Sharing the catch of migratory rock lobster (*Panulirus ornatus*) between sequential fisheries of Australia and Papua New Guinea

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ABSTRACT
The rock lobster (*Panulirus ornatus*) fishery in Torres Strait is an important commercial and traditional fishery in both Australia and Papua New Guinea. The lobster stock is first fished in Torres Strait by divers from two countries and then vulnerable to Australian trawlers in the great northeast channel, followed by PNG trawlers in the Gulf of Papua during its breeding migration. The trans-boundary sharing of the lobster stock in Torres Strait between the two countries is governed by the Torres Strait Treaty ratified in 1985, but the sequential fishing of breeding lobsters has been controlled by bilateral agreements. Although a trawl ban has been instituted since 1984 in both countries, over the last few years, some trawling has been conducted in the Gulf of Papua and there is renewed interest in PNG to resume trawling. This paper develops a model to evaluate the impact of trawling migrating breeding lobsters on the fishery. The results show that fishing for breeding lobsters will further reduce the spawning stock and cause a loss of catch to the fishery when the fishery is fully or over-exploited. The loss increases with fishing mortality and the amount of catch taken from the breeding stock. If trawling only occurs on the PNG side, a redistribution of catch between Australia and PNG will result. This may present a small gain in catch for PNG at the expense of Australia in the Torres Strait dive fishery.
Key words: rock lobster, *Panulirus ornatus,* Torres Strait, trans-boundary sharing, sequential sharing

INTRODUCTION

The ornate rock lobster *Panulirus ornatus* is distributed across the Torres Strait between Australia and Papua New Guinea (PNG) and supports important commercial and traditional fisheries to the indigenous fishers of the Torres Strait Islands and the adjacent coastal villages of PNG. The annual value of the catch from this fishery was about $A15 million in 2005 and provides a major source of income for Torres Strait traditional inhabitants on both sides of the border.

The Torres Strait lobster is a migratory species (Moore and MacFarlane, 1984). From early September to late November lobsters nearing 3 years of age migrate out of Torres Strait across the Gulf of Papua to the breeding grounds near Yule Island in the east coast of PNG (Moore and MacFarlane, 1984; Macfarlane and Moore, 1986; Bell *et al*., 1987, Trendall and Prescott, 1989, Dennis *et al*., 1992). The larvae released in the PNG coastal waters are thought to be transported via currents back to the Torres Strait and to the East Coast of Queensland (reference for FRDC modelling project). They recruit to the fishery about one year following settlement in Torres Strait at about 1.5 years of age (Ye et al., 2004). With a new minimum legal size restriction and seasonal closure in place, the age at first capture has been delayed to about 2 years.

Both Australian and PNG divers fish lobsters in Torres Strait where they are distributed widely on the reefs of the central and western parts of the Torres Strait before they start their breeding migration around September to October. The migrating lobsters form large aggregations and can be easily captured by trawlers. In the early 1970s, the breeding migration was first fished by PNG prawn trawlers in the Gulf of Papua. Australian trawlers also found the migration further south in the Australian area of jurisdiction and began to target these lobsters in the early 1980's. So, there is a trans-boundary sharing in Torres Strait and a sequential sharing along the migratory route.

The trans-boundary sharing of the lobster stock between the two countries is governed by the Torres Strait Treaty ratified in 1985. The Treaty creates the "Protected Zone" to protect the traditional way of life and livelihood of the traditional inhabitants and specifies the shares of the commercial fisheries for each party and their responsibilities for the sustainable development of fisheries within the Protected Zone (Fig.1). Fishing activity for lobsters outside the Protected Zone has also been managed based Treaty provisions that allow the parties to negotiate "supplementary conservation and management" arrangements for Protected Zone stocks that spill over to adjacent areas.

Targeting the breeding stock during the migration was believed to have a negative impact on the productivity of the lobster stock and was banned in both countries in 1984 (prior to the Treaty coming into force). However, over the last few years, some trawling has been conducted in the Gulf of Papua and some PNG trawl operators, many of whom have experienced financial hardship recently, have sought to have the trawl ban lifted. This paper reviews the history of the lobster fishery and develops a model to analyse the potential impact of trawling on the lobster stock and its cost and benefits to both countries.

