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Ka Hao Te Rangatahi: New Directions for the New Zealand Scampi Fishery?

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Abstract

This paper addresses the conference themes by describing a Maori commercial fishing enterprise pursuing innovation that will deliver commercial added value while caring for the environment. In 2013 Cawthron Institute and industry partners Waikawa Fishing Company were granted six years' Ministry for Business Innovation and Employment (MBIE) funding to investigate two options for new directions for New Zealand's scampi (*Metanephrops challengeri*) fishery beyond the practices of the current deep water trawl fishery. In this paper we detail the economic rationale for this research, and report progress in the development of innovations for scampi aquaculture and pot fishing industries.

Keywords: innovation, aquaculture, technology change, value added.

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Introduction

Maori, the indigenous people of New Zealand, have always fished, and fishing traditions have been passed down through generations. Such traditions are part of a wider body of indigenous knowledge, known in New Zealand as mātauranga Maori. The Maori owned Waikawa Fishing Company Ltd. recognise that existing approaches to the scampi (*Metanephrops challengeri*) fishery may be developed to improve resource utilisation. They see a timely need for innovative ways for harvest in the fishery, and one approach is to solidify links between what are often considered two distinct bodies of knowledge: mātauranga Maori and applied fisheries ecology, to achieve goals of improved economic and ecological outcomes from the available resource.

In this paper we discuss a program of research to develop two approaches that to date have not found expression in the exploitation of the species in New Zealand waters. The first lies in new potting technologies that align 21st century tools such as acoustic telemetry and chemo-attractants with concepts whose origins lie in matauranga Maori to provide an alternative to conventional trawling methods. In the second, wild caught female scampi carrying fertilised eggs will be harvested as broodstock for a new land-based scampi aquaculture industry. Little research has taken place in this space previously.

The paper is organised as follows. The first section provides a description of the species *Metanephrops challengeri* and the New Zealand scampi fishery. A discussion of the economic rationale for various approaches to innovation follows which sets the scene for this instance of "active" and "disruptive" innovation. Subsequent sections focus on the challenges, rewards and potential avenues for resolution in the two development areas – fishery refocussing and aquaculture. We present research outcomes to date which lead to a brief discussion of the nature of the innovation and concluding remarks.

The New Zealand Scampi (*Metanephrops challengeri*): species and fishery

The species

Scampi is the common name used to describe two genera of clawed lobsters (Crustacea: Decapoda: Nephropidae), *Nephrops* and *Metanephrops*. The sole representative of the Nephrops genus, *Nephrops norvegicus,* lives in the North-Eastern Atlantic Ocean and parts of the Mediterranean Sea, whereas *Metanephrops* is represented by 18 extant species ranging from Japan to the Sub-Antarctic islands of New Zealand. *Nephrops* and *Metanephrops* are both marine, crawling, elongate crustaceans with a cephalothorax, 6-segmented abdomen and 10 walking legs. The genera are separated by a number of small morphological differences, rather than one sweeping feature (Tshudy, 2013). Prior to 1972, *Metanephrops* species were considered to be part of the *Nephrops* genus. However the discovery of a fossil on a New Zealand beach prompted a sweeping taxonomic change and the creation of the *Metanephrops* genus (Jenkins, 1972). Subsequent DNA analysis has further separated the two genera, suggesting that Nephrops is more closely related to *Homarus* lobsters than *Metanephrops* (Tshudy et al., 2009).

New Zealand scampi (*Metanephrops challengeri*) is the sole representative of the *Metanephrops* genus in New Zealand. It inhabits the continental shelf from the Bay of Plenty to the Sub-Antarctic Islands and live between 140-600 m deep (MPI, 2013). Scampi are heterogeneously distributed on the ocean floor due to variations in sediment characteristics, as they prefer muddy or silt covered sediments in which they can burrow. These burrows are U-shaped and have been used to estimate the abundances of scampi: 0.03-0.13 per sq. m. (Cryer et al 2001). Commercial fisheries reported catch rates show that scampi typically emerge from their burrows during daylight hours and that the sex ratio of animals caught changes due to patterns of moulting (Bell et al., 2013).

