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Typology and dynamics of a spatially and temporally heterogenous fishery: the Tasmanian rock lobster fishery

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Abstract: The paper presents a complex framework to analyse spatially and seasonally heterogenous fisheries. Typologies based on multivariate analysis have been applied on multi-species fisheries to identify patterns in fishing effort and subsequent impacts on various species. Although the Tasmanian rock lobster fishery is a single species fishery, it displays highly variable spatial and seasonal patterns of fishing effort. Rock lobster is a stationary species, so the stock of rock lobster is heterogeneously distributed along the Tasmanian coast depending on local removal from catch. The various perturbations undergone by the stock for the past decade, (overexploitation, introduction of individual transferable quotas (ITQs), climate change) led to the reorganisation of the allocation of effort by the fishers. The implementation of ITQs constrained fishers in the amount of lobsters they could land. Therefore fishers strategies evolved from targeting a high volume of lobsters to targeting the best value lobsters by changing their spatial and seasonal allocation of effort. To study the evolution of fishing strategies in the Tasmanian rock lobster fishery, a typology of fishing activities has been defined. Fishery typologies have traditionally combined ordination technics and classification methods. In the current analysis, principal component analysis and multiple correspondence analysis on catch and effort data were followed by hierarchical agglomerative clustering to group individual trips.

Fifteen fishing tactics were identified through the analysis of effort allocation and consequential catch. Each fishing tactic was characterized by a number of attributes concerning the geographical and seasonal distributions of effort and the types of lobsters caught. The resulting typology is a set of tactics, homogenous in terms of fishing areas, depths, seasons and lobster categories. The tactics can be used to study the evolution of the fishery. ITQs affected the number of trips through rationalization and effort reduction because of the rebuilding of the lobster stock. While investigating the temporal trends in fishing allocation in the tactics identified, few features were highlighted. First the trend shows a decrease of proportion of allocation in few tactics compensated by the increase in allocation in others. The effort was redirected from deep south-west areas to shallower waters. The depth at which lobsters are caught is important because it influences the colour and the robustness of lobsters. Deep waters lobsters are whitish and less resistant to transportation than the red shallow lobsters. This impacts the price processors get on the Chinese market and consequently the beach price fishers get.

The identification of the evolution of fishing strategies can have big impact on the management and conservation of the resource. By understanding and being able to predict fishers behaviour under external perturbations, managers can identify regulation measures robust to those perturbations.

Keywords: *fishing tactics, fleet definition, typology*

1. INTRODUCTION

Understanding the behaviour of fishermen has been identified as the key to successful fishery management worldwide (Branch et al, 2006; Hilborn, 2007). Scientists and managers seek better understanding of the decisions taken by the fishermen, particularly on the choice of their spatial and temporal distribution of effort and how those decisions vary with external perturbations such as management measures or change in ex-vessel prices. Murawski et al. (1983), Bertignac (1992), Rogers and Pikitch (1992), Lewy and Vinther (1994) and others used numerical analyses to describe the complexity of multi-species fisheries in terms of fishing practices and their impacts on fish stocks. While there is a consensus on the need for typology to describe fisheries, the methods used are diverse and the names of the resulting groups can be confusing. Ordination and classification technics are used to define groups of fishing practices with similar characteristics, either combined (Pelletier and Ferraris, 2000) or separately (classification: Murawski et al 1983 and ordination: Biseaux and Gondeaux, 1988). The groups defined by typology of fishing operations have been called 'métiers' (Biseaux and Gondeaux, 1988, Jabeur et al. 2000 and Mahévas et al. 2008), 'fishing tactics' (Pelletier and Ferraris, 2000 and Fall et al., 2006), 'directed fisheries' (Lewy and Vinther, 1994), 'fisheries' (Ulrich and Andersen, 2004), 'fishery management units' (Murawsky et al., 1983) or 'fishing strategies' (He et al., 1997, Tserpes et al. 2006). The term 'fishing tactic' will be use in this study.