MATERIALS AND METHODS

Overview of the lobster fishery

Ornate rock lobsters haven been fished by the traditional inhabitants of Torres Strait, probably for centuries, and commercial fishing began in the late 1960s (Pitcher et al. 1997). Two fishing methods have been used to capture lobsters. Today the only legal way to catch lobsters is by hand, usually by divers spearing the lobsters although some are taken alive. The other method which has produced large catches is trawling. Commercial diver fishing in the PNG area of the Torres Strait was already of large scale in the 1970s, and its catch exhibited a continuous increase until 1995 (Fig.2). Over the last 10 years, PNG's catch was maintained at about 80 t of tail weight but with large fluctuations. There were no reliable catch statistics prior to 1978 in Australia. Catches from 1978-1985 averaged about 120 t (tail weight), and higher catch was seen thereafter. Fluctuations of the Australian lobster catches were very large, between 50t in 2001 and 350 t in 2003 (Fig.2). There is also a lobster fishery along the east coast of Queensland, but of much smaller scale. The east coast fishery also has a history similar to the Torres Strait lobster fishery. However, its catch increased significantly only after 1985 (Fig.2). The combined catch from both countries' diver fisheries averaged about 300 t (Fig.2).

Trawling was mainly used to target lobsters during the migratory season in the Great North East Channel in the Torres Strait and then in the shelf waters of the Gulf of Papua. There was also a small scale, traditional, diver fishery for breeding lobsters around Yule Island. Trawl catches of aggregated migrating lobsters in the Gulf of Papua were large in the early 1970s, about 200 t in 1973, and 1980-1983 (Fig.3). Australian fishermen also started lobster trawling in 1980 in the Northeast Channel of Torres Strait following about 8 t of incidental catch taken by the prawn trawlers (Channells *et al.*,1987). Australian trawl catches jumped to about 50 t in the following three years (Fig.3). Trawling was carried out over a very short period from mid September to early October (Channells *et al.*, 1987). In 1984, a ban on target fishing for rock lobsters by prawn trawlers was instituted in both Australia and PNG following a series of quota control trials in 1978, 1981-1984 (Fig.3) in PNG.