Studies of the stomach contents of New Zealand scampi have identified crustaceans, fish, molluscs, annelid worms and foraminifera (Bell et al., 2013). Other studies of *Metanephrops* species have identified similar diet items, suggesting that they are an opportunistic scavenger or predator, attacking mobile fauna and tearing off appendages (Wassenberg & Hill, 1989). Scampi moult several times per year in early life and about once a year after sexual maturity, which is reached at about 30 mm orbital carapace length (OCL) in females, although this varies between areas (Cryer et al., 2005). This is consistent with *N. norvegicus* which achieves sexual maturity between 23-36 mm OCL with shallower animals maturing before deeper animals (Bell, et al., 2013). No estimates have been made for the life span of *M. challengeri*, but growth rates are consistent with *N. norvegicus*, taking 3-4 years to grow to 30 mm OCL, it is reasonable to estimate that they have a similar life span of 15-20 years (Cryer, et al., 2005).

The New Zealand scampi fishery

Commercially important scampi species in their home regions include *Nephrops norvegicus*, *Metanephrops armatus* (Taiwan), *M. andamanicus, M. australienes, M. velutinus* (N.W. Australia) *M. formosanus* (Taiwan), *M. japonicas* (Japan), *M. mozambicus* (S.E. Africa), *M. thomsoni* (Korea, Taiwan) and *M. challengeri* (New Zealand) (Holthuis 1991). *Nephrops norvegicus* supports the highest value commercial crustacean fishery in Europe, with fisheries in Ireland, the United Kingdom, Portugal, Italy, Spain, Greece, Sweden, and Norway with a combined worth of US$270 Million (Bell, et al.,, 2013). In 2010 66,500 tonnes of *N. norvegicus* were landed, the majority caught in the UK (58.1%) (Ungfors et al., 2013). *N. norvegicus* is primarily caught in mixed fisheries by bottom trawled single or double rigged otter nets, although creel (trap) fisheries operate in Scotland, Sweden and Portugal. These fisheries operate over depths from 20 m in the lochs of northern Scotland, to over 500 m on the shelf ridge of the Hebrides Islands (Ungfors, et al., 2013).

The New Zealand scampi trawl fishery developed in the 1980’s and the first recorded landings were in 1986-87. Initially most landings came from two areas off of the North Island, however as new fishing grounds in the Chatham Rise were developed landings doubled from 450 t in 1990-91 to 900 t in 1991-92 (Bell et al., 2013). Landings were maintained at this level, until recently when they declined, for example in the 2008 – 09 period when 600 t of scampi where caught worth an NZD$11 million in exports (Anderson 2012). Access to the scampi fishery is managed by the New Zealand Ministry of Primary Industries under the New Zealand Quota Management System (QMS). The QMS is an output controlled fishery management system featuring individual transferable quota (ITQ).

The fishery is managed under the National Deepwater Plan where annual catch limits are established to maintain estimated stock biomass at or above the New Zealand default 40% unfished biomass reference level (MPI, 2013). The fishing fleet consists of vessels that are 20-40 m in length that fish double or triple-rigged bottom trawl otter nets. The major fishing grounds are the Chatham Rise, Bay of Plenty, Hawkes Bay, Wairarapa Coast and Sub-Antarctic Islands (MPI 2013).

The existing bottom trawl method for catching New Zealand scampi has issues for both sustainability and efficiency. Environmental damage is caused by benthic disturbance and the by-catch. The efficiency of the fishery is reduced by damaging scampi with the fishing gear, low catches per unit effort (CPUE) and high fuel costs involved with bottom trawling in relatively deep water. By-catch is a significant feature of the scampi fishery. Scampi account for only 17% of the estimated catch in observed scampi targeted trawls since 1990-91. This is the highest rate of by-catch for any New Zealand commercial fishery (Anderson, 2012). In New Zealand trawl fisheries by-catch of seabirds and marine mammals is a significant issue. Seabird captures on scampi boats have been recorded for a number of years (Abraham & Thompson, 2011), while by-catch of New Zealand fur seals and Hookers Sea Lions are considered a rare occurrence (Baird, 2005; Thompson, Oliver, & Abraham, 2010). The impact of trawling gear on benthic environments has been widely recognised (Thrush & Dayton, 2002). In a New Zealand context, otter trawls, including those from scampi fisheries, are known to have significant impacts on the benthic environment in the Bay of Plenty, by modifying the benthic community structure (Cryer, Hartill, & O'Shea, 2002).