The Tasmanian rock lobster (*Jasus edwardsii*) is exploited in the coastal waters of Tasmania, Australia (Fig 1). Except for a seasonal closure for moult in October, the fishery operates all year long. The Tasmanian rock lobster fishery has been managed with individual transferable quotas (ITQ) since 1998 and most lobsters are shipped alive to the Chinese market (Haddon and Gardner, 2008). Although the fishery targets a single species, rock lobster, it presents complex spatial and temporal patterns due to heterogeneity of the stock and commercial fishing fleet. The Tasmanian rock lobster population is spatially contrasted in terms of i) individual size, from small lobsters in the south to big ones in the north of the state, and ii) population density, with higher densities in the west and in deep waters, and iii) shell colour, shallow water lobsters are bright red while lobsters caught in deeper water are "strawberry" or whitish (Bradshaw et al, 2000). The size and colour of lobsters are highly influential to determine the price fishers will get, driven by the Chinese market. For example, white lobsters are not suitable for the international market because their mortality rate is high during transportation. In addition to spatial discrepancies, the availability and quality of lobsters varies highly between seasons. A peak in catch rates is observed right after the moult in November. This is due to the entry of previously undersized lobsters in the exploitable biomass through growth, but also because 'new shellers' starved during moult and are subsequently very attracted to bait. On the other side, winter fishing displays lower catch rates because the catch of females is prohibited from May to September for reproduction.

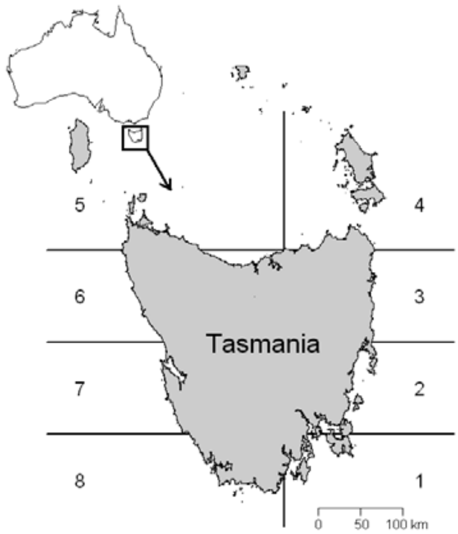

Figure 1 Location of the Tasmanian rock lobster fishery and the assessment areas

The fishing fleet also presents spatial patterns. The western part of the state has very little infrastructure and most fishers come from the east and north of Tasmania where they live. The east coast, with better weather conditions and more resident fishers, is overfished while the west coast, subject to rougher weather conditions and longer steaming time display higher catch rates. Because of the spatial and temporal heterogeneity of the stock, it is important to integrate the fishing practices in the analysis of the fishery as each fishing tactic is likely to impact the stock in a particular way (Pelletier and Ferraris 2000). Fishing behaviour in the Tasmanian rock lobster fishery was modified with the implementation of ITQ in 1998. Since, fishers have been allocated the rights to fish a fixed share of the total allowable catch (TAC) and their revenue from rock lobster fishing has depended on the relative value of the lobsters caught and the costs involved in fishing them. Fishers have been targeting more valuable lobsters, which are red, weighting less than two kilograms and have a hard shell (Hamon et al submitted). They have also increased their winter fishing because of a higher price offered for lobsters on the international market in winter.

The main objective of this analysis is to identify fishing tactics. Biseaux and Gondeaux (1988) described the definition of fishing tactics as the preliminary step of bio-economic modelling of fisheries. Each tactic identified represents an alternative fishers can select depending on their personal characteristics (e.g. home port) and the characteristics of the choice (e.g. abundance). Tactics are then used to feed a model of fleet dynamics based on discrete choices as in Marchal and Horwood (1996) and Vermard et al (2008). A model of the dynamic of the rock lobster fleet is already implemented in the stock assessment model (Haddon and Gardner, 2008). However, the linear models used to predict the effort allocation does not include the possibility of change in strategies due to external perturbations like the introduction of new management measures or change in the market. Fishing tactics are identified from catch and effort data and the evolution of the distribution of effort in those tactics is then analysed.

