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Analysis of fishing effort allocation and fishermen behaviour through a system approach

(Running Head: Fishing effort allocation in TCI fisheries)

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Abstract:

In the present paper we analyse the fishing effort allocation of fishermen in the artisinal fisheries of the Turks and Caicos Islands. These fishermen use free-diving technique to exploit simultaneously the local stocks of queen conch and spiny lobster. Using a system analysis approach, i.e. an integrated multi-disciplinary analytical framework where emphasis is put on the interactions (linkages) that exist between the different components of the fisheries, we attempt to identify the biological, economic and social mechanisms which govern the fishermen' effort allocation between the two targeted stocks. The analysis shows that the seasonal dynamics of the whole system is essentially dictated by the lobster fishery. Although this result tends to espouse the predictions of classical economic theory, the analysis also shows that fisherman individual economic rationality is in fact "overcome" by a set of collective and individual constraints related to the specific qualities required to operate in the two fisheries. In particular the higher skill and diving abilities necessary for lobster fishing and the higher labor intensity nature of conch fishing makes lobster fishing appear as a more "noble" activity than conch. This explains that even when bioeconomic incentives are in favour of conch, fishermen still allocate a higher share of their effort to the lobster stock.

Keywords:

Fishing effort allocation, Fisherman behaviour, System analysis, System management, Conch and Lobster artisinal fisheries, Turks and Caicos Islands.

Introduction

Necessity to integrate fishermen behaviour

It is now well admitted that fisheries science, in its central attempt to understand the joint dynamics of both fish stock and fishermen, should not merely focus on fish population dynamics but should also integrate the analysis of fishermen behaviour and fleet dynamics (Opaluch and Bockstael 1984, Hilborn 1985, Allen and McGlade 1986, Hilborn and Walters 1992). This statement derives from the recognition that efficient regulations can not be found and fisheries be properly managed if the whole dynamics, in particular fishermen behaviour, is not well described and understood. Hilborn (1985) for instance recalls that the crises in the Canadian cod and salmon fisheries in the 1980s were not due to a lack of knowledge of the exploited stocks, but rather to external factors and the failure to understand and manage fishermen. Likewise, Glantz and Thompson (1981) successfully managed to show that the collapse of the Peruvian anchoveta fishery was not due to a biological collapse of the stock following the 1971 El Nino event but rather to the inability of the Peruvian authorities to reduce the fleets' fishing effort in the two subsequent years. In fact, experience suggests that failure to anticipate and respond to fishermen's allocation and redistribution of effort among fisheries and harvest areas can result in severe declines or collapse of fish stocks. Understanding the response of fishermen to changes in biological, economic, and regulatory conditions in fisheries is thus critical to designing management plans that will sustain both resources and fishing activities. In other words, as asserted by Opaluch and Bockstael, "the fishermen's decision as to allocate effort level is perhaps the most important type of behaviour to be understood" (1984, p.3) if one wishes to maintain the biological (stock) and anthropic (human) viability of fisheries. The present paper espouses this statement. The main question to be addressed is the understanding of fishing effort allocation and the empirical example on which the study relies is the artisinal fisheries of the Turks and Caicos Islands, a group of seven small islands located at the south-eastern end of the Bahamas archipelago (British West Indies).

Fishing effort allocation: theory and empirical studies

From a methodological point of view, the understanding of fishing effort distribution can be addressed through two main steps: (1) description of the patterns of fishing effort and (2) identification of the rational which governs the allocation of this fishing effort. The patterns are the changes in fishing effort allocation that present some degrees of periodicity, seasonality or regularity and which can thus be pointed out from the general picture. These patterns are spatial and temporal in a mono-species fishery, and spatial, temporal and inter-species in a multi-species fishery. The rational is the rule or set of rules which governs the fishermen' decision making process underlying the effort distribution. In theory, assuming "average" fishermen with homogeneous behaviours, the prediction of the distribution of fishing effort is straightforward: it will be determined by the expected economic returns to individual fishers from fishing in alternative fisheries and locations (Gordon 1953). Empirical studies, however, reveal that simple models based on ad hoc behavioural assumptions about aggregate effort may not provide accurate predictions of effort distributions. Even in a mono-species fishery, where the decision making process applies only to the spatial and temporal allocation of effort on one species, the effort distribution turns out to be the outcome of a multi-component choice which usually includes fishermen' past (traditional) patterns, various risk-taking/risk-averting factors, the cost and catch expectations, available technology, management regulations, biological availability of the stock, general markets conditions, etc. (Hilborn and Walters 1992). Béné (1996, 1997) for instance shows that in the case of the French Guyana brown shrimp fishery, the fleet's effort allocation results from the combination of stock availability, market constraints and the structure of the crew remuneration system. In the case of the northern California pink shrimp fisheries, Eales and Wilen (1986) shows that the fishermen' decision on where to fish is largely influenced by the position of the fleet on the preceding day. Likewise in the New Zealand hoki fishery, Vignaux (1996) showed that the fishermen apply the same type of strategy, except that they use their own catch rates of the previous day to decide where to fish and only integrate information about the location of the rest of the fleet if their individual catch turns out to be low.

In multi-species fishery, components of fishing effort become more heterogeneous and therefore more difficult to link to factors related to single population of fish. This makes the prediction of distribution of fishing effort between species, areas, and time period much more complex. Very few empirical studies have attempted to address this question. Hanna (1992), analysing the Oregon shellfish and groundfish fisheries, concludes that the major elements that drive the fishermen choice between groundfish, shrimp, and crab stocks are the seeking of risk reduction, changes in relative prices of the targeted species, changes in markets conditions, and processor arrangements. More recently, Holland and Sutinen (1999) developed a sophisticated statistical model that tends to describe the effort redistribution between different areas of the multi-species trawl fisheries of New England. The model shows that skipper's experience in particular areas and fisheries affects their propensities to fish in the same areas/fisheries in the future. The authors suggested that this may be due to comparative advantages based on individual knowledge of the areas and species, but may also reflect a tendency to maintain traditional fishing patterns despite potential gains that could be derived from altering these traditional patterns.

An answer to the complexity of fisheries: the system analysis approach

These different empirical models show that reality is far more complex than suggested by the "simple" theoretical economical model of Gordon where effort is distributed in such a way as to equalise average profit rates among areas. Environmental, social, historical, political and anthropological elements have to be added to the economic incentives if one wishes to understand the process that governs the allocation of fishing effort. We are in fact facing a rather complex dynamic and multi-disciplinary process.

There are two major ways in science to address such a complexity. The first approach is to break down the problem into as many separate elements as might be possible and then rely on additive and static cause-effects explanations to predict the properties of the whole system. This so-called "analytical" method works admirably well insofar as observed events are apt to be split into isolable causal chains (one cause - one effect) between two or a few variables. This is the approach adopted by Holland and Sutinen (1999) in their model of the New England fisheries.

The complementary approach is the system analysis (or systemic approach). This approach tackled the problem from a different angle. It asserts that concepts like organisation, human behaviour, goal-seeking and purposiveness do not result from simple additive and linear causal trains and consequently can not be "captured" in analytical models. This approach is based on the empirical observation that real systems acquire qualitatively new properties through emergence, resulting in continual evolution. In that case the behaviour (or properties) of the whole system can not be predicted by adding together the properties of the individual elements since the system will be displaying a more complex behaviour with new (emergent) properties. The main feature of the systemic approach is thus to consider systems in their totality, their complexity, and their own dynamics. It concentrates on the interactions between the elements (rather than their nature like in the analytic approach) and studies the effect of these interactions on the dynamics of the whole system. This is the approach adopted by Hanna (1992) in her analysis of the Oregon multi-species, multi-fleet fisheries. This is also the approach adopted in the present study for the Turks and Caicos Islands fisheries.

The Turks and Caicos fisheries: an easy switch between conch and lobster

Today the fishing activity in the Turks and Caicos Islands (TCI) consists essentially of the exploitation of the local stocks of two of the most important commercial species in the Caribbean: the Queen conch (*Strombus gigas*) and the Caribbean spiny lobster (*Panularis argus*). In TCI, both species live in the shallow-waters of the Caicos Bank, which provides an ideal habitat. The TCI fishery, which lands more than 750 t of conch per year, is now the second largest supplier of conch meat to the US market, accounting for more than 26% of the total US imports (Mulliken 1996). At the same time, the fishery, with a yearly landing volume of about 350 t of lobster, yields an average gross income of US$ 1.8 million to the local fishermen (Department of Environmental and Coastal Resources, unpublished data). The two stocks are exploited on various fishing grounds of the bank by the same community of fishermen who use only one fishing technique (freediving, i.e. breath-hold diving) with mask, fins and snorkel, to fish lobster (collected using hooks) and conch (collected by hand) from small 3-4 m, 40-90 h.p. engine boats. The fishermen can therefore switch very easily from one stock to the other. The decision making process that governs this switch, however, does not appear to be a random or haphazard process. Instead, it seems that fishermen follow specific (and possibly) quantifiable processes. Using a system analysis approach, the purpose of the present study is to understand the overall fishing effort distribution of the TCI fishermen through the description and the analysis of the switch between conch and lobster stocks.