Waikawa Fishing Company

Central to this research programme is mātauranga Maori held by personnel of the Waikawa Fishing Company (WFC), a partner in the research. Precursor studies on potting for other fish species showed that WFC-held mātauranga Maori on pot design, deployment, habitat-scale placement, and on-vessel logistics are central to optimising catch value (Ogilvie et al., 2010, 2012). The application of this mātauranga Maori will be an important consideration in innovating the scampi fishery.

WFC was incorporated on the 4th October 1983. The company is a whanau (extended family) based fishing company operating out of the Port of Picton, New Zealand. WFC are not quota-owning stakeholders in the New Zealand Quota Management System. Their access to the various fisheries they operate in comes from leasing quota. From its inception, the WFC vision has primarily been focused on the well-being of the whanau and the sustainability of the environment. Over time, WFC has employed several generations of the wider Connor whanau: parents, siblings, children, nephews and nieces. This has been in line with the vision and has cemented the whanau relationships.

The pro-active approach the company has taken to the development of new catching methods to mitigate the effects from fishing on the environment have proven that their sustainability goals are attainable, and technological development through R&D is an effective strategy for this whanau. The Ka Hao Te Rangatahi scampi project is a further example of the progression of the vision. Evolving from a purely wild fishery based solution to aquaculture is further evidence of the developing and innovative attitude that underpins the WFC ethos. The second part of the vision is about how the whanau can work in the fishing industry whilst promoting the economic and environmental sustainability of the fishing industry itself. WFC involvement in R&D over the last decade is premised on a vision of improving sustainable harvesting (by addressing impacts on the seafloor, unwanted by-catch, and waste), significantly improving catch quality and reducing costs. The company currently operates four vessels; FV 'Te Kahurangi', FV 'Sea Hawke II', FV 'Kobus' and FV 'Pacific Challenger'. Vessel range in length from 18.9 metres 'Te Kahurangi', up to the 29 metre 'Pacific Challenger' and 'Kobus'. WFC markets some of its own product under the "Connors Catch" brand name.

The Economic Rationale for an enhanced *Metanephrops* fishery

In this section of the paper we examine the two approaches to enhance the existing fishery: fishery technology development and aquaculture. The key concept behind both approaches is improved resource utilisation by focusing on higher value product market segments than the trawl fishery currently does – whole live versus frozen product. To achieve this goal from the wild capture fishery requires a change in mind-set around fishing technology with a move to potting or creel fishing as practised in the inshore rock lobster fishery. Augmenting potting improvement in the wild capture fishery relies on adding value through creation of a new industry in two stages. First, one based in the culture of eggs that are currently lost in the frozen product creation process. Second, using wild caught brood-stock to close the lifecycle of *Metanephrops* and begin an industry independent on the wild capture fishery.

Development of the economic case for innovation in this fishery begins with a review of progress in Portuguese *Nephrops* fishery where trawl creel (pot) operations are conducted in conjunction with a trawl fishery in similar depths to those in the NZ *Metanephrops* fishery. Recognition of the potential returns that accrue to the high value live product supplied to Spanish markets that results from the creel fishery there motivates consideration of a similar technology in New Zealand, as well as development of an aquaculture industry initially based on culture of *Metanephrop* eggs harvested from the current trawl fishery.

