish quality standards for domestic and export use. NZFSA Shellfish relies on the expertise of the Marlborough Shellfish Quality Programme Inc (MSQP) who has responsibility to monitor and maintain water quality standards for shellfish production in the Marlborough Sounds and Golden Bay. It assures that all shellfish produced from the Marlborough Sounds and Golden Bay comply with the National Water Quality and Marine Biotoxin programmes as well as stringent United States Food and Drug Administration (USFDA) Standards. Companies that primarily process bivalve molluscan shellfish (BMS) in New Zealand are charged a monthly levy based on total tonnage of shellfish captured. The export levy rate is charged on all BMS processed at plants or on vessels that process for export regardless of whether it is destined for the domestic or export market. Primary processors of bivalve mollusc shellfish pay $NZ 3.88 per tonne BMS shellfish processed (domestic) $NZ5.65 per tonne (export).

Spatial Distribution

Estimates of biomass by area are necessary for spatially distributed invertebrate fisheries. King clam distribution in a bay is generally patchy and dependent on suitable substrate (Breen, 1994; Bradbury et al., 2000). Spatial estimates of king clam abundance are dependent on density, patch size, and overall weight of individuals within a patch. In addition, observations of king clams depend on a show factor, S, when siphons are exposed above the substrate and can be seen by specialised king clam divers. Density of discrete fishing areas or tracts can be determined on an annual basis in pre-fishing surveys to determine the status of fishing areas. Fishing areas can be specifically defined as those in New Zealand paua (Breen et al., 2000) and orange roughy fisheries (Clement et al., 2008). Pre-harvest surveys on individual fishing areas intend to survey sufficient numbers of transects and individual clams to allow for an unbiased estimate of biomass. A series of transects along systematically placed gridlines in spatially organised distances at an average contour depth consistent with clam distribution provide sufficient samples. Systematic grid sampling is cost effective and may provide quality and cost effective information.

Opportunities for harvester involvement in research for the king clam fishery rely on the spatial component of king clam distribution and divers trained to spot the location of king clams. Specialised divers, trained using surface supplied air can learn to observe king clam siphons. Costs to train surface supplied underwater divers for this fishery range from $NZ6000-$11,000. King clam divers generally work as contract divers and are paid for every clam they harvest (D. Cunliffe, personal communication). Costs for specific dive surveys are expensive and the paua fishery has developed commercial diver sampling for cost effectiveness. Given commercial sampling, costs for dive surveys in the paua fishery have declined from 100,000 to 45,000. A reasonable expectation for king clam dive surveys for the Golden Bay and Marlborough Sounds king clams tracts would be $45,000.

Following the work of Bradbury et al. (2000) mean density in a given king clam tract can be described as:

$$D=\sum_{n=i}^{n} d_i / n_D \tag{1}$$

where the estimate of density (clams per m^2) for an individual transect is calculated by adjusting the observed density by a show factor: $d_i = d_{obs}/S$ where d_i = density of clams (clams per m^2) on the ith transect, d_{obs} = density of clams (clams per m^2) observed by 2 divers in a survey on the ith transect and divided by the length in m^2 of the transect, S = show factor is the ratio of visible siphons from a single observation and the true abundance of harvestable clams. A show factor of 0.75 is used to estimate density and is considered a conservative estimate of harvestable biomass with variance given as:

$$\delta_D^2=\sum (d_i - D)^2 / n_D - 1 \quad . \tag{2}$$

Mean Weight per king clam is described as W = Σ wi / nW where W = estimated mean weight per clam, wi = weight of the ith clam from dig samples, nW = n samples for weight with variance of mean weight given as:

$$\delta_W^2=\sum (w_i - W)^2 / n_W - 1 \quad . \tag{3}$$

Total biomass in a fishery area can be described from king clam density and weight:

$$B_{Area}=D \cdot W \cdot A \quad \text{where} \quad A = \text{total surface area of the clam tract (m}^2\text{).} \tag{4}$$