Materials and Methods

Nature of the data and techniques used

Whenever possible, accurate quantitative data were assembled to identify the dynamics and the trends characterising the TCI fisheries but also to describe the local economic environment within which these fisheries have developed. In particular, the time-series of the TCI solar salt production, which turns out to be a key-element in the evolution of the conch fishery, has been included in the analysis. For this quantitative material in general, daily, monthly, or yearly data were utilised, depending on the phenomenon analysed. Some basic techniques of time series analysis (time series decomposition) were applied at some stage of the analysis. Qualitative information, either from previous studies or from personal unpublished data, was also used to characterise the social background of the community and more globally the socio-historical environment of the fisheries. Finally, optimal foraging theory was utilised as a basic guide to interpret some aspects of the fishermen's behaviour.

Data sources

The quantitative material was acquired from different sources. The monthly series of the total landings, fishing effort, and total landing values over the period 1989-1998 for both lobster and conch were extracted from the Department of Environmental and Coastal Resources (DECR) data basis. The annual series of lobster landings over the period 1947-1984 were obtained from Olsen (1985) along with the annual series of conch landings recorded over the period 1904-1984. These data however had been obtained by Olsen from various unpublished reports from the DECR and two individual studies (Kurcharchy 1982 and Simon 1983). Using different sources of information (DECR unpublished data and Sadler 1997) we were able to extend the conch landing series back to 1887. The annual data of salt production over the period 1879-1968 was obtained from Gregory's research (1970). Finally, since individual fisherman skills revealed to play a major role in the decision making process, individuals' daily data on landings and fishing effort were also extracted for the period Aug.95-Jul.98 from the DECR data set.
For the qualitative information, the authors used personal data obtained when employed at the Center for Marine Resources Studies (CMRS), along with several unpublished reports (Blackman 1992, Dow 1992, Gitlitz 1992, Purdy 1997, Tilney 1998) available at the CMRS. The CMRS, located on the island of South Caicos, where the majority of the fishing activity takes place and the largest fishermen community is established, offered a perfect basis for these social studies.

Organisation of the paper

The paper begins by describing the historical development and current context of the TCI fisheries. We will then move on to the core of the analysis by addressing the two main analytical steps mentioned earlier: (1) description of the patterns of fishing effort, and (2) analysis of the decision making process underlying the effort distribution. For both steps, emphasis will be put on the interactions (linkages) that exist between the different components of the fisheries but also between these components and the general economic environment of the fisheries. The nature of these linkages will be outlined through the identification and analysis of several factors (ecological, economic, social, and anthropological) which govern, at both global (fleet) and individual (fisherman) levels, the interchanging of the fishing effort (switch) between the two targeted species. These analyses will be conducted over different time-ranges: century and decade, using yearly data, and season using monthly data. Finally, the biological and socio-economic consequences imposed on both stocks and fishermen by the linkage between the two fisheries will be emphasised, and some of the implications that this linkage induces in terms of fisheries management will be discussed.

Historical development and current status of the TCI fisheries

The earliest stages of the conch fishery development

Queen conch has been a principal food source for the TCI inhabitants since the indigenous Lucayans and Arawack Indians first used these islands, initially as temporary fishing platforms. Later the Bermudans, loyalists and descendants of slaves and plantation workers who had stayed on the islands, continued to fish conch, primarily for local and personal consumption (Sadler 1997). The stock first became exploited for commercial purposes in the middle of the 18th century (Doran 1958). The trade lasted until the 1950's. At that time, conch were fished from small boats worked by two men, one driving the vessel while the other looked for conch though a waterglass. Conch were thus caught from depths up to about 7 meters (approximately 25 feet) using a conch hook (a two-pronged rake at the end of a long pole) and a good crew of two could on a good day capture up to 1000 conch. The conch were then dried and shipped aboard sailing sloops to Haiti. In Fig.1 the TCI landings series is presented for the corresponding period (1887-1954). The visual analysis reveals that the landings have been fluctuating rather substantially over the whole period with two periods of remarkably high landings, one around 1915-1918 and the second from 1942 until the end of the 1950s.
When they occur closely after war events, periods of high landings are classically interpreted as the result of stock recoveries due to low fishing activities during the hostility periods. In general, in those cases, the change in landings is assumed to reflect the dynamics of the stocks. This is for instance what is though to have happened for most of the North Atlantic stocks after WWII, where the post-war catch rates were particularly good (Saville 1980). In the case of TCI conch, however, the periods of high landings *do not follow* but are *simultaneous* with the war periods. Our conjecture is that these peaks in the landings do not reflect changes in the stock abundance but changes in the historico-economic environment of the Turks and Caicos Islands, as will be explained now.

In TCI, the history and economy have been dominated over the last two centuries by the production of solar salt which has represented for a long time the unique source of economic revenue for the islands. The first "salinas" (the portions of land used to produce salt from natural evaporation of seawater) are said to have been created around 1673 (Sadler 1997). South Caicos rapidly became the leading salt producing area of the whole archipelagos. The production of salt was arduous and labour intensive, and the majority of the islanders were involved in the activity of raking, packing and loading the salt on vessels which then shipped it around the world. The production was exported to Europe (mainly U.K.) and North America. Turks and Caicos Islands dominated the salt trade with the United States for years, constituting about 80% of the imports until Word War II (Gregory 1970). The salt was also exported to Canada where it was used essentially by the cod fisheries of Newfoundland. With the advent of World War I and II, however, much shipping was diverted to the war effort in Europe and despite a high demand of salt due to the slowdown of the Mediterranean production, increasing difficulties of transportation dramatically reduced the Turks and Caicos salt exports. This drove people out of the salt industry and into the only alternative activity at that period: fishing conch. These switches of labour between salt industry and conch fishing during the two world wars appear clearly on Fig.1.

After World War II (unlike the years following World War I), the salt industry had no chance to recover. In 1946, the British Government stopped purchases and salt production immediately sank to extremely low levels. The salt industry survived few more years with the last operating company closing on 31 December 1964. This event ended almost three hundred years of salt production in the TCI.
From this historical analysis, two points need to be emphasised. (1) The large fluctuations observed in the conch landings series do not reflect changes in the stock abundance (as classical approach might have suggested) but reflect a modification in the dynamics of the whole socio-economic system of the Turks and Caicos Islands. (2) Conch already appears as a "secondary" resource to which men switch when the productivity of the primary resource (in the present case the solar salt production) is reduced.

The post World War II period: development of the lobster industry

Between the two World Wars, a commercial lobster fishery was initiated in the TCI. From the 1930s to the 1950s, fishermen used nets fixed on poles approximately 20 feet long and waterglasses to fish the shallow waters from boats. This technique, which was made possible due to the very high abundance of lobsters in shallow waters, remained common until the early 1960s. In 1956, however, twenty American free-diving fishermen and the French record breath-holding diver Jacques Mayol introduced the free-diving technique to the fishery (J. Mayol, South Caicos, Nov. 1997, pers. comm.). The introduction of the free diving technique, using masks, snorkel, and fins to access the stock, as well as the rapid adoption of the hook as the fishing gear changed the character of the fishery. Prior to the hook, «tosses», (local name for wire nooses) were used as the common gear with the free diving technique. The hook, however, which was first used during the 60s, rapidly turned out to be a much more efficient catching technique. Indeed, conversely to the toss (or the net used from boats) for which lobsters had to be outside their dens to be caught, the hooking technique allows fishermen to catch the animals from within their dens where they aggregate during the day.