Scampi trawl fisheries the world over have issues with benthic damage, by-catch and discarding live scampi. This is highlighted by the North-Eastern Atlantic Nephrops fishery which has the fifth-highest discard ratio in the world, primarily due to catching undersized *Nephrops* and non-target vulnerable fish (Catchpole, van Keeken, Gray, & Piet, 2008). In European waters *Nephrops* minimum size regulations have been introduced which have motivated innovations in trawl design to reduce the number of discarded animals caught. Innovations to address these issues include, square mesh panels placed at set distances from the cod-end, windows of larger mesh sizes in the upper panel of the net, structures to separate the trawl into horizontal layers, and the using firm grids (Nordmøre grids) to physically remove larger fin-fish species and sieve scampi through to the cod-end (Bell, et al., 2013; Catchpole, et al.,, 2008; Ungfors, et al., 2013).

Efforts have been made to introduce these European trawl design innovations to the New Zealand scampi fishery and reduce the amount of by-catch (Hartill et al., 2006). Nordmøre grids and varying mesh sizes in the main body and cod-end of nets were trialled in 1992 and 1996 respectively. Since 1992, differential minimum mesh sizes for the main body of the net and cod-ends have been introduced. Nordmøre grids were not adopted due to concerns with losing scampi, crew safety, and difficulties deploying them (Hartill, et al., 2006).

Only about 20% of the scampi that are trawled from the seabed are returned to the surface whole (pers. comm. Waikawa Fishing Company). The remainder of the scampi are damaged and worth a fraction of the premium grade whole frozen scampi, which can sell for up to NZD$250 per kg in China (Oravida, 2014). CPUE in the four main fishing areas has been decreasing since 1995 (MPI, 2013). Combined with the low CPUE and high fuel costs of up to 9 litres of diesel per kilogram of scampi landed (Pers comm, Waikawa Fishing Company Ltd.), there is a clear opportunity to increase the efficiency of operations and resulting revenue of the New Zealand scampi fishery.

While attractive from some perspectives, potting and creel technology is not without limitation. Natural bait is expensive, difficult to handle and can require freezing. The cost of purchasing and storing bait is significant (Chanes-Miranda & Viana, 2000), and fish products that are suitable for human consumption are used for baits (Archdale & Kawamura, 2011). In the *Nephrops* creel fisheries for example, the cost of bait is estimated to comprise 5-10% of total fishing expenses, using on average 1.1 kg of salted herring per kg of lobster caught (Ungfors, et al., 2013). European *Nephros* creels have been observed to catch non-target species as well, such as conger eels, curled octopus, poor cod, squat lobsters, and crabs (Morello, et al., 2009). Variations in catch rates of creels have been observed, lower than expected catch rates are typically due to poor capture efficiency of animals that approach the creel and loss of bait due to scavengers can lead to catch rates (Morello, et al.,, 2009; Ungfors, et al.,, 2013).

It is informative to consider the economic potential available by converting from trawl to pot technology in the New Zealand *Metanephrops* fishery. Leocádio et al., (2012) undertook a comparative analysis of the performance of trawl and creel fishers for *Nephrops* in Portuguese waters which provides insight into the potential to increase performance of the NZ fishery. Table 1 summarises their results.

Prices achieved by creel fishing are on average 5.3 times that for trawl; CPUE for creel is 2.7 greater than for trawl, and daily fuel consumption for creel fisher 10% of trawl. The net present value of annual economic surplus for creel fishing is nearly double that of trawl with trawl fishers showing a loss. (The by-catch of rose-shrimp makes Portuguese trawl operations profitable with a contribution to ten year NPV of the order of € 1m.).

On the basis of these data, it can be inferred that the economic rents in the Portuguese *Nephrops* creel fishery can be valued at €232 per kg based on the present value of the estimated future profit stream from fishery operations. If fisheries management in Portugal was conducted under an individual transferable quota system, as in New Zealand, then the expected price per kg of that quota share of some total allowable catch would be of the order of 232 € per Kg. Actual quota prices may differ from this projection because of factors other than expected future profit streams such as speculative and strategic motives in holding quota (Batstone and Sharp, 2008).