Statistical precision of the biomass estimate utilises 95% upper and lower confidence limits (i.e, α=0.05, two-tailed) and a required precision for total biomass estimates of ±30%. A variance of products formula is used to calculate an unbiased estimate. If clam density and weight are independently subject to sampling error (with no correlation between density and weight) then biomass variance is given as:

$$\delta_B^2=D^2(\delta_W^2/n_W)+W^2(\delta_D^2/n_D)-(\delta_D^2\delta_W^2/n_D n_w) \quad . \tag{5}$$

BIOECONOMIC MODEL

To investigate the opportunities for harvesting king clams, a dynamic programming bioeconomic is constructed as a working model utilising the expected costs for a king clam quota owner and harvester. Modelling a fishery with little catch and effort information requires specification of known biological parameters and a range of harvest regimes. The model is designed after Breen (1994) and incorporates key operational characteristics in New Zealand harvest strategies production and costs. The model is intended to be used for comparative purposes to simulate the alternative governance arrangements and harvest strategy scenarios for fishery development.

Age structured population dynamics can be used to to track the number of king clams in a cohort vulnerable to fishing. Because the king clam fishery may be seasonal and instantaneous rates of fishing mortality are estimated as low, this fishery can be modelled as a Type 1 fishery (Ricker, 1975) where fishing occurs at the beginning of the season and natural mortality is subsequent. This is true of the fishery in New Zealand as the fishing year begins 1 October and the high market demand at Christmas generates fishing effort commensurate with meeting that demand.

Age and Natural Mortality Estimates

The relationship between virgin biomass and sustainability depends primarily on the natural mortality rate for *P. zelandica*. The instantaneous rate of natural mortality, M = 0.02 - 0.12 is based on longevity studies of *P. zelandica* in Golden and Kennedy Bays (Breen, 1994, Gribben and Creese, 2005) as as well as North Island populations, where M= 0.02-0.07. Maximum ages for king clams in New Zealand range from 38 to 85 years (Gribben and Creese, 2005). *P. zelandica* are protandric, maturing into males at age 3 and developing into females as they age. For long lived species such as king clams, biological parameters are crucial in determining the appropriate harvest rates.

Growth

King clam growth in length is rapid for the first 13-15 years and minimal thereafter. Average von Bertalanffy growth curves have been constructed using shell length at age data form *P. zelandica* (Gribben and Creese, 2005) but growth in weight shows a more continuous increase (Breen, 1994) as shell and meat weight continue to increase with age. In New Zealand, quotas are based on whole weight the model used the following equation (Haddon, 2001):

$$W_k = W_{inf} \cdot (1 - \exp(-K(k - t_0)))$$ where W is mean whole weight at age k. (6)

Recruitment

Recruitment in *P. zelandica* can be modelled using the Beverton - Holt stock recruitment relationship relying on the spawning biomass as:

$$R_t = B_t / (\alpha + (\beta \cdot B_t)) \tag{7}$$

where R_t is the expected recruitment to the population (at age 1), B_t is the population biomass (recruited to the fishery) in year t and α and β are parameters as well as a steepness parameter *s,* as the percentage of the virgin level of recruitment when the population is at 20% initial biomass, B_0, and can vary from 0.2 (proportional) to 1.0 (constant).

$$\alpha = (B_0 / N_{0,0}) \cdot (1 - ((s - 0.2)/(0.8 \cdot s))) \quad \text{and} \quad \beta = (s - 0.2)/(0.8 \cdot s \cdot N_{0,0}) \tag{8-9}$$

where $N_{0,0}$ and B_0 are numbers and biomass of the initial population respectively.

Recruitment is not likely to remain high when biomass approaches zero, but bivalve molluscs can experience high recruitment from low levels of spawning biomass. Some clams live at deeper depths than the fishery, in unsuitable fishing substrate or at densities too low to be fished and act as a breeding refuge to the fished population. Past recruitment for the kth cohort is estimated from:

$$N_{1,t-k} = N_{k,t} \cdot \exp(M \cdot k)$$ where k is age (from ring counts) and t is the sample year. (10)