The development of the lobster fishery is represented on Fig.2.a through the series of landings over the period 1947-1984. The curve presents the classical succession of phases that characterise the development of a new fishery (compare for instance with Fig.4.1, p.105 in Hilborn and Walters, 1992). Using these authors' terminology, it can be said that, from 1947 to around 1967, the fishery went through a period of "initiation through exploratory activity" (characterising the first stage along the development of a new fishery), followed from 1967 to 1984 by a period of "growth and later decline to the bionomic equilibrium" (where the rapid entry of new fishermen in the fishery -incited by the efficiency of the hooking technique- leads to a first overexploitation of the stock -which occurred in 1972). On Fig.2.b is represented the conch landings over the exact same period. These conch landings show a constant decline from 1947 to 1967 and a recovery from 1974 onwards.
Represented as such (i.e. as two separated times series) the conch and lobster landing series describe the individual dynamics of the two fisheries (independent succession of states $X_i(t)$, i = 1,2 as functions of time t). This representation is the classical (analytical, segmented) way to describe a phenomenon. Another way is to look at the relationship (linkages) that may possibly exist between two variables through the construction of the phase-diagram of the system. In a

phase-diagram, the simultaneous states of the variables are represented as couples of co-ordinates along the X-Y axes of the diagram. Fig.3 represents the phase-diagram between the landing series of conch (X-axis) and lobster (Y-axis) over the same period than Fig.2, i.e. 1947-1984. In other words, Fig.3 is another way to represent the information contained in Fig.2. However, the interpretation of the phase-diagram gives a completely different insight into the dynamics of the fisheries. It shows that the whole TCI fishery, as a system composed by two subsystems (the conch and lobster fisheries), is characterised by a strong linkage between the two individual fisheries. Over the period 1947-1960, the fishery was fluctuating around a first bionomic equilibrium state with low lobster catch (around 500 tons per year), few fishermen involved in that activity, and a high levels of conch landing (around 2.5 million conch per year) caught by the majority of the fishermen. With the introduction of the free diving and hooking techniques which dramatically increased the lobster catchability (higher efficiency), a large number of fishermen switch and started to target this species. This made the landings of lobster increase and those of conch decrease simultaneously, as indicated on the figure for the period 1960-72. Interestingly enough the switch from one target species (the conch) to the other (the lobster) follows an almost perfect Cobb-Douglas indifference curve (see Fig.3). Finally, in 1972, when the landings of lobster started to decline due to the (very likely) over-exploitation of the stock, the fishermen switched back to the conch fishery, following a slightly deviant indifferent curve that led to a second bionomic equilibrium.

In summary, the phase-diagram suggests two major conclusions. (1) The dynamics of the whole fisheries system seems to be governed by the existence of a strong interrelationship between the two fisheries. This strong linkage results from the switching behaviour that the fishermen have developed between the stocks of lobster and conch. (2) The two targeted species are considered as two substitutes by the TCI fishermen, but in an asymmetrical way: lobster seems to be the "preferred" or primary target, its availability/abundance determining the move along the indifference curves, while conch looks like a "secondary" target to which fishermen return when the availability/abundance of lobster decreases.

During the rest of this paper, we will show that the switch between conch and lobster takes place at both inter-annual and intra-annual (seasonal) time-scales. Secondly evidences will be presented that the fishermen' preference for lobster is a phenomenon which involves bio-economic as well as socio-anthropological factors, and that this phenomenon has roots at both the aggregate (i.e. fleet) and individual levels.

Patterns of fishing effort

Intra-annual dynamics of the switch

In TCI the official lobster season runs from August 1 to March 31 whereas conch is fished all year round. Over the four months of the lobster closed season (April 1 - July 31) no lobster landings are allowed in the entire fishery. This regulation obviously determines, to a large extent, the allocation of the fishing effort and subsequent landings over the season. Fig.4.a and 4.b represent the 1989-1998 series of monthly fishing effort and landings for the two species. Fig.4.c represents the associated catch per unit of effort (CPUE) data for the two species. In absence of better, i.e. direct, stock assessment data, CPUE series can be used as rough indicator of stock abundance. These CPUE are thus assumed to reflect the resource availability/abundance within the successive seasons.

All six series exhibit clear-cut seasonal patterns which can be identified and quantified through a seasonal decomposition. We used in the present case the multiplicative ratio to moving average procedure (Makridakis et al. 1983) based on the following formulas:

$$I_j = 100 \times \frac{1}{K} \sum_{k=0}^{K-1} \frac{x_{j+12k}}{T_{j+12k}} \text{ for conch, and } I_j = 100 \times \frac{1}{K} \sum_{k=0}^{K-1} \frac{x_{j+8k}}{T_{j+8k}} \text{ for lobster,}$$

where I_j is the seasonal index for the month j (j = 1 to 12 for conch and 1 to 8 for lobster), $k = \{0, \ldots, K-1\}$ K being the number of seasons for the whole time series (K = 9 in the present case), x_{j+12k} and x_{j+8k} are the raw data in months j+12k or j+8k, and T_{j+12k} and T_{j+8k} are the corresponding trend values estimated by centred 12 or 8 moving average procedures. The seasonal indexes are furthermore expressed in percentages to allow for comparison. These indexes are displayed on the three diagrams on the right side of Fig.4.

The three seasonal indexes show that during the first month of the season (in August) when lobster availability is very high (Fig.4.c), fishermen exclusively concentrate on this stock (Fig.4.b), catching as many lobsters as possible (Fig.4.a). Analysis of the data shows that about 35 to 40% of the total annual catch are landed during the first month of the season (August). Locals call these first weeks of high lobster harvest the "Big Grab". The consequence of the Big Grab on the stock is disastrous and the abundance of lobster declines sharply in the following month (the average drops after the first month is 26% for the period 1989-1997). Consequently, a significant number of fishermen switch to the conch stock in September and October (see Fig.4.b). The remaining of the season is characterised by a slow decrease in effort for both conch and lobster until January-February where a minimum is reached in both fisheries (Fig.4.b). This corresponds to the winter period where the weather conditions (wind, waves, and water temperature) make the diving conditions more difficult. The winter months also correspond to the period where conch are known to move to deeper feeding grounds and to bury themselves in sand to protect against rough environmental conditions (Randall 1964, Hesse 1979). This behaviour affects conch availability, which is reflected in the very low CPUE value observed in January (Fig.4.c). After the lobster season ends in March, the fishermen re-direct their effort toward conch, as clearly shown by both effort and catch indexes for April and May. Finally, the last two months (July and August) are characterised by a significant decrease in the conch availability (Fig.4.c). Since nothing in the biological cycle of the animal nor in the external environment (e.g. weather) allows to explain it, this decline in CPUE may be seen as the biological consequence of the drastic increase in fishing effort that takes place over the two precedent months.

The reading of these seasonal indexes raises a series of comments in terms of management implications. These will be addressed in the discussion section. At this stage, two points need to be emphasised. (1) The identification of clear-cut patterns in the effort allocation of both lobster and conch fisheries indicates the strong linkages that exist between the two fisheries at the seasonal scale. (2) The seasonal dynamics of the whole system is essentially dictated by the dynamics of the lobster fishery (biological availability, seasonal closure). Lobster therefore does appear to be the primary target and conch is only targeted as a second option.

Inter-annual allocation of effort

It is possible that the linkages observed in Fig.4 at the seasonal scale may also occur at the inter-annual scale and that lobster abundance acts as the predetermining factor of the effort allocation at the inter-annual scale. If this assumption (which was already suggested by the landings data analysis in Fig.3) is correct, then a dynamic relationship should link the effort distribution to the annual lobster availability/abundance index. In particular, the share of the total effort allocated to the lobster stock should increase when the lobster availability/abundance increases and vice versa. Fig.5 displays that dynamic relationship: the Y-axis represent the percentage of the time spent by the fishermen fishing lobster and X-axis represents the annual lobster CPUE data. The percentage of the fleet effort spent on lobster is an index of the fleet effort allocation between lobster and conch, and the CPUE series is used as indicator of the stock abundance/availability. The dynamic relationship (represented by the arrows) that links the two variables appears very clearly on the diagram. As expected the effort allocated to lobster decreases (increases) with the decline (increase) in lobster availability. Furthermore the almost perfect linear shape of this relationship indicates that there is no delay phenomenon in the dynamics: the fishermen responds instantaneously (i.e. during the same season) to changes in lobster availability (a delay in the fishermen' response would have induced a circular shape in the relationship).
This analysis confirms that lobster is regarded as the primary species by the fishermen, who accordingly allocate their effort between the two stocks depending on the availability/abundance of lobster. This last result extends the previous analysis of seasonal decomposition by revealing that the allocation of effort does not only vary within the fishing season but also from one season to the other. The pattern of effort allocation is thus characterised by a double mechanism of adjustment which takes place at two different time-scales.