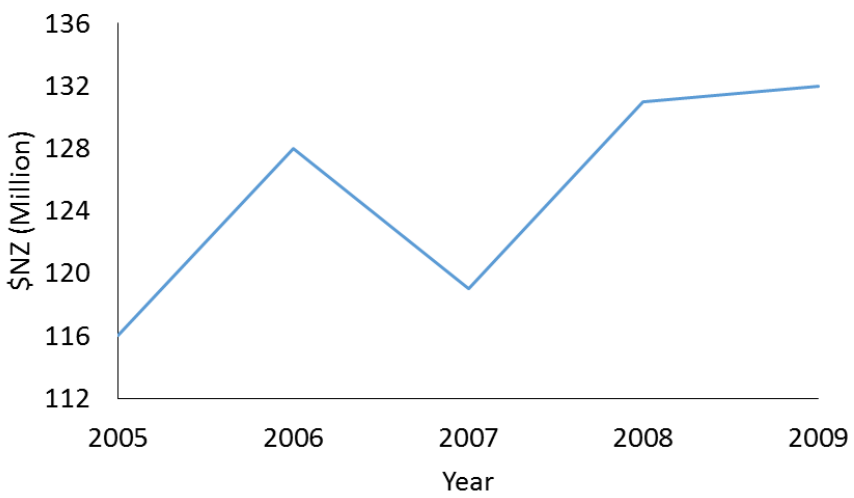
Using that estimate of economic rents generated by the Portuguese *Nephrops* creel enables anticipation of the change in the valuation of the New Zealand *Metanephrops* fishery with a change to potting methods.

Table 1: Portuguese Nephrops fishery, trawl and creel comparative economic performance (Leocádio et al., 2012)

Performance Indicator	**Trawl**	**Creel**
Average annual port price(€per kg)	15	80
CPUE (Kg per day effort)	26	70
Days fished	198	45
Daily fuel consumption (liters)	2,134	238
Average vessel total annual fixed cost (€)	35,457	12,000
Average vessel annual variable cost (€)	41,088	6,000
Estimated *nephrops* net present value (NPV) 10 year annual net surplus (€) (Discount rate = 5%)	-799,893	737,585

The United Nations recommends that valuation of resource stocks be based in market transactions (United Nations, cited in Tai et al., 2000). Consistent with this, the valuation of New Zealand fisheries is based in quota share prices. Figure 1 describes the valuation of New Zealand's *Metanephrops* fisheries using trawling for the period: 2004 – 2009 (Statistics New Zealand, 2014).

Figure 1: NZ *Metanephrops* Fishery Valuation



The Total allowable Commercial Catch (TACC) for *Metanephrops* in the New Zealand Exclusive Economic Zone (EEZ) is 1,224 tonnes of which only 730 tonnes were landed in the 2012-13 fishing year (MPI, 2014). The principle reason for this under harvest is an economic one – the returns available to New Zealand trawl fishers are not sufficient to make harvests in the more distant regions of the NZ EEZ commercially feasible (Pers comm N. Penwarden). However the markedly improved commercial performance of creel over trawl demonstrated in Table 1 motivates review of that assessment. On the basis of the Portuguese experience of creel technology – the gear combined with the tacit knowledge, the "matauranga" of Portuguese creel fishers – an estimate of the NZ TACC valuation under creel harvesting methods is of the order of 2014 NZ$ 381m, an increase of nearly 290%. The driver of this magnitude of change is the paradigm shift that reduces operating costs through less carbon intensive demands of potting and increases returns by accessing high end markets for high quality products, again available under potting, but not under trawl operations. To provide context for this, the value of the entire NZ QMS increased by 47% between 1996 and 2009 from NZ$2.7b to NZ$4b (Statistics NZ, 2014).

A New Zealand Scampi Potting Fishery

In order to achieve outcomes of that order, deep technological innovation is required to overcome the challenges facing commercial viability of trap fishing. Amongst them are the effectiveness of traps in the offshore, deep-water conditions of the scampi fishery, their ability to manage by-catch, and the low concentrations of the organisms on the seafloor reported by Tuck et al (2014).

