An Investigation of the Effects of Increasing Fishing Efficiency on the Productivity of the Queen Conch (*Strombus gigas*) and Caribbean Spiny Lobster (*Panulirus argus*) Fisheries within the Turks and Caicos Islands

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ABSTRACT

Fishery management decisions throughout the world are often based on incomplete data, fortunately historical landing data exists for the Turks and Caicos Islands (TCI) dating back to 1887 (Sadler 1997). The fishery based upon Queen Conch (*Strombus gigas*) and the Caribbean Spiny Lobster (*Panulirus argus*) is typical of many fisheries because it is characterized by numerous increases, a leveling off and then a decline in catch landings. Lobster catch landings have gradually increased over the past century, from 90,700kg of whole lobster in 1947 to a maximum of 590,758 kg in 1992. Likewise, conch landings have increased from 117,550 kg in 1968 to the present total allowable catch (TAC) value of 736,960 kg.

Fishermen within the TCI have increased their fishing efficiency by acquired knowledge of the best fishing grounds as well as improving their fishing skills and developing new fishing techniques and technologies. The fishery within the TCI has transformed from one dominated by wind powered sailing sloops in the early 1900s to a fishery dominated by fishermen using 85-115 hp (three and four cylinder) engines with their fishing boats. Simultaneously, fishermen have switched from utilizing glass buckets to locate conch and lobster to free diving using mask, fins and snorkel. In the lobster fishery where nooses were used in the past, hooks are the main method now in use, however prohibited substances such as bleach are also used.

Several input and output mechanisms are being considered to manage the fishery. However, many of these mechanisms such as the maximum sustainable yield (MSY) are derived using catch per unit of effort (CPUE) data. Increases in fishing efficiency over time result in increased effective effort, although the nominal/apparent effort may seem to be unchanged. Hence, the CPUE may render misleading information on the economic and biological status of the fishery. To combat such, it is imperative that effort is standardized, and is reflected in local legislation to control technology creep.

KEY WORDS: Effective Fishing Effort, nominal/apparent fishing effort, technology creep

Investigación sobre los Efectos del Incrementos de la Productividad y la Rentabilidad en las Pesquerías de Caracol y Langosta en las Islas Turcos y Caicos

La administración de pesquerías en el mundo, se encuentra a menudo basada en informaciones incompletas. Afortunadamente, en las Islas Turcos y Caicos, existe información que data de 1904. La pesquería sobre caracol (*Strombus gigas*) y langosta espinosa (*Panulirus argus*) es la típica de muchas pesquerías, pues los desembarques se caracterizan por numerosos incrementos, estabilización y declinación. Para la langosta, las capturas tuvieron un incremento gradual durante el pasado siglo, desde 200 000 lbs. de langosta entera en 1947 a un máximo de 690 846 lbs. en 1998. De igual forma el caracol, aumento de 259 191 lbs. en 1968 a una captura permisible (TAC) actual de 1.6 millones de lbs.

Los pescadores de TCI han incrementado su eficiencia de pesca a través de las prácticas adquiridas en las mejores áreas de pesca así como mejorando sus conocimientos pesqueros y desarrollando nuevas técnicas y tecnologías. La pesca en TCI ha sido transformada desde un predominio de embarcaciones veleras en los inicios de los 1900 a una pesquería dominada por pescadores que utilizan motores de tres y cuatro cilindros (85-115 hp) en sus botes. Simultáneamente, los pescadores han cambiado el mira-fondo de vidrio para localizar la langosta y el caracol por la careta de buceo con snorkel y las patas de rana. En la pesquería de langosta donde el método principal fue el lazo en el pasado, el gancho es ahora el predominante para colectar la especie, sin embargo sustancias prohibidas como el peróxido son también usadas.

Diversos mecanismos de entrada y salida son actualmente utilizados para el manejo de la pesquería. Sin embargo, muchos de estos mecanismos como es el caso de el TAC para caracol, se derivaron de los datos de captura por unidad de esfuerzo (CPUE). El incremento de la eficiencia de pesca a través del tiempo resultó en un incremento efectivo del esfuerzo, no obstante el esfuerzo aparentemente parece no haber cambiado. Para enfrentar esto, es imprescindible que sea estandarizado el esfuerzo, y que esto se vea reflejado en una legislación local para controlar los cambios tecnológicos cambiantes.

PALABRAS CLAVES: Efectos del incrementos de la productividad y la rentabilidad, caracol, langosta

INTRODUCTION

The Turks and Caicos Islands are an archipelagic overseas territory of the United Kingdom located in the British West Indies (Figure 1). Scale fish are caught for subsistence usage as a by-product of the principle commercial fisheries of lobster and conch.