Decision-making process of effort allocation

A first look at the bio-economic paradigm

Economic theory predicts that fishermen behave as rational economic actors and, as such, should distribute their fishing effort according to the expected economic returns from fishing in alternative fisheries. In the present case this would imply that fishermen target the species with the highest expected return (let's say lobster) and switch to the other species (conch) when the expected return from lobster falls below the conch's return. Expected return is not directly measurable, but it can be approximated through the bioeconomic revenue per unit of effort (RPUE), where RPUE is calculated as follows:

$$RPUE_{i,j} = CPUE_{i,j} \times p_{i,j}$$

with $CPUE_{i,j}$: the annual CPUE value of the stock i for the period j (assumed to reflect the average availability/abundance of the species for that period) and $p_{i,j}$: the unit price of the species i for the same period j (reflecting the economic incentive of targeting this species).
The annual RPUE for the two fisheries were computed over the period 1989-1997 and the difference between the two RPUE was calculated for each season. These RPUE differences indicate for each season which fishery was the most attractive (bio-economically speaking) for

the fishermen. A positive difference (a point on the right hand side of the diagram) for a given season means that the lobster fishery was more attractive than the conch fishery for the season considered. Conversely, a negative RPUE difference means that conch has been more attractive than lobster. The percentage of the fleet effort spent on lobster is reported along the Y-axis. The points on the diagram represent the empirical combinations (RPUE, effort allocation) characterising the fishery for each season over the period 1989-97. The objective is to try to determine whether fishermen did respond to the bioeconomic indicators in a rational economic manner. If fishermen based their decision on the respective expected returns from the two species, a vertical switch in the effort allocation should be observed when the RPUE difference crosses the 0 value along the X-axis, and the curve should consequently display a S-shape, as illustrated by the dotted line on the diagram. From the view of Fig.6, three major remarks can be pointed out. (1) The majority of the points are located on the right hand side of the diagram, which means that over the period 1989-1997 the lobster fishery has yielded higher annual RPUE than the conch fishery. This can explain partially the fishermen's preference for lobster. (2) Logically the proportion of effort allocated onto lobster increases along the Y-axis when the RPUE difference increases along the positive part of the X-axis. (3) However, the general shape of the trend is different from the rational economic S-shaped curve. The trend is almost linear and the values stay well above 0.5 even for negative differences. In particular, the intercept value of the estimated trend is 63.78%. From the empirical point of view, this means that when the lobster fishery stops to be more attractive than the conch fishery (on the basis of the bio-economic indicator $RPUE_{i,j}$), the TCI fishermen still allocate more than 63% of their fishing effort on lobster. This suggests that the fishermen do not merely rely on bio-economic rationality to allocate their effort preferentially on the lobster fishery. This preference has to have some foundation outside the sphere of the bioeconomic paradigm.

Socio-anthropological analysis at the individual level

So far, the fishing effort allocation has been described, relying on aggregated data (i.e. regrouping the whole fleet) and assuming fishermen to behave as rational economic actors prompted by profit maximisation. However, this approach is misleading at two levels: (1) Basing interpretations on aggregated data can be limited by the difficulty of capturing the logic and the behaviour that characterise fishermen as individuals. (2) Individual (or even collective) behaviour will very often result from a combination of factors and considerations that go beyond the simple profit maximisation principle usually adopted by economists to try to explain fishermen behaviour. In particular, it has been observed in the previous section that this approach does not allow an explanation of the aggregate shared allocation of effort between the two stocks. It remains to understand why TCI fishermen still allocate more than 63% of their effort on lobster when the bio-economic indicator suggests that fishing conch would be more profitable. For this, we concentrated on the fishermen behaviour at the individual level, using a series of socio-anthropological surveys recently conducted within the fishermen community of South Caicos (Dow 1992, Blackman 1992, Purdy 1997, Tilney 1998). The question we tried to answer was: "What is (are) the factor(s) that would explain the fishermen' preference to land lobster rather than conch even when the lobster RPUE is lower than that for conch?"
The review of the different surveys reveals that although this preference phenomenon is the result of a combination of various factors, these factors can be regrouped under two major generic

categories: (1) a "peer" or "community" pressure, and (2) an individual incentive. These are presented below.

The community pressure

An important "peer" or "community" pressure exists amongst the fishermen of South Caicos. This pressure derives from the fact that fishermen who can make their living from fishing exclusively lobster will enjoy a higher social status within the community than other fishermen. Surprisingly enough this social phenomenon is related to the ecology of lobster and conch based on two reasons: (1) mature lobsters are caught from within their dens where they concentrate during the day. These dens (and a fortiori the lobsters) are not always visible from the surface. Their location thus requires a great deal of experience. Conch, on the other hand, are nearly immobile animals found in visible aggregations on the sandy plains that cover a large portion of the bank. Their capture, therefore, does not require a particularly high skill level. (2) Data analysis (Dow, 1992 and Béné, unpublished data) reveal that productivity in the lobster fishery depends on the fishermen' ability to dive deep, while, on the other hand, depth does not appear to affect productivity in the conch fishery.
Thus, lobster fishing, both for site location and catching technique, requires more skill and experience than conch. This reality is largely recognised within the fishermen community and the free divers who catch preferentially lobster (and implicitly display increased fishing skills and ability to dive deeper) consequently enjoy a higher social status. For illustration, Blackman (1992), when ranking a group of South Caicos free divers through a class system based on direct observed social cues (greetings, welcome, comfort in presence of other persons, reprimand, etc.), emic ranking (perception by the other local fishermen) and productivity (individual landings), observed that one divers had a lower emic ranking than suggested by the direct cues and the productivity rankings. Further investigation by Blackman revealed than this fisherman was the only shallow water diver in the group surveyed.
In summary, the TCI fishermen face a community pressure which induces them to fish preferentially for the lobster stock, regardless of its bio-economic relative status with respect to the conch stock.

Individual incentive to fish lobster

The survey analysis also reveals that fishermen have strong individual incentives to fish preferentially for lobster. These incentives can be loosely related to the "optimal foraging strategy" theory (even if no full attempt to apply this theory will be done in the present article). In human ecology, optimal foraging theory has been particularly useful in studies of hunting strategies (see Smith 1983 for a critical review) and a few studies have attempted to apply it to fishing strategies (McCay 1981, Beckerman 1983, Begossi 1992). In short, optimal foraging theory regroups a large number of different models (diet-breath, patch choice, time allocation, foraging-group size, etc.) that apply to specific situations and address different questions regarding hunting strategies. The general principle underlying these models is that predators (in this case fishermen) will attempt to maximise their return (landings) while minimising their costs (effort). Therefore, if a fisherman has to choose between two species (lobster and conch) which yield the same return (catch $\times$ unit price) at a given period in the season, optimal foraging theory predicts that the fisherman will go for the one which requires the lowest cost (effort). In this regard, it is necessary to mention a few additional details about the two fisheries. Beyond the fact that the unit price for lobster is around 4 times higher than for conch (US$ 2.65 per lb. versus US$ 0.70 per lb. for the season 1997), lobster are sold whole to the processing plants, while conch are knocked by fishermen at sea (i.e. the animal is removed out of its heavy shell) with only the meat being landed at the plants. Therefore, to yield the same return at the dock, the conch diver will have to make a much larger number of dives with the added burden of repetitively carrying up the heavy conch shells to the surface. Conch is thus a much more labour intensive, strenuous activity than lobster, and interviews of fishermen do confirm this: "Lobster requires more skill but conch takes a lot out of you" (A. Duncanson, South Caicos fishermen, in Purdy 1997). Following the general principle specified above it appears clearly that for the same return, fishermen will prefer to fish lobster which is associated with a much lower fishing burden than conch.

When combined together, the major features differentiating lobster from conch fishing (the higher skill and diving abilities required for lobster and the higher labour intensity component for conch) make lobster appear as a more "noble" species than conch. This explains that even when the bioeconomic incentives (i.e. RPUE) are in favour of conch, fishermen still allocate a higher share of their effort to the lobster stock.

Diving skill as the principal limiting factor for fishing lobster

Although fishermen are collectively and individually driven to fish preferentially for lobster, some of them switch to conch during the lobster season when the availability of lobster is apparently still relatively high. Different surveys (Purdy 1997, Tilney 1998) provide the explanation of this behaviour. These studies reveal that the principal individual factor that leads fishermen to switch to conch is their physical ability/limitation to dive. This is in agreement with the conclusions proposed above regarding the "peer" pressure. This qualitative information was further confirmed quantitatively by re-analysing Menil's 1993 data. The survey data shows that local divers who define themselves as "lobster fishermen", i.e. who target lobster over the whole season, pretend to be able to operate regularly at depth ranging from 30 to 50 feet (with an average of 43 feet, i.e. about 13 m). "Conch fishermen" who concede that they have to switch to conch very early in the season, admit that they can only operate regularly at depths ranging from 20 to 35 feet (27.5 feet in average, i.e. about 8 m). This difference reveals that divers who are limited by their diving abilities are forced to switch to conch, even though lobster would be their preferred catch. "If I could I would fish for lobster all year" (S. Forbes, South Caicos fishermen, in Tilney 1998).