2. MATERIAL AND METHODS

2.1. Data

The catch and effort data analysed in this paper were extracted from the Department of Primary Industry, Water and Environment (DPIWE) database, which consists of compulsory logbook data recorded by fishers at the fishing operation level since 1993. DPIWE's principal role is to manage Tasmanian natural resource. In addition to catch and effort data, spatial and technical details concerning fishing shots and vessel characteristics are recorded in the database. In this study, the fishing activity is studied at the 'trip' level in order to identify the fishing tactics characterized by the spatial distribution of fishing. Because of the lack of information on the real duration of fishing trips in the fishery, trips used in this study are defined as the monthly aggregation of fishing operations for each vessel.

The Tasmanian rock lobster fishery being a single species fishery, the different fishing activities are defined by the time and place when fishing occurs. To account for the change in fishing tactics, the description of the fishery is carried out for all years of data 1993 to 2006 simultaneously. Before the analysis, 6889 trips with missing information on location, catch or effort were removed, leaving 24097 trips to analyse. However, the size of the dataset led to computational issues and given the importance of spatial allocation (Fig 2), the dataset was divided into groups with respect to the origin of the vessels. Hence, eight groups were formed according to vessels home ports: 'SE' south-east (area 1) except Hobart, 'HBT' Hobart, 'E_C' east coast (areas 2 and 3), 'N_C' north coast, 'W_C' west coast (areas 6 and 7), 'FI' Flinders Island (north-east of Tasmania), 'KI' vessels from King Island (north-west of Tasmania) and 'OTH' with vessels from other states (Fig 2). King Island and Flinders Island were separated from the north coast because as islands the possible alternative activities fishers can undergo are different from Tasmania's main land and this can influence the fishers behaviour. All analyses were performed with the statistical software R (R team, 2008).

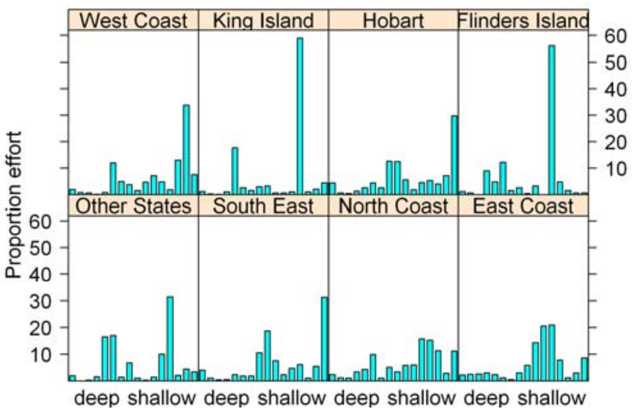

Figure 2 Spatial distribution of effort into the eight areas and depth range for the eight regions of origin

2.2. Methodology

The fishing tactics are determined from both catch and effort data as Pelletier and Ferraris (2000) advocated. The analysis design is adapted from Ulrich and Andersen (2004), several steps are carried out as described on Fig 3: 1) identification of location profiles, representing the spatial repartition of effort during single trips, 2) identification of catch profiles as lobster categories, 3) analysis of relationship between location and resulting catch. For the first step, identification of location profiles, the Tasmanian waters were separated in a number of fishing areas. Those areas are a combination of the management areas (Fig 1) with a depth gradient, deeper or shallower than 40 meters leading to 16 fishing grounds. The heterogeneity of the stock is captured in those

16 fishing zones covering all the possible combinations of the three gradients: north-south for the size, west-east for the abundance and deep-shallow for the lobster colour. A principal component analysis (PCA) was carried out on the matrix with individual trips in rows, and percentage of effort in each of the 16 fishing grounds as variables. The number of observations or trips analysed ranged from 513 to 5300 for the different regions. The PCA was performed on the correlation matrix in order to have normalized data. The grouping of trips with similar geographical distribution was achieved with a hierarchical agglomerative cluster (HAC) on all the PCA factorials. Ward's minimum variance method (Ward, 1963) was used on euclidean distances. To the author's knowledge, there is no optimal way of choosing the appropriate number of clusters and that number depends on the objectives of the analysis. For a descriptive analysis a high number of clusters would be preferred, while for modelling purposes a lower number of clusters should be favoured. In this analysis, the proportion of variance explained was used to determine the number of clusters retained (Legendre and Legendre, 1998). At each step of the analysis (Fig 3) and for each region, the number of groups was chosen as the number for which the increase of variance explained levelled off (Ulrich and Andersen, 2004).