Initialisation for modelling purposes places recruitment, R_1, at 1 million when t=1. Subsequent recruitment follows as:

$$N_{k,1} = R_1 \cdot \exp(-M(k-1)) \tag{11}$$

Fishery Production

New Zealand choices for king clam harvest strategies can be best referenced from established king clam (geoduck) fisheries. The harvest strategy in Washington State was once a constant catch strategy at 2% initial biomass (Bradbury, et al., 2000) but has changed to 2.7% current biomass, B_t. Alaska has chosen a 2% constant catch rate and the harvest strategy in British Columbia is also primarily constant catch at 1% B_0 so that in 50 years the fishery is expected to take 50% of the initial stock biomass (Orensanz, et al, 2000; Bradbury et al., 2000; James, 2008). In the model, harvest yield is a function of the chosen harvest strategy:

$$HY = f(HS) \tag{12}$$

The harvest strategy outlines the fishery dependent and independent actions that contribute to setting the TAC and ultimately the harvest yield. Initial biomass is calculated and used to generate target catch (Y_T) from the specified total allowable catch (TAC). In the model, the target harvest strategy HS is a fixed percentage of initial biomass taken annually and the fishery takes place in year 1. If fishing takes place each year, then the harvest yield HY is that proportion of initial biomass. In subsequent years, however, a natural variability factor θ, is included based on the natural mortality rate of the stock. Stocks with lower natural mortality such as king clams, have multiple age classes and are expected to withstand changing environmental conditions and the natural variability factor would have less effect. When θ, is large or close to 1, the rate of exploitation becomes relatively large. For king clams, the fishery is unlikely to remove a large fraction of the remaining population as: not all clams are visible (showing) at any one time, fishing disturbance causes retraction of siphons, and clams are found in areas deeper than the fishery and in less suitable substrate that is uneconomic to harvest. A realistic maximum exploitation rate is 0.35 where 35% of the clam stock in an area can be harvested in a year.

$$HY_t = (HS_t/100) \cdot B_0 \cdot \theta \tag{13}$$

The rate of exploitation each year is calculated as:

$$U_t = HY_t / B_t \tag{14}$$

To model harvest yield over time the sum of harvests at age are multiplied by the clam weight at age:

$$HY_t = \sum_k (N_{t,k} \cdot W_k) \cdot U_t \tag{15}$$

Clams age in the model population each year according to:

$$N_{k+1,t+1} = N_{k,t} \cdot \exp(-M) \quad \text{where k indexes cohort and t indexes year.} \tag{16}$$

As the clam stock is reduced into subsequent years, the model advances clam biomass at age:

$$N_{k+1,t+1} = N_{k,t} \cdot (1 - U_t) \cdot \exp(-M) \tag{17}$$

where recruitment to the commercial fishery begins at age 4 and is substantial by age 8. It is necessary to address incidental mortality on juvenile clams. Small clams that would be unmarketable (age 2 through age 5) are given an incidental mortality at half the exploitation rate on recruited clams. Juvenile mortality can be modelled:

$$N_{k+1,t+1} = N_{k,t} \cdot (1 - 0.5\,U_t) \cdot \exp(-M) \, 1 < k < 6 \tag{18}$$

The principal objective of many fisheries is to maximize net present benefits to the fishery over time. Net present value can be calculated as the discounted sum of annual net benefits. Annual net benefits are the result of revenues from fishing under particular harvest strategies minus the variable and fixed costs to secure fishing rights, support scientific sampling and research as well as management, enforcement and policy.

$$NPV = \sum_{t-1}^{T} (1/1+\delta)^t \cdot HY_t \cdot [P_t - VC_t(HS_t)] - FC_t \tag{19}$$

where δ is the discount rate used by the Statistics New Zealand Fish Monetary Stock Account (2010) at 9%. Statistics New Zealand uses this rate because it is consistent with the return on similar assets in the New Zealand economy. Tests on the validity of this rate using Quota and ACE trade values from 2002-2009 support the use of an 8-9% discount rate. Export price is exogenous to the model as New Zealand king clam is less than 2% of global production.

Cost Component

Quota owners are responsible for contributing to services through quota levies. Annual quota levies from the Ministry of Fisheries contribute to research, compliance, policy and fishery management. The cost component is equal to 5% of the annual TACC or 4% of the value of the fishery. Quota levies from the Seafood Industry Council (SeaFIC) are called commodity levies and generally run at 0.525% of the port price. Stock specific levies for research or projects are distributed among the specific quota owners and will not exceed 5% in any single year. In addition, the industry management frameworks in each fishery may also impose quota levies to pay for specific research projects, scientific sampling regimes, and enhancement activities. The additional costs a quota owner is required to pay is a function of the amount of quota owned and TACC as well as specific directly purchased king clam research projects (DR).