Potting has been suggested as an alternative and more sustainable method for harvesting this species (MBIE, 2014). Previous attempts to catch NZ scampi in European-style pots resulted in a large bycatch of hagfish, *Eptatretus cirrhatus*, and sea lice (Martin Cryer, pers. comm. 2015). Hagfish secrete a large volume of mucous when entrapped which can make pots difficult to handle, reduce the ability of the pot to continue fishing and potentially suffocate any scampi inside the pots, as occurs in the white-spotted conger eel, *Conger myriaster*, fishery in Japan (Harada et al., 2007). There is a small hagfish fishery operating in New Zealand: there are concerns over the state of the stock of this species leading to consideration of closer control on the numbers of smaller hagfish being caught (MPI, 2014). Reducing the amount of hagfish bycatch through attractant selection and pot design is one of the greatest challenges for refocussing the New Zealand scampi fishery toward the adoption of potting technologies (Major et al., 2016).

Crustaceans rely on their chemosensory systems to track odours released by potential food items into the water column (Derby & Sorensen, 2008). This chemosensory system is 'tuned' to specific mixtures of stimuli that are present in the tissues of preferred prey (Barbato & Daniel, 1997; Carr et al.1996; Derby, 2000). Traditional baits are usually chosen after centuries of trial and error. However, the processes of choosing the most effective bait or chum may be accelerated when the processes of chemo-attraction and feeding behaviour are properly understood in the context of the individual species (Atema, 1980). To develop effective chemoattractive baits to pot for New Zealand scampi, an understanding of crustacean chemoattraction and investigations into their feeding behaviour and how they respond to a range of chemical stimuli are required. To achieve these ends – by-catch reduction and improved catchability – The Ka Hao Te Rangatahi project has joined with the

University of Auckland to conduct research in the area of chemo-attraction to further the effectiveness of potting over trawling for scampi in New Zealand waters. This is a vital component in the effort to overcome catchability issues associated with low abundance concentrations.

Scampi aquaculture

The second innovation direction WFC wish to pursue is to address the potential to complement wild harvest through aquaculture. Their vision is around the commercial potential for culturing eggs on sexually mature female adults that under current practice are frozen along with their bearers and shipped to markets as part of the frozen trawled scampi product. This idea has been addressed by creating a research scale land based recirculating seawater system to hold trawl caught berried females and other mature adults. There are three objectives: to hold organisms for pot design and chemo-attractant trials in flume tanks; to explore the culture of the eggs held on berried females, and to examine the potential to close the life cycle of *Metanephrops challengeri.*

Achievement of the latter objective would create an industry independent of the wild capture fishery. No successful scampi aquaculture has been achieved before, although organisms have been held in tanks. Crustacea in general pose huge challenges to culture in artificial environments – their life cycles are characterised by multiple growth stages as they progress from egg to larval and beyond to post-larval adults. Land based recirculating aquaculture systems are expensive to establish and energy intensive to run and maintain. However they afford the advantage of control of culture conditions through the differing growth stages, and create the as yet unexplored potential for grow out in marine environments.

The product is a different product to that resulting from the trawl fishery. Cultured product from other species has product attributes that differ from wild caught product – taste and texture, for example. It is intended to address high value live markets in Asia already targeted by the inshore rock lobster potting fisheries here and in Australia. There are opportunities for forward integration for producers in value chains that supply high end business customer restaurants that cater to conspicuous consumption motivations of clients already evident in seafood preferences in the likes of the markets for rock lobster and geoduck in Asia (GSGisalon, 2012).

Anecdotal evidence as to supply conditions in the markets for frozen M*etanephrops challengeri* suggest an excess of demand over supply of the order of four times at current prices. Creating indices of exchange prices in value chains that supply live rock lobster to consumers suggests live M*etanephrops* product landed in China and on-sold to wholesalers could return prices of the order of $200 - $250 per kg (G. Connor, pers comm), with final consumers paying twice that when the live product is served in restaurants. The final product is distinctive and extremely scarce. Premium *Metanephrops* are ivory in colour, with distinctive crimson bands on their tails and chelipeds (pincers), a feature attractive to a culture that highly values red/crimson hues in products.

While addressing the purely technical biophysical challenges of this aquaculture, the necessary physical culture conditions to satisfy the commercial potential is explored through development of a Monte Carlo bio-economic model to evaluate the interaction of key culture parameters – growth rates, food types, food conversion to biomass ratios, water quality parameters (e.g. temperature), and other physical influences such as photoperiod.