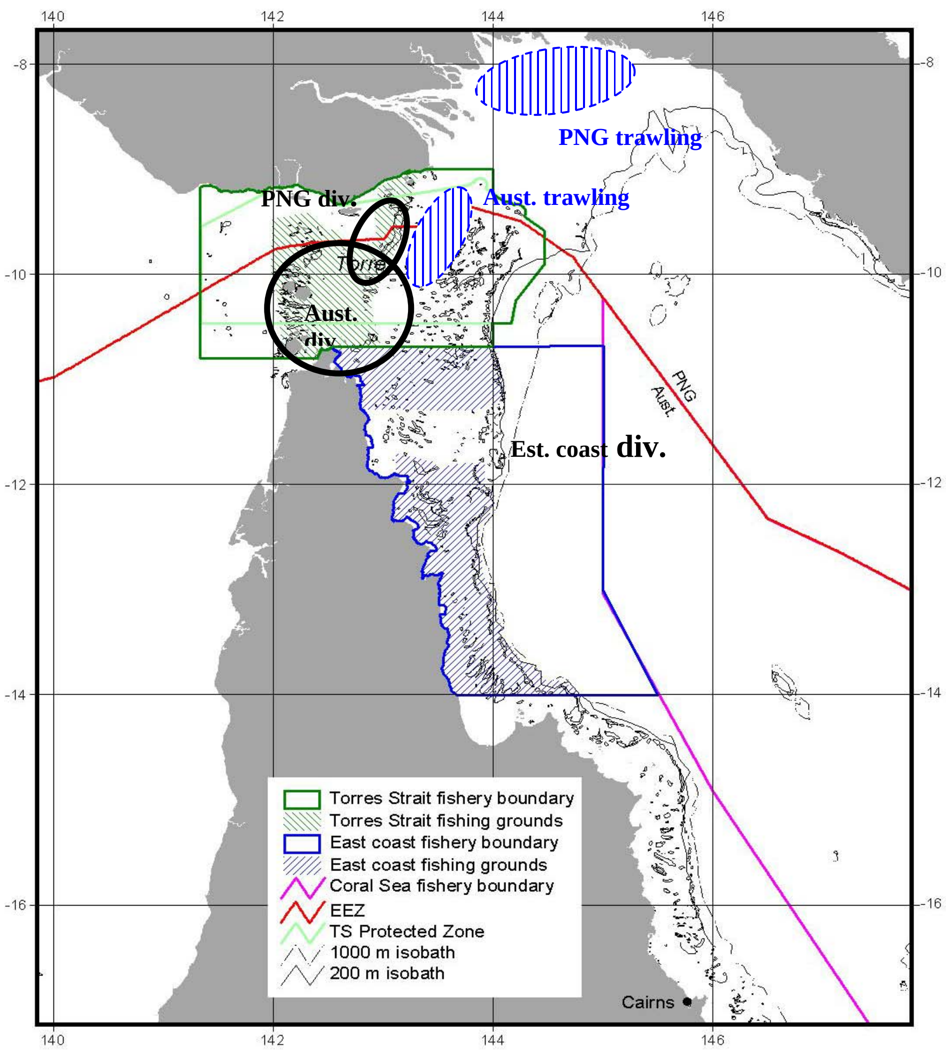

Fig.1 Different components of the rock lobster fishery in Torres Strait

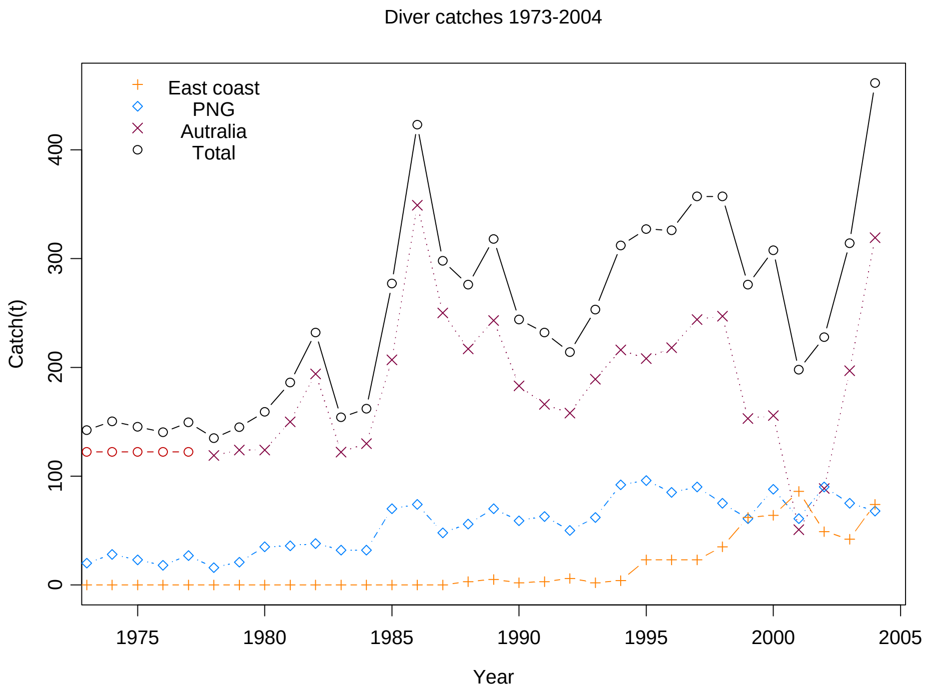

Fig.2 Catches of the three lobster diver fisheries

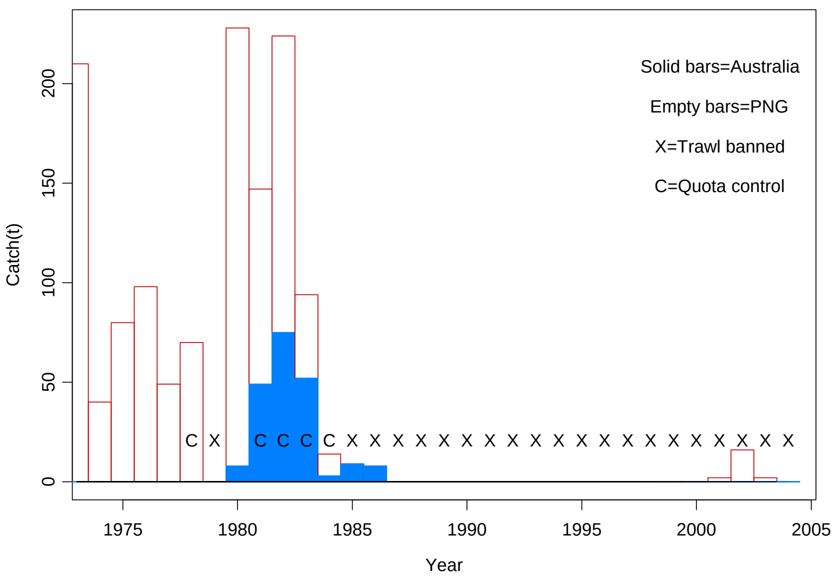

Fig.3 Landings of rock lobsters from trawling in Australia and PNG

The reason behind implementing the ban on trawling breeding lobsters was that it would have reduced the spawning stock with consequent reductions in recruitment. Catch statistics in subsequent years suggest that the reasoning was well founded. The 1984 trawl ban was followed by a great increase in diver catch in 1986 (Fig.4) and as no minimum size restriction was in place at that time, lobsters should become fishable at an age of about 1.5 years, meaning the positive consequence of the trawl ban in 1984 should have showed up in 1986. The peak record of catch seen in 1986 (Fig.4) could be attributed at least partially to the protection of spawning stock. It seems unarguable too that the average of diver catches after 1984 is much higher than that before the trawl ban. However, the impact of trawling could not be scientifically quantified without resorting to mathematical models. In the next section, we develop a mathematical model to evaluate the potential consequences of trawl fishing of the breeding stock.

Fig.4 Comparison between the diver (circles) and the trawl catch (triangles)

Modelling the impact of trawling

With the current size limit of 115 mm (tail length) and a hookah ban in October-January in Australia, lobsters become the target of the fishery only when they reach an age of 2 years (Ye *et al*., 2006). In PNG the fishery operates more continuously with free divers taking lobsters in all months and a hookah ban from December to March. The largest proportion of