Fixed costs to quota owners include operational fixed costs and are proportional to the amount of TACC in a fishery:

$$FC_t(Q_t, TACC_t) = \alpha + 0.05(Q_t) + 0.5(TACC_t) + DR_t \tag{20}$$

The additional costs king clam quota owners are required pay to purchase research and diver surveys to prove up a fishery are incorporated by specifying the level of research each year until a fishery management decision will increase the TACC. Variable Costs to quota owners are a function of the harvest strategy as well as operational requirements. Variable costs in the king clam fishery are a result of vessel, dive gear, contract divers, and overhead (Cunliffe, D. personal communication). Although variable costs are specified as free of the TACC, variable costs must consider the harvesting result of increased annual catch. In these scenarios, additional vessels, and divers must be contracted to cover increased catch entitlements.

$$VC_t(HS_t) = U_t(HS_t) + Fuel, Contract\ Diver, Handling, Export \tag{21}$$

PRELIMINARY FINDINGS AND DISCUSSION

New Zealand king clam quota owners have important choices in the progression of this developing fishery. Even if the fishery shows promise on a global scale, the expected costs to prove up the fishery may or may not prove worth the effort. Preliminary findings for the king clam fishery model indicate that additional allowable catch in PZL 7 (from 23.1 mt to 50 mt) would enhance development of the fishery without triggering additional capital costs in the fishery. However, research and monitoring costs would increase from Ministry of Fisheries levies. The additional level of research levies given a doubling of the TACC would require tri-annual diver surveys of clam tracts, port sampling and investigations into additional clam beds in PZL 7. The model run with a TACC greater than 50 mt showed greater effort for the fishery in the form of vessels, divers, transport and storage. In addition, chill houses or live holding facilities would need to be considered to address peak demand seasons. Oresanz, et al., 2000 Stress the importance of recruitment information in management decisions citing lack of recruitment events as contributors to fishery decline in king clams in the northeastern Pacific. Therefore, additional research addressing recruitment in deepwater king clams would be required as well as research on benthic effects of fishing. In addition, Booth and Cox (2003) describe marine fishery enhancements in NZ and identify deepwater king clams along with other estuarine shellfish options for seeding of hatchery reared spat.

Production costs under ITQs in an underutilised fishery reveal constraints that may hinder fishery development. The dynamic bioeconomic model demonstrates that issues addressing costs of production can reveal options for governance and opportunities for research delivery in a developing fishery. At present, there are only 16 quota owners for king clam who must share the costs of specific research to prove up this fishery. The success of the British Columbia geoduck fishery has been attributed to the small spatial scale of management, the co-management arrangements with the fishers and limited entry schemes into the fishery as well as small numbers of participants (Kahn, 2006; James 2008). Understanding recruitment, harvest rates and predation continue to challenge the fishery. Redefining co-management arrangements will lead to allocation and equity issues while securing markets outside Asia. However, low nominal harvest rates (1-3%) commensurate with estimated natural mortality is crucial to fishery sustainability. King clam quota owners can adapt portions of the British Columbia fishery to pursue increased participation and control in fishery decisions.

This paper identifies opportunities and constraints for governance, research participation and operational management of the New Zealand king clam fishery. The institutional framework and scientific excellence in New Zealand should provide valuable guidelines for king clam fishery vision. Further research addressing fishery management costs on fisheries production is warranted, however. In Bentley and Stokes (2009) the utility function included costs while identifying a representative level of quota owner objectives and performance measures common in management procedure evaluation and consistent with New Zealand nearshore fisheries. Management objectives included: yield, abundance, stability, efficiency (costs of management) and sustainability. The cost of management was used as a performance measure (the cost of data collection) with a function for efficiency in costs for fishery management. Grafton, et al., (2005) favor approaches that empower fishers with incentives and mandates for marine stewardship; thus promoting sustainability. By forcing harvesters to pay the full costs of fisheries adjustments and providing fishers with decision-making responsibilities, incentives can align with sustainability goals and developing fisheries can become viable.

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