There are no stock sustainability issues incurred through the collection of berried females. The collection of organisms for research and brood-stock is undertaken within the catch limits and regulatory apparatus of the QMS. There are no requirements to return of females carrying eggs to the sea. This is impractical because of the depths the fishery is conducted in, the bulk of target organisms are dead when landed on deck, or unlikely to survive the catch and return process conducted in the inshore *jasus edwardsii* rock lobster fishery. The eggs are currently sent to market, hence the opportunity to complement an already lucrative trawl fishery is lost.

Given marked increases internationally for marine crustacean products Jeffs and Davis (2003) reviewed the potential for crustacean aquaculture. Their principal conclusions lie in the potential for the culture of tropical species over temperate species due to the abundance of seed lobsters and higher growth rates. Noting that both sea cage and tank based culture were feasible, they cautioned much R&D was needed into culture parameters such stocking densities and the development of cost effective artificial diets. Jeffs and Hooker (2000) indicated that unless culture costs could be reduced and productivity improved dramatically, land based culture of NZ crustaceans was unlikely to be economically viable.

Results and Discussion

This discussion proceeds along two broad directions. The first addresses early outcomes of an MBIE funded program of research and innovation in the wild capture and aquaculture domains motivated by the economic rationale. The second notes the nature of the innovation pursued in this project, noting the peripheral position of the WFC fishing entity in the NZ QMS and their particular ethical stance as the motivation for what the literature describes as "active innovation (Le Floc'h and Fuchs 2001), as opposed to the contrasting innovation mode, "passive innovation" (Le Floc'h and Fuchs 2001) that appears to characterize the innovation stance of other fishers in the NZ scampi fishery.

The hypothesis that pots are a viable alternative fishing method in the New Zealand scampi (*Metanephrops challengeri*) trawl fishery was assessed by comparing the bycatch rates from four different designs of pots used in similar deep sea lobster fisheries overseas. The effects of bait and location on bycatch were also assessed by using three different bait types and fishing the pots at two different scampi commercial fishing sites around 200 km apart (Major et al., 2016). The results to date indicate that the development of potting methods for New Zealand scampi has the potential to reduce bycatch of some fish species, but will need to focus on reducing hagfish and invertebrate bycatch through improved pot design and spatially-targeted fishing (Major et al., 2016).

The quantities and composition of the bycatch caught in four designs of European pots at two offshore sites was influenced by a combination of the pot design, the bait used and the location of pot deployment. Overall the bait selection does not appear to be an important consideration for reducing bycatch. Accordingly, further research will focus on developing pots that enable hagfish and other fish species to escape from pots whilst retaining scampi and identifying locations where hagfish bycatch can be minimised. Compared to the bycatch in the trawl fishery for New Zealand scampi the pots caught a lower proportion of fish species and higher percentages of hagfish and invertebrate bycatch. Together these results suggest that a potting fishery, using careful pot design and spatially-targeted fishing, has the potential to reduce bycatch in the New Zealand scampi fishery, and potentially many other crustacean fisheries that are currently fished with bottom trawling methods (Major et al., 2016)

The capacity to undertake research into the effectiveness of alternative species' specific pot designs and chemo-attractants for *M. challengeri* is contingent on the supply of healthy trial animals to the laboratory. A land-based, biosecure, recirculating aquaculture system has been established and broodstock acquired. The techniques for harvesting suitable live organisms from trawls conducted in the dark, high pressure depths of up to 400m have been refined to the point that successive replacement brood-stock cohorts have been recruited to the research recirculation facility with high survival rates. Caches of 200 individuals at a time resulting in upwards of 72000 eggs are now reliably delivered to the facility.

Four months after the first broodstock scampi were introduced into the purpose designed system, 73% of the adults were still alive. Eggs have been hatched: the eggs of this species are large, and may take months to hatch. However, when the eggs hatch the larvae are large (8 mm orbit to tail) and well advanced. Hundreds of eggs have been hatched and a small number have reached post larval stage as small adults. Larval mortality has been high and improvements in systems, diet and understanding of the species should result in improvements in survival (K. Heasman, pers comm).