stock is found in the Australian area (reference) so this means that a cohort of lobsters predominantly suffers only from natural death from the age of 13 months to 24 months. Starting from the 25th month, the cohort is depleted by both natural mortality and fishing of Australian and PNG divers in the Torres Strait before lobsters migrate out in later September or early October (months 33 to 34). Before the trawl ban since 1984, lobsters were fished heavily first by Australian prawn trawlers and then by PNG trawlers. This whole process is a simple single cohort depletion process (Fig.5).

Let R be recruitment (12 month old lobsters), M natural mortality rate, F fishing mortality rate, γ the percent of the October biomass taken by trawlers. Channells et al. (1987) reports that maximum catches were usually made over a 4 to 14 day period between mid-September and early October on the Australia side. Given the short time of trawling, for simplicity we express the catch as a percentage of October lobster biomass as PNG trawling occurs slightly later. The spawning stock biomass left over after trawling is

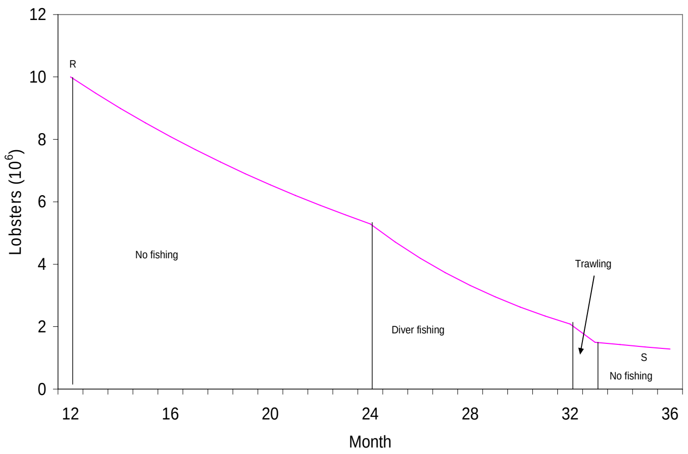

Fig.5 Depletion process of a single cohort of lobsters

$$S = R * e^{-M-0.75(M+F)})(1-\gamma)W_{34} \tag{1}$$

where W_{34} is the individual weight of lobster in October, corresponding with an age of 34 months. The stock recruitment relationship for lobsters takes Ricker's form (Ye et al. 2006):

$$R_y = aS_{y-1}e^{-bS_{y-2}} \tag{2}$$

where R is the number of recruits, S is the spawning stock biomass in tonnes and y is year. When the stock is in equilibrium, dropping the y in Eq.2 and replacing the R in Eq.1 with Eq.2 gives the spawning stock biomass at equilibrium:

$$S_e = \frac{1}{b}(\ln(\frac{aW_{34}}{1+\gamma}) - 1.75M) - \frac{3}{4b}F \tag{3}$$