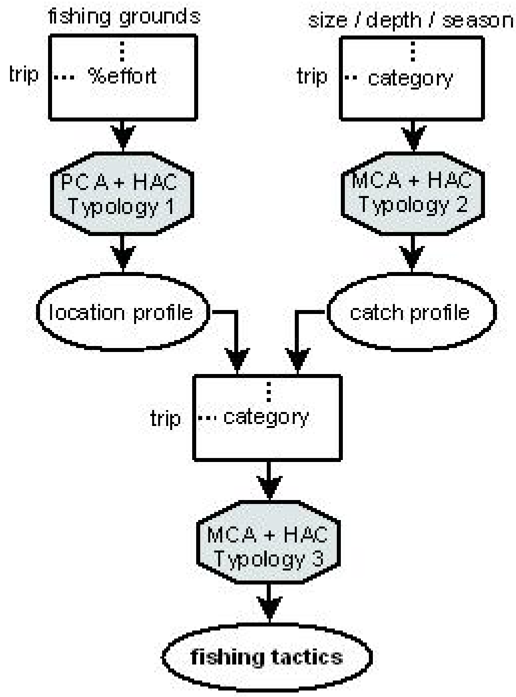

Figure 3 Steps in the analysis

The second step of the analysis (Fig 3) aimed at characterising the catch with regards to the type of lobsters unloaded. The two factors defining lobster categories in the market are the colour and the size. The colour is approximated from the depth at which lobsters are caught with deeper lobsters being sold exclusively on the local market at a lower price. Trips were therefore split into three categories: i) shallow - more than 90% of the catch in shallow waters (less than 40 meters deep), ii) mixed depths - between 50 and 90% in shallow waters and iii) deep – more than 50% of the catch in waters deeper than 40 meters. The size influences the price in the way different sizes are consumed differently. From the information gathered from a processor who exports lobsters to China and have an insight in the Chinese market, four size categories were defined: i) small lobsters, weighing less than 0.8kg are demanded for weddings where each guest is served a lobster, ii) the ones between 0.8 and 1kg are served as half in restaurants, iii) the premium lobsters between 1 and 2kg can be served for two to four guests and iv) the lobsters bigger than two kilograms that are not really valuable because used chopped in cooked dishes. The average lobster size for each trip was computed as the ratio catch weight by number of lobsters caught. The last factor affecting the catch is the catch rate. Because there can be a year effect in the catch rate due to lobster abundance, only a rough indicator of seasonal changes in catch rate was included. Three categories where defined: i) newly moulted lobsters with high catch rates in November, ii) female ban from May to September with lower catch rates and iii) summer months, December to April, with average catchability. A multiple correspondence analysis (MCA) was performed on the matrix with trips as individuals described with the three categorical variables size, depth and catch rate. A HAC similar to the one performed in the first step was then applied on the factorial axes.

In the third step, the location and catch profiles resulting from steps 1 and 2 were used as categorical variables and analysed with an MCA and a HAC as in step 2. The clusters identified in step 3 for each region were examined together and fishing tactics presenting the same characteristics regarding main fishing location, targeted lobster categories and seasonality were pooled manually. The final tactics were all assigned more than 1% of the studied trips per year at least once in the time series.

The temporal evolutions of the final tactics were investigated. For each fishing tactic, the proportion of trips allocated to the tactic was calculated as the ratio the number of trips in the tactics over total number of trips that year and the null hypothesis 'there is no temporal trend in the proportion of trips allocated to the tactic' was tested with classical linear regression models. Proportions were preferred to real numbers because there were more trips with missing information non included in the study at the beginning of the series.