In July 2016 the project team celebrated the "first birthday" of the eldest organism (named "Camilla") to hatch from eggs carried by broodstock, and fertilised in the facility (TVNZ, 2016). There appear to be four stages in the life cycle of captive *Metanephrops*: egg, larval, post larval juvenile, and adult, each requiring specific diet and culture conditions for survival and ultimately optimization for commercial viability (K. Heasman, pers comm). These outcomes are world firsts for this species – the outcomes are being prepared for publication in scholarly journals.

The innovations we have discussed in the section describing the NZ scampi fishery that refine trawl gear go some way to mitigating the negative effects of trawling on biota. However they are incremental innovations that do not address the significant benthic effects reported in New Zealand waters (and elsewhere) by Thrush and Dayton (2002). The move to static gear such as pots would achieve this. However to date the innovation effort around the fishery for *M. challengeri* seems path dependent and incremental (Varadarajan, 2009), displaying characteristics the technology change literature refers to as "passive adoption". Passive technology adoption occurs within a particular technological paradigm and is exampled by more fuel efficient engines that address rising input costs, or gear refinement that meets regulatory innovation, leading to persistence of the paradigm (Le Floc'h et al., 2011).

In turn that persistence may contribute to ecological and commercial vulnerabilities that act to diminish the resilience of the scampi fishery system (Taylor and Moench, 2012). In ecological terms the long term effects of benthic habitat disturbance of trawling on *M. challengeri* abundance is poorly understood, and rising fuel costs present threats in the commercial domain.

This research seeks solutions in the social (prices in premium markets) and technological (harvest technology development) domains to relieve those vulnerabilities. A key feature of both the strands of the research described in this paper is that they are "active" adoptions. Active adoption is more likely to be evident in small firms in fishing industries (Le Floc'h and Fuchs 2001). This kind of active adoption of new technology effects a disruptive innovation process (Markides, 2006) that achieves major breakthroughs into new technological and commercial realms. In contrast to many other jurisdictions, New Zealand manages its fisheries through a rights-based system that does not feature economic subsidy or technical control over the extent of fishing effort. From the point of view of the theory of Individual Quota Management (ITQ) fishery management systems, it is of interest that this output controlled fishery has produced small firms that are willing to take up the innovation challenge without the incentives that are held to flow from quota ownership.

Waikawa Fishing Company, without economic rents from owning quota, and motivated by their ethical stance on the marine environment, faces strong incentives to innovate in this way to improve their organisation's resilience and returns to their operations. Using static gear uses less fuel and produces higher quality product, which in turn commands higher prices in product markets. In New Zealand's output controlled fishery successful technological innovation may lead to competitive advantage in markets for annual catch entitlements that harvest-only firms purchase from quota owners. This in turn may build a virtuous cycle of improved fishery access leading to greater commercial success.

The development of a new aquaculture industry certainly meets the definition of an active innovation process that is likely to be disruptive. While the path to a fully functioning commercial scale system of culture in land based facilities for M*etanephrops* is years in the future, the outcomes presented here suggest that the potential is reasonably high. The effects of cultured production on the markets for wild capture product are uncertain.

The potential for land based culture of species not of indigenous nature is not without precedent. The development of the competitive advantage this research builds opens avenues for investment in culture of this and other indigenous marine species, both in New Zealand and in locations close to key markets and at scales not contemplated to date.

Concluding Remarks

In this paper we have described the background and economic rationale for a fishery innovation project that seeks a paradigm shift in the conduct of harvest operations. Without consideration of the contribution of a new scampi aquaculture to export receipts, the potential from the development of unique kiwi pots to increase the value of the scampi fishery by 200 – 300% is commercially attractive.

The emergence of high value markets for live product in Asia based in conspicuous consumption motivations and the precedent of the "new" technology in European waters motivate the shift to static gear. Further, the development of land based recirculation systems in the sixteen years since pessimistic assessments of the commercial potential for temperate water crustacean aquaculture makes consideration of NZ scampi aquaculture reasonable.

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