If γ is fixed, S_e is a linear function of fishing mortality rate F. The equilibrium catch for diver fishing is then:

$$C_e = R_e e^{-M} \frac{F}{F+M}(1-e^{-(F+M)/12})\sum_{t=25}^{33} e^{-(M+F)(t-24)/12}W_t \tag{4}$$

where t is in months. Eq. 4 can be used to easily investigate the impact of the lobster trawling on the equilibrium catch of the fishery as we know a=$1.545*10^{-2}$, b=4.3×10^{-4} (Ye *et al.*, 2006) and W_t defined by a von Bertalanffy growth equation (Trendall *et al.*, 1988).

RESULTS

The consequences of different fishing strategies can be expressed in an useful way using catch and stock status when the fishery is at equilibrium as it indicates the long-term outcomes. The estimates of equilibrium catches for the lobster fishery are the same as estimated in Ye et al. (2006). The maximum sustainable yield from the fishery including both Australia and PNG Torres Strait jurisdictions is about 280 t of tail weight at F=0.5 $year^{-1}$(Fig.6). Spawning stock is a linear function of fishing mortality rate (Eq.3). If there is a trawl fishery that targets the breeding stock, the sustainable spawning stock is still a linear function of fishing mortality (Fig.6), but moves downwards in parallel as Eq.3 shows, indicating that trawling has a negative impact on spawning stock. This impact may look small; dependent on the value of γ. Recruitment decreases as F increases following a non-linear relationship (Fig.6), and the rate of this reduction increases with F.

Of the most concern in fisheries is the impact of trawling on the sustainable catch of the fishery. If there is a trawl fishery that targets the migratory lobsters, the equilibrium catch curve shifts to the left (Fig.6) and is no longer symmetric as we assume that even if F=0 from the dive fishery, trawling of the spawning stock is still occurring. Comparison between the two catch curves shows that there is a critical level of F above or below which the catch decreases. When F is larger than this critical level, trawling has a negative impact on the total catch and causes a loss to the fishery. However, if F is lower than the critical level, trawling actually leads to an increase in the equilibrium catch. This is because the stock is underexploited when F is below the critical level (Fig.6).