3. RESULTS

Table 1 Characteristics of the final fishing tactics. Catch per unit effort is expressed as average kg/trap. In parenthesis are indicated [1] percentage of effort in locations, [2] percentage of catch in targeted size classes and [3] standard deviation of catch rates. [4] the significance of the trend is indicated by stars * 5%, ** 1%

	Fishing tactics	Trips	Main locations[1]	Targeted size[2]	Season	CPUE[3]	Trend[4]
1	Shallow N	1589	Shallow 5 (49) and 4 (39)	Premium (95)	July to September	0.86 (0.73)	0.04
2	Shallow NW	1922	Shallow 5 (75)	Premium (89)	Winter	0.84 (0.47)	0.10
3	Shallow NE	2121	Shallow 4 (59), 5 (15) and 3 (13)	Premium (96)	Winter and November and December	0.77 (0.45)	-0.03
4	Shallow W	926	Shallow 7 (47) and 6 (16)	<1kg (91)	Average seasonality	1.18 (0.76)	0.02
5	Shallow E	1971	Shallow 3 (36) and 2 (26)	<1kg (86)	Average seasonality	0.76 (0.81)	0.10
6	Shallow mid latitudes	957	Shallow 6 (28), 4 (16) and 3 (15)	0.8 - 1kg (69)	Higher in summer	0.94 (0.50)	0.09**
7	Shallow SW	4141	Shallow 8 (39) and 1 (15)	< 0.8kg (63)	High November	0.92 (0.61)	0.38*
8	Shallow S	2296	Shallow 8 (43) and 1 (29)	< 0.8kg (59)	June and July	0.82 (0.90)	0.32**
9	Deep NW	1476	Deep 5 (25) deep 6 (27)	Premium (51)	November and summer	1.63 (1.18)	0.00
10	Deep SW	2225	Deep 8 (28) and 6 (18)	< 0.8kg (62)	September to February	1.34 (0.90)	-0.47**
11	NW	1212	Shallow 5 (39) deep 5 (30)	Premium (76)	Summer	1.31 (0.67)	-0.04
12	W	403	Shallow 4 (13), 5 (13), 7 (10) and deep 6 (10)	0.8 – 1kg (51)	Except November and December	1.02 (0.51)	-0.00
13	SW	456	Shallow 7 (13), 8 (12) and deep 8 (17), 7 (14) and 6 (14)	< 0.8kg (79)	September to December	1.21 (0.66)	-0.10**
14	S	2009	Shallow 8 (25), 1 (14) and deep 8 (12)	< 0.8kg (74)	November to March (low in winter)	1.00 (0.82)	-0.37**
15	Mix winter	393	Mix of deep and shallow waters of all areas	0.8 - 2kg (96)	Winter	0.82 (0.57)	-0.02

3.1. Typology of fishing activities

The analyses were performed in the 8 cases with vessels originated from different regions. As seen on Fig 2, the spatial repartition of effort is highly dependent on the origin of the vessel. Some regions of origin present highly specialized fishing allocation, e.g. King Island, Flinders Island and other states. Fishers from these regions concentrate their effort in the north of the Tasmania whereas fishers from the north coast, east coast, west coast, south east and Hobart distribute their effort more evenly around the state. The first step (Fig 3) was applied on datasets for each region and resulted in the identification of 15 to 19 location profiles accounting for 79 to 83% of the variance. The location profiles were all described by one or several dominant fishing grounds. In the case of several fishing grounds, they were always adjacent, either in the same area at different depth or in neighbouring areas at the same depth. The additional fishing grounds present were usually shots made on the way, between the home port and the targeted fishing ground. The catch per trip was characterized with the three categorical variables, size, depth and season, and grouped into six to eleven clusters explaining 83 to 97% of the variance. Most groups were described by one or two strong categories, either size, colour or season. The number of clusters selected for the first two steps of the analysis were voluntary high to keep as much information as possible in terms of location and catch. Some of the clusters were redundant or had low allocation (less than 1%) but they were all kept for the third step.