Whether fishermen actually switch on individual basis to conch is then determined by the perception that each of them has about the respective status of the two stocks counterbalanced by his individual diving abilities. To test this statement, we looked at the daily fishing data for a set of six local fishermen over the three seasons 1994-1996. These seasons corresponds to a critical period for the fisheries since the lobster availability was so low that the conch return exceeded the lobster return (see Fig.6). Fig.7 represents the individual fishermen' responds to this situation. In 1994, all fishermen surveyed were preferentially fishing lobster and the individual strategies were very homogeneous. For all six fishermen surveyed, individual lobster fishing times was concentrated in the top 15 %. Conversely, over the next two seasons, the homogeneity in the fishermen behaviour seems to break up and a new strategy appeared: two fishermen gave up fishing lobster and re-directed their fishing effort toward conch. Those are fishermen who were limited in their diving abilities and were forced to switch to conch due to the low availability of lobster.

Discussion

Limits of mono-fishery, biologically-based management approaches

For the most part, fisheries are managed under mono-fishery biologically-based approaches. This type of management however suffers two major drawbacks. First, although undertaken for legitimate conservation reasons, biologically-based models miss the fundamental essence of fishery management. Fisheries management is not about stock management. It is about managing the interactions between the exploited stocks and the human activities which depend upon the exploitation of these stocks. Consequently, within fisheries science, the study of fishermen behaviour should receive the same deal of attention than marine ecology or stock assessment / population dynamics. As Hilborn asserted "I therefore argue that a major element of fisheries science should be the study of fishermen and fleet dynamics" (1985, p.3). A rapid survey of the major international journals in that field reveals, however, that fifteen years after Hilborn's appeal, the number of published articles including some trace of fishermen behaviour analysis is still desperately low.
Second drawback: management models based on mono-fishery approaches are unable to describe and, a fortiori, control fishermen effort allocation in the case of multi-stock and/or multi-fleet situations, because they are not designed to integrate the whole system's (emergent) dynamics that results from the linkages between the different components of the system. Hanna (1992) suggested an example to illustrate this assertion. In a multi-species fishery, setting a fishing season on a mono-species basis will necessary generates external effects on the other fisheries. This will in particular lead fishermen to re-adjust their global allocation of effort between the different fisheries. Therefore, not only imposing regulation on a mono-fishery basis is wrong because it fails to recognise the linkages (whole dynamics) of the fisheries but also because it generates externalities (additional disturbances) that can not be predicted and therefore controlled (i.e. managed) using a mono-fishery management approach.

The TCI fisheries management revisited: room for a system management approach

In the case of the Turks and Caicos Islands fisheries, our believe is that the study of the decision making process that leads the fishermen to switch from the lobster fishery to the conch fishery and vice versa is of critical relevance to the goal of sustainable and effective management of the whole fisheries system. Both seasonal and inter-annual changes in effort distribution create linkages between the two fisheries (simultaneously at the human -fishermen- and biological -stocks- levels). In particular, because a majority of TCI fishermen rely on lobster status to allocate their effort between the two fisheries, any biological, economic, or regulatory event that affects the lobster fishery will also affect the conch fishery and impact the whole fishery system.

In that respect, the effects of the «Big Grab» on the fisheries as a whole are tremendous and turn out to be disastrous. First, from a mono-species fishery perspective, the direct consequences of this Big Grab on the lobster fishery are twofold. (1) Biologically, on the lobster stock itself: Tewfik and Béné (unpublished) show that 63.5% of the Big Grab landings are small, immature juvenile lobsters which are captured in shallow nursery habitats before they have any chance to grow -and a fortiori to contribute to future reproduction. (2) Economically, on the lobster fishermen themselves: due to the growth overfishing induced by this high proportion of juveniles caught during the first weeks of the season, fishermen don't get the maximal return they could expect from the fishery. These two consequences are direct and their exact impact on the lobster fishery can easily be assessed and evaluated through a mono-species fishery approach (see Tewfik and Béné, unpublished, in this respect).
However, the system approach adopted here shows that, due to the linkages between the lobster and conch fisheries, the «Big Grab» also has strong indirect effects (externalities, in economic language) on the conch fishery. First, economically on the conch fishermen. Each season, a large number of fishermen switch to the conch stock only after few weeks, due to the severe decline in lobster availability that occurs at that time. For these fishermen, the loss in revenue is not merely equivalent the loss induced by the growth overfishing that affects the lobster stock. Their loss is that induced by an early switch to the conch stock, the price of which is 4 times lower than the lobster price. Secondly, the Big Grab has also a "biological externality" on the conch stock. The early reallocation of fishing effort to the conch stock by a large number of fishermen obviously affects the conch stock itself, which must support a higher fishing pressure over a longer period than it would if the switch was taking place later within the season.
The solution to eliminate (or at least to mitigate) these direct effects and externalities would be a strict control of the lobster fishing activity during the first weeks of the season. Two management alternatives may be envisaged. (1) the implementation of a system of quota per trip as it has been developed in some other seasonal fisheries (e.g. the Oregon groundfish fisheries) to limit/control the lobster catch rate during the first weeks of the season, and (2) a spatial closure of the shallow part of the Caicos Bank where fishermen rush at the beginning of the season to "grab" all the juvenile lobsters before they have time to migrate to deeper ground (see Tewfik and Béné for a more detailed discussion on the issue of implementing these regulations).

At the inter-annual scale, the effect of the Big Grab on the fisheries is more difficult to evaluate. It is however reasonable to assume that the repeated stress applied year after year onto the juvenile lobster population by the Big Grab must have some detrimental effect in the long run on the local stock (especially if a large part of the stock is recruited locally). The general decline in catch observed since 1992 (Fig.4.a) and the fact that fishermen have now to travel further South on the Caicos Bank to try to maintain their yields (C. Hall, DECR Director, Grand Turk, 1998, pers. comm.) may be seen as two serious signs suggesting an overfishing situation. Even more alarming is the 24% decrease in the average individual weight of landed lobster, observed between 1974 and 1998 (see Tewfik and Béné, unpublished for details). These results are however difficult to directly/scientifically relate to the Big Grab. They may result from a long term environmental trend or cycle. What is unquestionable on the other hand is the consequences that the general decline in lobster catch has induced on the TCI fishermen community and, in particular, on the fishermen who had been forced to change their long-term fishing strategy by re-directing their yearly effort to the conch stock (see Fig.7 for recall). For these fishermen, the change is far more consequential than a simple seasonal switch few weeks earlier in the season. They have actually changed their primary targeted species for a species which is worth four times less. Consequently, not only the loss is financially substantial, it is also statutory. By switching to a more labour intensive, less skillful-requiring, less remunerative and above all less socially valued species, these fishermen have lost part of their social status in the eyes of the community.

Conclusion: A plea for system analysis and system management approach

Understanding the response of fishers to changes in biological, economic, and regulatory conditions in fisheries is critical to designing management plans that will ensure the sustainability of both resources and fishermen activities. In particular it is essential to identify the mechanisms that govern the fishermen' allocation of effort if one wishes to achieve an adequate control of that effort. In the present study we aimed to understand and describe the decision making process followed by the fishermen of the Turks and Caicos Islands in their choice of effort allocation between the local stocks of lobster and conch. From the analysis it appeared that the two fisheries are strongly linked through the decision-making process which governs the seasonal and inter-annual re-distribution (switch) of effort. In particular it appears that lobster is regarded as primary target and conch as substitute by local fishermen. A closer analysis showed that relying exclusively on the economic rationality and the expected returns of the two fisheries to predict the allocation of effort does not permit to explain entirely the observed fishermen behaviour. In particular the economic rationality approach fails to explain why a large proportion of the effort is still allocated to lobster when the conch fishery is apparently more profitable. A series of socio-anthropological surveys conducted within the South Caicos fishermen community revealed that the individual economic rationality is in fact "overcome" by a set of collective and individual constraints (peer pressure, individual diving ability) which derive directly from the specific qualities necessary to operate in the two fisheries.

The normative content of this paper goes beyond the attempts to address the specific management issues facing the Turks and Caicos fisheries. Firstly, the present study showed that the understanding and description of the dynamics of a given fishery can not be achieved if the interactions that this fishery has developed with the other elements of the whole system from which it is part are not recognised, analysed and integrated into the analysis. In particular, this means that in the case of multi-fisheries systems, the level of effort imposed at one period on one stock will result from a decision making process which does not simply rely on the perception/information that fishermen have about the (past, present and expected) bio-economic returns from the targeted species but also on the perception/information that they have about the other stocks. These perceptions are further largely influenced by the socio-historico-cultural environment within which the fishermen evolve.