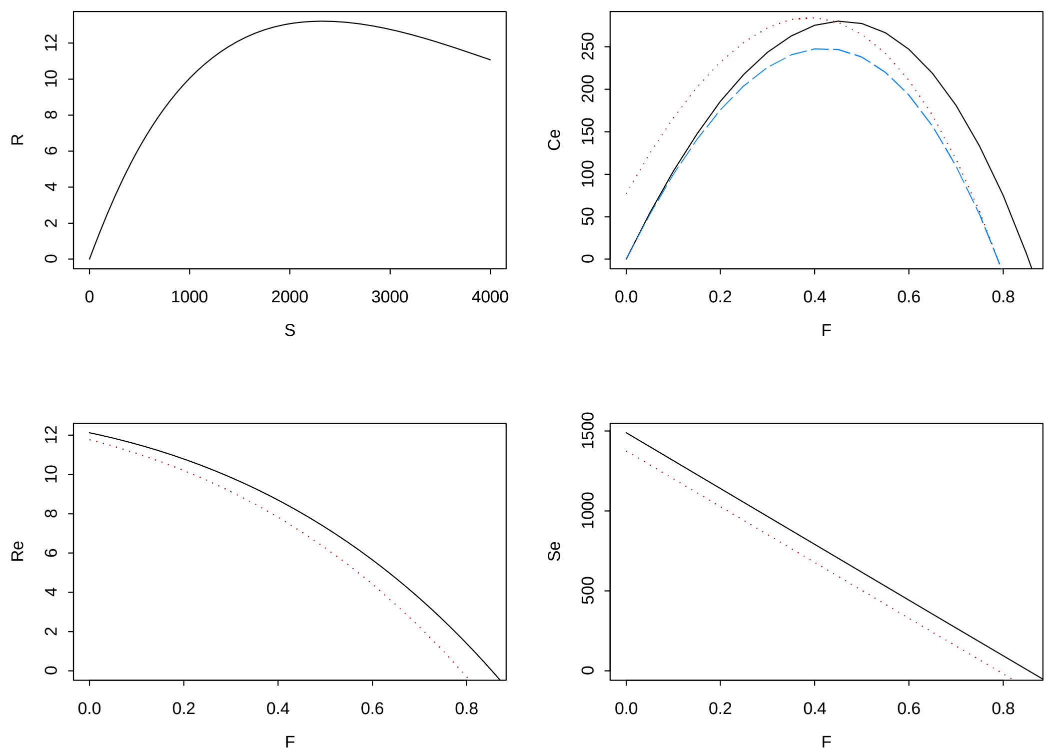

Fig.5 Stock recruitment relationship (top row left), equilibrium catch Ce (top row right), equilibrium recruitment Re (bottom row left) and equilibrium spawning stock Se (bottom row right). R and Re in million and Ce and Se in tonnes. Solid lines indicate γ=0, and broken lines γ=5%.

The difference between the catches without and with trawling can be considered as a loss to the dive fishery (Fig.7). In contrast, the lobster catch caught by trawling the breeding stock is considered as a nominal gain (Fig.7). It can be clearly seen that when γ=5% (5% of the spawning stock biomass is trawled), the trawl catch decreases with F because under high fishing mortality the spawning stock is driven to a low level reducing recruitment and the resultant catch. At F=0.8 year^{-1}, total catch drops almost to zero, which is consistent with Fig.6.

The loss in total catch of the fishery caused by trawling of the breeding stock occurs only when fishing mortality is beyond a certain level. It is about 0.42 year^{-1} when γ=5% (Fig.7). This level of fishing mortality changes with γ. Obviously, the catch loss increases sharply with F, suggesting trawling poses a great risk to the stock when the stock is fully or over-exploited.

In the above analysis, we assume that γ=5%. From Eq.3, it can be clearly seen that the equilibrium spawning stock under a certain level of fishing mortality is a function of γ. Through the stock recruitment relationship (Eq.2), γ will subsequently change equilibrium recruitment and catch. Fig.8 presents the results when γ assumes a value of 1% to 10%. It is unmistakeable that the impact of trawling breeding lobsters increases with the level of the trawl catch. When no diver fishing occurs, γ=10% means that trawling can have a catch of about 150 t. However, when the stock is overfished, say F=0.6 year^{-1}, γ=10% means trawling takes 24 t of lobsters, the fishery will lose 86 t after taking into account the 24 t catch taken by trawlers (Fig.8). In summary, trawling for breeding lobsters has a harmful impact on the stock and results in a low catch when the fishery is fully or overexploited, and this impact increases with the level of catch the trawlers take.

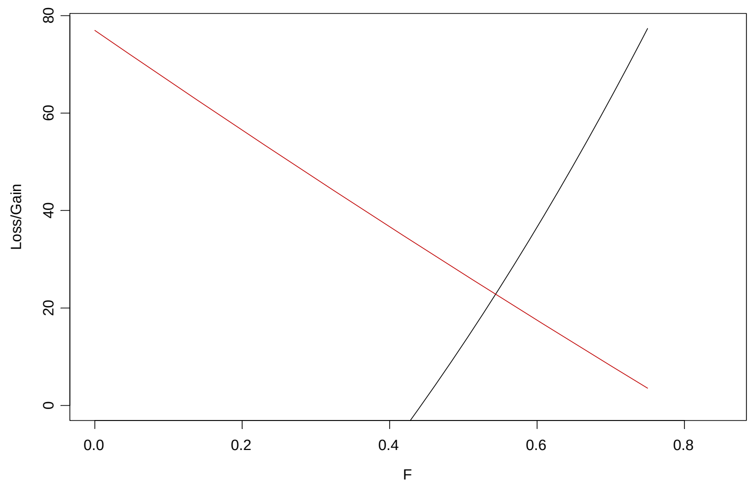

Fig.6 Losses and nominal gains in catch from trawling of the breeding stock under various fishing mortality levels.