The third step (Fig 3) combining catch and effort information for each region resulted in the identification of five to eight groups of trips explaining 89 to 97% of the variance. The total amount of clusters in this final step was 53. Those clusters were pooled manually into 15 fishing tactics by looking at the dominant fishing grounds, the relative importance of the clusters (with 1% of trips as trigger point) and the similarity with other clusters in terms of lobster categories and seasonality. As described in Table 1, the importance of each fishing tactics in term of number of trips varies from 393 or 403 for tactics 12 and 15 to more than 4000 trips for tactic 7. Eight of the final tactics are targeting shallow waters and red lobsters exclusively, two are entirely focused on deep water with high catch rates and the remaining five combine deep and shallow fishing grounds. The geographical repartition along latitudes shows that a third of the tactics are in the north targeting premium lobster (tactics 1, 2, 3, 9 and 11), a third in the south targeting small lobsters (7, 8, 10, 13 and 14) and four tactics towards mid latitudes with lobsters weighing between 0.8 and 1kg (4, 5, 6, 12). The last tactic combines trips from all over the state with a high range of lobster sizes and colour but mostly winter trips. In average, the dominance of a few fishing location is higher for shallow tactics (higher percentages of effort in the main locations). In fact while fishing in deeper areas, fishers also set a few traps on the way, spreading the effort in terms of proportion.

3.2. Trends in activity

The allocation of trips to tactics evolved over the period. Most tactics (1, 2, 3, 4, 5, 9, 11, 12 and 15) conserved the same proportion of trips, with low, non significant trends (table 1). Few tactics showed significant reduction in the allocation of the trips, the allocation of fishing trips in the south-southeast areas in summer decreased by 0.1 to 0.47 percent per year. The decrease in proportion in those tactics was counter-balanced by the concentration of trips in the shallow southern areas and shallow mid-latitudes (tactics 6, 7 and 8).

4. DISCUSSION AND CONCLUSION

The introduction of an ITQ system in the fishery in 1998 led to changes in the fishery, one of them being the reduction of the number of vessels by a phenomenon called rationalization. The number of vessels operating in the Tasmanian rock lobster fishery fell from 325 in 1997 to 216 in 2006, this led to a reduction of fishing trips and therefore the only meaningful trends to investigate were the relative allocation of trips. ITQs are also believed to have had an effect on the behaviour of fishers who started targeted lobsters with higher market value (Hamon et al. *subm.*). Lobsters from shallow waters are bright red whereas deeper lobster are whitish or 'strawberry', the former are favoured on the Chinese market. Moreover, deeper lobsters are less robust to live transportation, thus fetching lower ex-vessel prices. The reduction of trips towards deep south lobster in favour of shallower areas could be explained by the fisher's will to target higher value lobsters in the south.

The typology of the fishery is useful when fishing allocation varies spatially and seasonally. Due to the variety of the vessels' geographical origins, a synthetic description of effort distribution was hard to achieve. The use of multivariate analyses permitted the objective identification of groups of fishing trips. The scientist's expertise only used later to pool meaningful clusters into sixteen fishing tactics described mainly with the location, depth and season of fishing. The simplification of the effort allocation into few fishing tactics will be used to parameterise the fleet dynamics model. The typology achieved is meaningful in terms of intra-groups homogeneity regarding the type of lobster targeted. Fishers are believed to be reactive to external stimuli such as stock abundance, management and change in prices. The advantage of having the fishery divided into small homogenous fishing tactics is that it restrained the possible choices of fishing allocation while keeping the diversity of tactics that individual fishers might want to apply. This diversity is very important to simulate the reaction of fishers to any perturbation in the fishery. On top of the list is global warming bringing new concerns in the Tasmanian rock lobster fishery. Recruitment has been poor for the past few years in the northern areas (Haddon and Gardner, 2008). The lack of recruitment is a major issue in the fishery and it could be linked to the change in water temperatures perturbing the settlement of puerulus (lobster juvenile form). The lobster population being stationary after the larval stage, the lack of puerulus settlement will lead to local depletion in the northern, warmer part of the state. The implication for management is really important as management measures need to be robust to a great range of unexpected events.

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