To analyse such a complex mechanism and the externalities that it involves, a global, integrated and multi-disciplinary approach is necessary. System analysis reveals to be a possible approach to embrace this complexity. System analysis is not a specific modelling technique or a sophisticated mathematical tool (unlike some people may still think), it is simply an analytical framework which is proposed as an alternative to reductionism approach when one needs to analyse multi-disciplinary-nature, multi-scale timed, interlinked-component-based systems.

Secondly, acknowledging the existence of frequent linkages (interrelations) between fisheries emphasises the need to move from a mono-fishery management approach to a system management approach. In this system management approach, the different components of the fishery are considered as one unique manageable entity and the interactions (externalities) between these different components are recognised, evaluated and taken into account before any action/regulation is implemented at the element's level. This approach is in fact the application of the system approach, but no longer simply as a methodological framework to identify and reconstruct the dynamics of a complex system, but as a decision framework to help policy-makers and managers with problems of controlling systems, while taking into account multiple objectives, constraints and resources.

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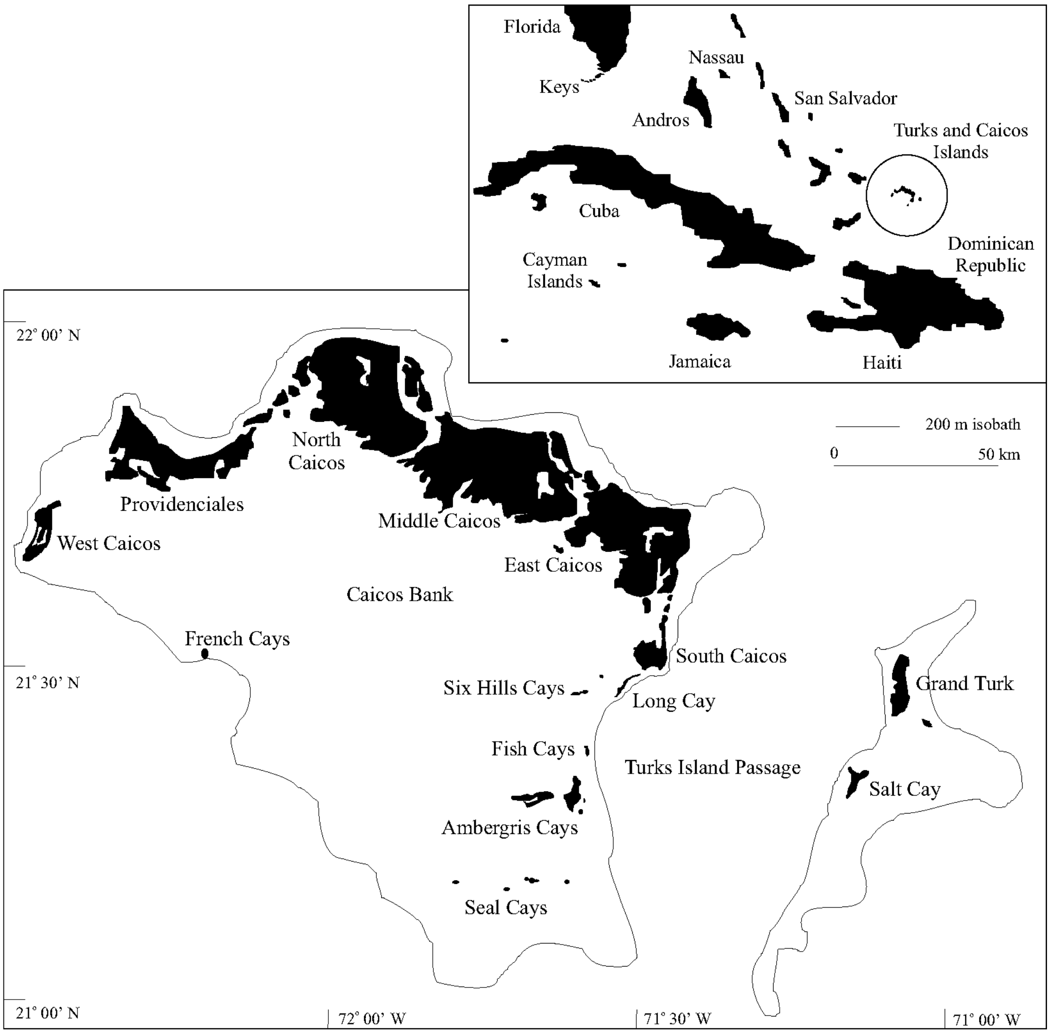

Fig.1. Location of the Turks and Caicos Islands in the Caribbean region and details of the Caicos Bank, including the main fishing grounds for conch and lobster. These grounds are located around Six Hills Cays, Fish Cays, Ambergris Cays, and Seal Cays.

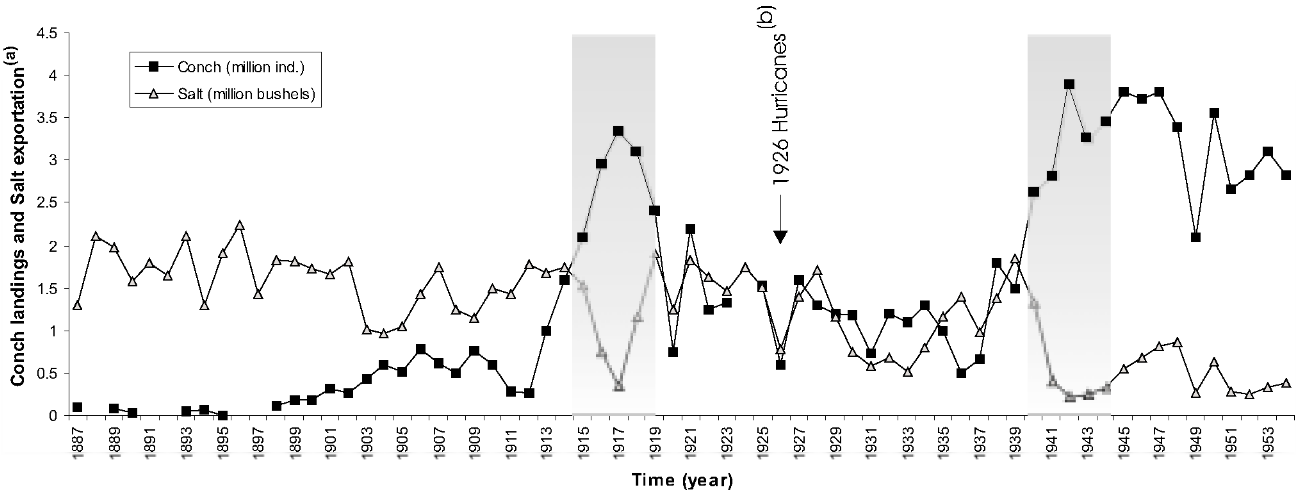

Fig.2. The conch landings and solar salt production in TCI over the period 1887 - 1955. The two shaded periods correspond to years where the salt industry faced difficulties to transport its production (the two World Wars). These periods show a significant increase in conch landings, due to the switch of the local labour from the salt production to conch fishing. After World War II, the salt sector did not recover and the majority of the men stayed in the conch industry. (Conch landings: in million individuals; salt production: in million bushels; one bushel = 80 pounds).

Source: salt production: Gregory 1970; conch landings: Saddler 1997 for period 1887-1903 and DECR for period 1904-1955.

Notes: (a) The salt series corresponds to the exports to North America and Europe. Between 1947 and 1949 some part of the production was exported to Japan. These exports are not represented on the figure. (b) In 1926 two devastating hurricanes passed over the islands. The second storm was so violent that in some places the coastline had been altered. A total of 163500 bushels of salt was lost, all in one day. These events had also an impact on the conch activity since 70 boats were destroyed, and 33 others damaged during the second hurricane, which explains the drop in landings recorded for that specific year.