DISCUSSION

Trawling lobsters during the breeding migration outside Torres Strait reduces the spawning stock and subsequently forces recruitment down in subsequent years. However, this does not necessarily lead to the conclusion that trawling is harmful to the stock. Only when the fishery is fully or over-exploited, fishing for breeding lobsters can reduce the spawning stock to a low level and cause a loss of catch to the fishery. This loss increases with fishing mortality and the amount of trawl catch.

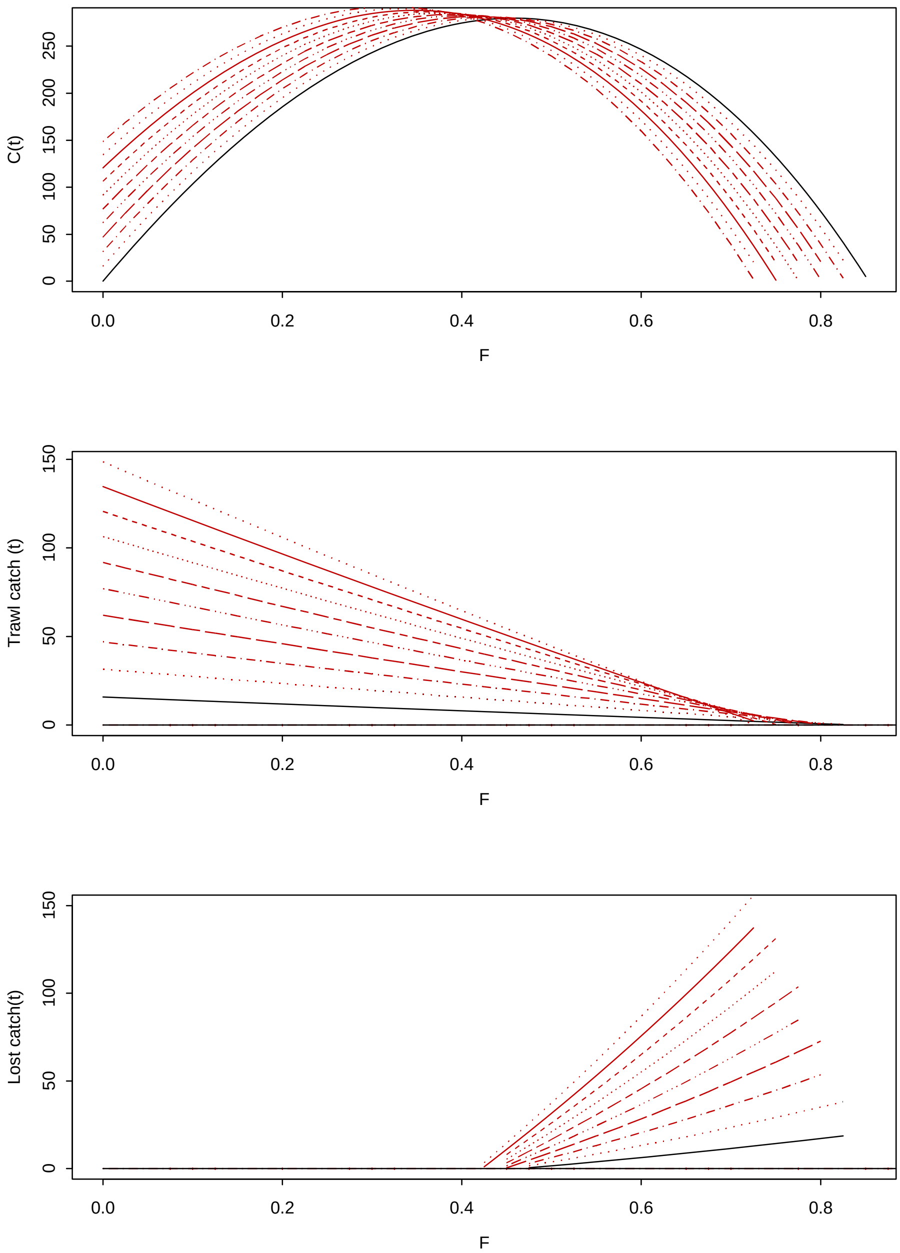

Fig.7 Sustainable catches of the fishery (top), trawl catches (middle) and losses in catch (bottom) under different fishing mortality rates and γ values (the 10 lines indicate γ =1% to γ=10% from bottom to top) .

Ye et al. (2006) estimated separate fishing mortality rates for age 1 and age 2 lobsters. The estimated fishing mortality for age 2 lobsters was slightly higher than 0.4 year^{-1} and that for age 1 lobsters about 0.15 year^{-1} between 1994 and 1999. When a single cohort is considered, the total impact of the fishing mortality rates over the two age groups is equivalent to that caused by a fishing mortality greater than 0.55 year^{-1}.

Fishing presently applies primarily to the first 9 months on the age 2 lobsters, and accordingly the real fishing mortality for the 9 month period is the fishing mortality multiplied by 0.75 (9 months out of 12 moths). Therefore, under this level of fishing pressure any scale of trawl catch will have a negative impact on the total catch of the fishery. The stock assessment for lobster has will be updated with recent (2001-2005) lobster abundance and catch data shortly and when this has been done the impacts of trawling should be re-estimated using recent estimates of F.

This study provides the first quantitative evidence that the ban on trawling during the breeding migration was right given the stated objectives for the fishery as set out in the bilateral management arrangements. Further, it is consistent with dramatic increase in the dive fishery catch after the 1984 trawl ban (Fig.4). However, some trawling in the Gulf of Papua has occurred in recent years. The official PNG trawl catch in 2003 was 16 t, and it is likely some PNG trawl fishers are advocating reopening the trawl lobster fishery in the Gulf of Papua. Based on the results of this study, resuming lobster trawling will certainly have a negative impact on the total sustainable catch of the fishery given the current high level of exploitation.

By way of illustration, let us assume the current fishing mortality is 0.4 $year^{-1}$ from the dive fishery and PNG takes 35 t lobster catch from the breeding stock (Fig.6). Although this will not reduce the total catch of the fishery, it will result in a redistribution of catch between Australia and PNG. The 35 t trawl catch will reduce the TS dive catch from 275 t to 240 t (Fig.6). The division of catch in Torres Strait between the two countries was about 70:30 over the last three years. If we suppose this division rate is not going to change, PNG will reduce its catch in Torres Strait by 10.5 t due to the lower recruitment caused by its trawling of breeding stock, but increase its total catch by 24.5 t. However, the reduced recruitment will decrease Australia's catch by 24.5 t, a catch redistribution from Australia to PNG. In the case of both Australia and PNG much of the catch lost to the dive fishery will be a loss to the traditional inhabitants of the region.

If the current fishing mortality rate is 0.6 $year^{-1}$, PNG still takes 5% of the breeding stock in October, i.e. about 17.5 t (Fig.6). The total catch will be reduced by 36.6 t. Given the same 70:30 division between the two countries, PNG will be better off by 2.5 t in total catch, but Australia will be worse off by 43.1 t. It is clear that the resumption of PNG trawling will lead to redistribution of catch between the two countries. The benefit PNG can obtain is decreasing with the current level of exploitation. At F=0.6 $year^{-1}$, a PNG's trawl catch of 17.5 t will be almost offset by its loss in the Torres Strait dive fishery caused by its trawling of the breeding stock.

This study has focused on the biological impact of fishing of breeding lobsters, and no economic consequences have been analysed. As any fishing incurs cost, economic consequences will certainly be worse than biological effects when the stock is fully or over-exploited. It is noteworthy that this study only analysed the impact of PNG's fishing of the breeding stock. While Australia has no intention of allowing a resumption of its trawl fishery for lobsters, its trawlers have the chance to target the migratory breeding stock before the lobsters reach the Gulf of Papua. If both countries decided to ignore the 20+ years of cooperation and resume trawl fishing for the breeding stock the consequences for the lobster stock would be dire. Munro (1979) and Laukkanen (2003) have provided solid analyses based on game theory and concluded that cooperative harvesting yields participants substantial gains in terms of expected payoffs. This study provides further quantitative evidences that Australia and PNG should use cooperative harvest strategies for the benefit of both countries and for the long-term sustainability of the rock lobster fishery.

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