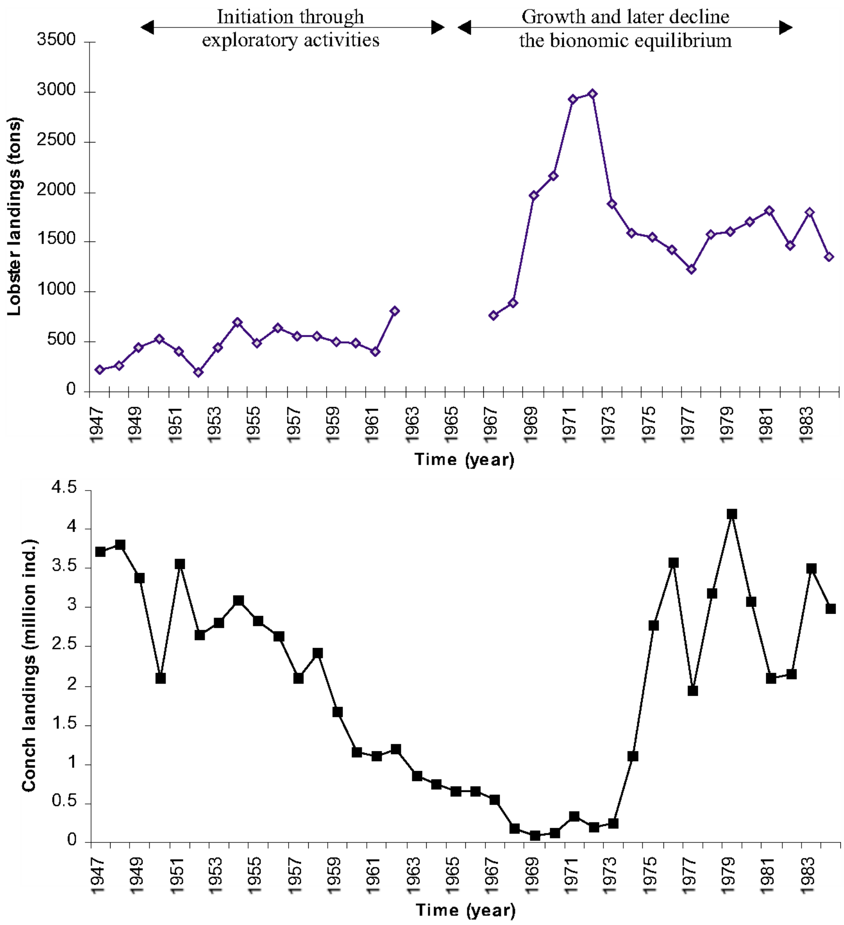

Fig.3 (a): Development of the TCI lobster fishery after the second World War. The series (annual landings in tons) displays the typical shape characterizing the first two stages of a newly discovered fishery: "the initiation through exploratory activities" followed by the "growth and later decline to the bionomic equilibrium" as described by Hilborn and Walters (1992). (b): The conch landings of the TCI fishery over the same period (in million individuals per year).

Source: DECR unpublished data, Kurcharchy 1982, Simon 1983, in Olsen 1985.

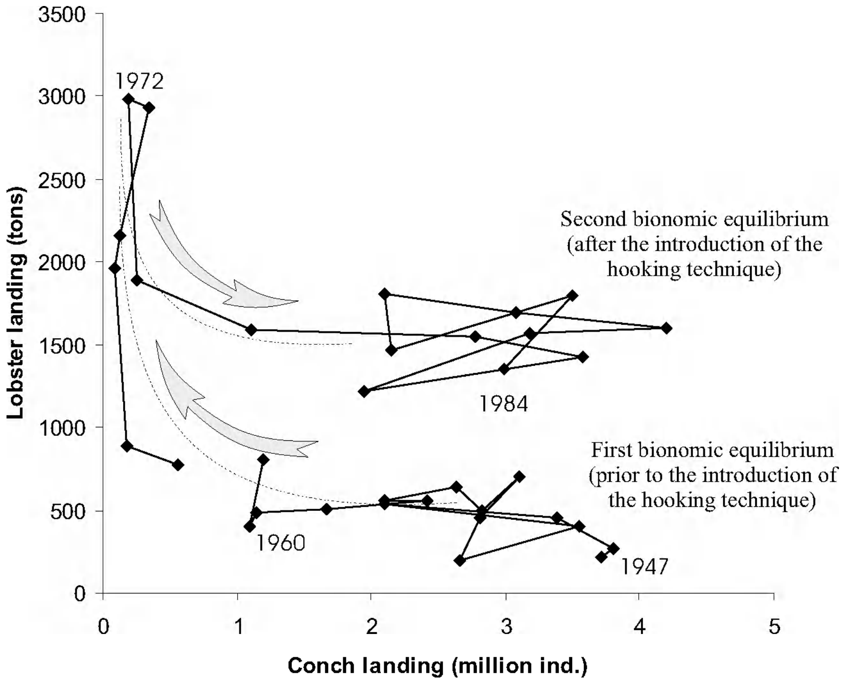

Fig.4. Phase-diagram of the TCI fisheries system between the landings series of conch (X-axis) and lobster (Y-axis) over the period 1947-1984. The two successive switches (from conch to lobster and then from lobster back to conch) are represented by the two grey arrows. Note that these switches follow almost perfect Cobb-Douglas indifference curves, materialised on the diagram by two dotted curves (added by hand). The higher level of lobster landing that characterised the second equilibrium (associated with the same level of conch landings that the first equilibrium) is due to the increased lobster catchability induced by the generalisation of the hooking free-diving fishing technique.

Source: idem Fig.2.

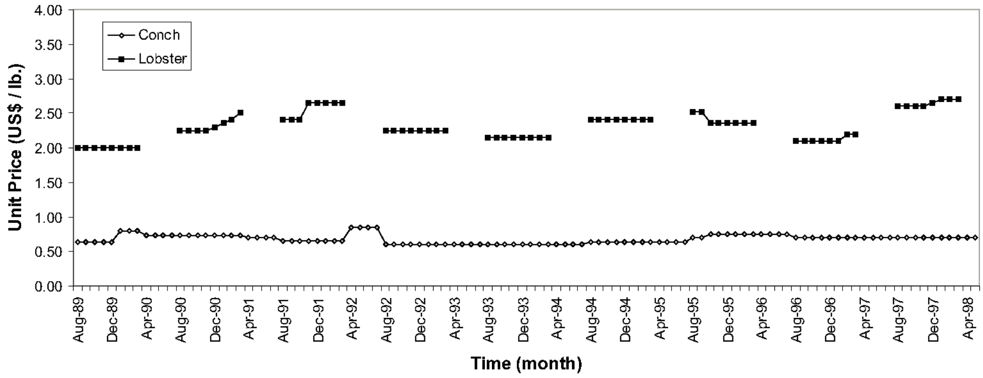

Fig.5. The South Caicos conch and lobster landing prices over the period 1989-98. The constancy in the series is due to the fact that the prices are not determined through a supply-demand mechanism but are set unilaterally by the plant owners at the beginning of each season (see text for detail). As a consequence, these local prices have increased by only 3% for conch and 10% for lobster over the period 1989-1997* while the prices in Miami have increased by 10% and 28% over the same period. Source: DECR unpublished data for local prices and Anon.(1998) for Miami price data.

* Note: For both local and Miami data, the price rises were calculated by comparing the average price of the period 1989-1990 with that of 1997-1998.

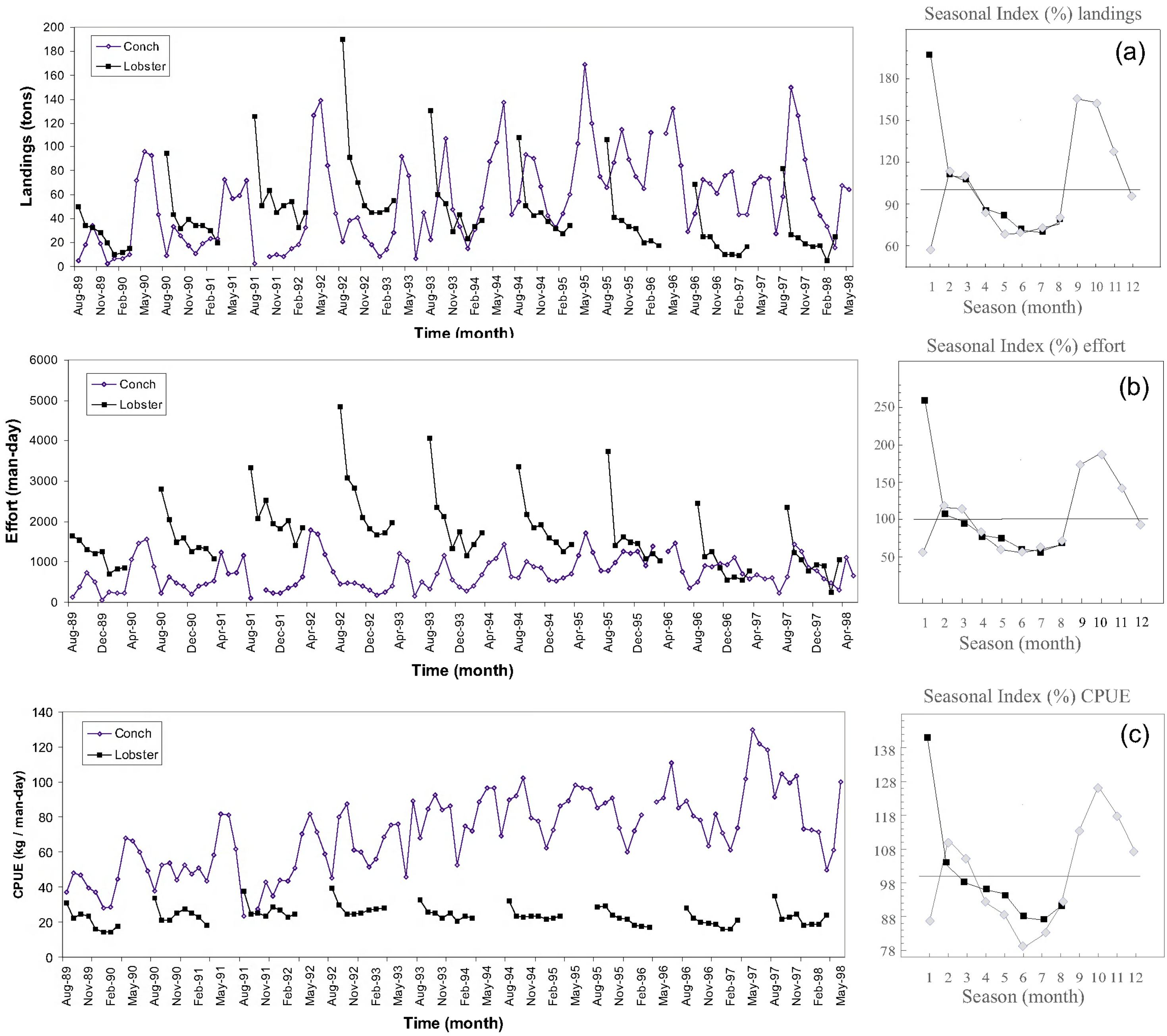

Fig.6. Seasonal dynamics of the TCI fisheries represented through the time-series data of (a) the landing volumes; (b) fishing effort; (c) CPUE, for conch (grey diamonds) and lobster (black squares). All series are monthly data and cover the decade 1989-1998. The seasonal indexes of the six series obtained by seasonal decomposition (see Appendix A for details) are shown on the three diagrams on the right. The first month of the seasonal indexes (noted 1) is the first month of the fishing season, i.e. August. The same symbols apply than for the time series, i.e. conch: grey diamonds; lobster: black squares.

Source: DECR unpublished data.

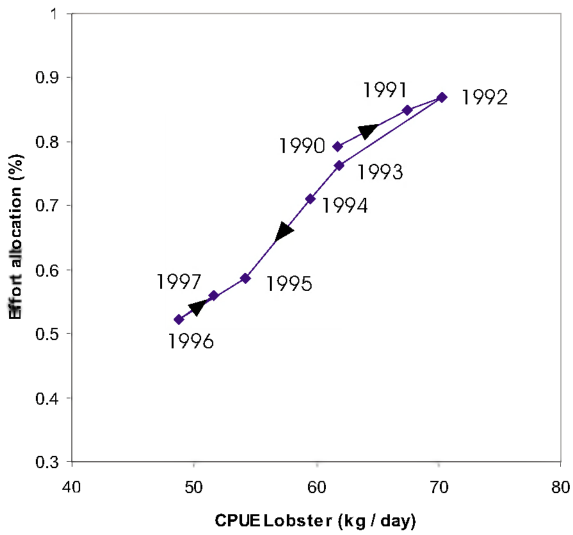

Fig.7. Phase-diagram showing the changes in the effort allocation of TCI fishermen (Y-axis) as a response to changes in lobster availability (X-axis) over the period 1989-1997*. The effort allocation is represented as the percentage of the fleet annual fishing time spent on lobster (e.g. a 0.9 value along the Y-axis means that the fleet spent 90% of the year fishing lobster) and the stock availability is estimated by the CPUE series (measured in kg day^{-1}). The dynamics of the relationship is shown by the arrows. The relationship is characterized by an almost perfect linear relationship (R^2 = 0.96, F = 178.84, d.f. = 6) (not represented on the diagram) which indicates the instantaneous nature of the fishermen' response (see text for details).

Source: DECR unpublished data.

* Note: The year figures on the diagram correspond to the fishing seasons, e.g. 1997 represents the fishing season August 97 - May 98.

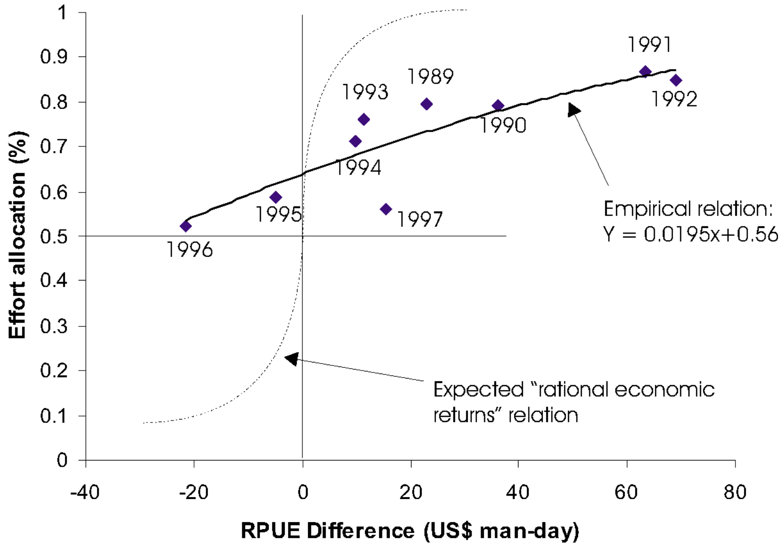

Fig.8. Distribution of the TCI fishermen effort between conch and lobster stocks (Y-axis) as a function of the RPUE difference computed for each season. The effort allocation is represented as the percentage of the fleet annual fishing time spent on lobster (like in Fig.7). The dotted line represents the theoretical relationship that should be observed between the variables if fishermen were distributing their effort according to the expected economics returns of the two fisheries. To allows for a possible S-shaped relationship between the empirical points (black diamonds), the effort allocation y was transformed in $Y = \ln \frac{y}{1-y}$ before a least sum of square linear model Y = ax+b was estimated where x is the difference in return. The estimated model: Y = 0.0195x+0.566 shows a significant relationship ($R^2 = 0.78$, F = 25.91, d.f. = 7). The black curve on the diagram corresponds to the estimated $\hat{y}$ back-calculated from the model.

Source: DECR, unpublished data.

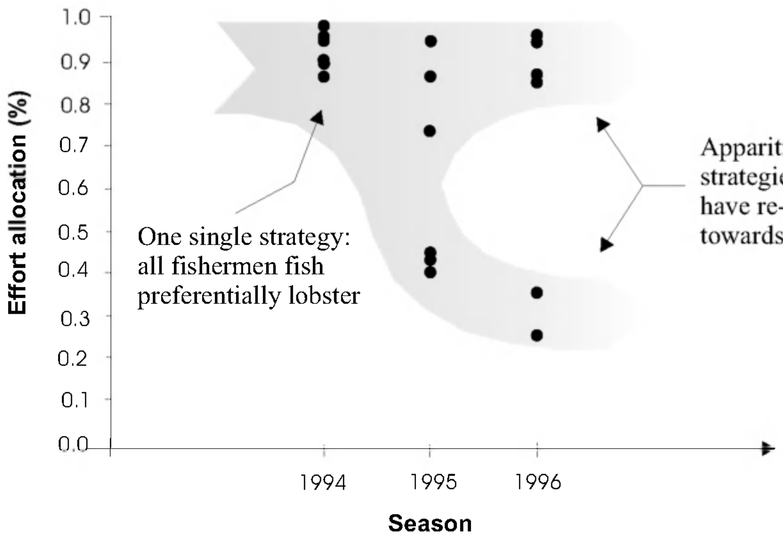

Fig.9. Individual fishermen' responds to changes in lobster/conch availabilities. The effort allocation (Y-axis) is represented as the percentage of individual fisherman's time spent on lobster. The general decrease in lobster abundance observed since 1992 induced the least-skilled fishermen to modify their fishing strategy and to re-direct their fishing effort towards the conch, easier target to catch but much less (socially and economically) valued product.

Source: DECR, unpublished data.