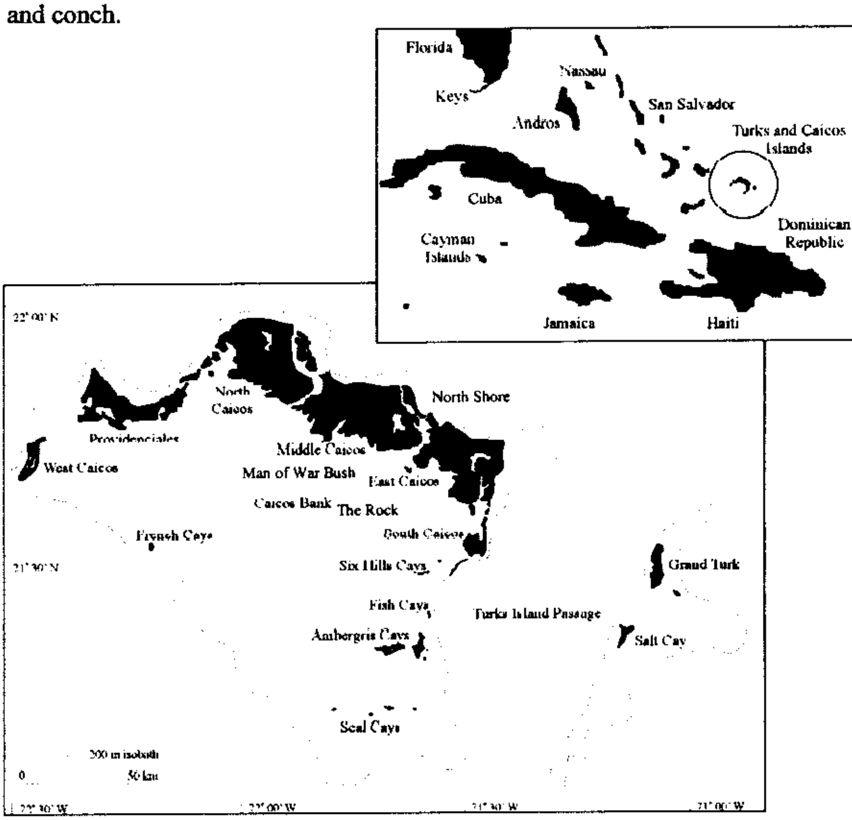

Figure 1. The location of the Turks and Caicos Islands in the British West Indies and the main fishing areas referred to in Table 2 later in this paper.

Effective management of any fishery that utilizes the MSY concept to predict fish stocks relies heavily upon often very basic input information to calculate yields through the use of surplus yield models. Such information is often merely catch and effort data (King 1995). It is well established that effort exerted within a fishery increases overtime for a number of reasons and that this 'technological creep' can mask detrimental changes in fish stocks (Pascoe1996, Cunningham 1980). It is this masking of increasing fishing effort within the TCI fisheries that is of interest and concern to those managing this fishery.

Technology creep occurs where fishermen increase their efficiency in catching fish through improvements in fishing gear over time. Unfortunately, technology creep is not reflected in the calculation of effort in most surplus production models. Increased efficiency of fishermen can occur through (Seijo 1998, Pascoe 1996, King 1995, Berg 1989):

i) The utilization and development of different fishing methods or gear,
ii) Changing the method of vessel propulsion thereby enabling fishermen to visit areas with more abundant fish stocks (generally those furthest away from fishing centers),
iii) Increased local knowledge regarding the location of fish stocks, and
iv) Increased skippers' skill.

When referring to fishing effort, it is wise to discern whether or not effective fishing effort or nominal/apparent fishing effort is being referenced. The difference, although appearing slight, is of utmost importance when determining if effort is increasing within a fishery. Eeffective fishing effort refers to the ability of a fisherman to remove a proportion of a mean population size, whereas nominal/apparent fishing effort reflects only the volume and not the effectiveness of resources devoted to removing a proportion of a fish population (Berg 1989, Cunningham 1980). For example, two fishermen in a five meter boat powered by a 150 hp outboard engine and utilizing hooks are far more effective at catching lobster than two fishermen in a four meter sail powered boat utilizing nooses. In this example it is clear that although the nominal fishing effort is the same (i.e. two fishermen and one boat) the effective fishing efforts exerted are disproportionate.

In fisheries where more than one species is fished at a time, effective effort exerted on a particular species can increase even though nominal effort remains unaltered as a result of a decline in a species abundance, forcing fishermen to fish other species, or the price returned on a particular species falls to such a level that it is economically unattractive to fish (Bĕnē 2001). Effective effort has increased in the TCI conch fishery even though nominal effort has remained the same, because fishermen are now spending a larger proportion of their time fishing conch over lobster per day due to declining lobster stocks (Berg 1989, Olsen 1985). A TAC, based on MSY calculations and landing data, is currently used to manage the conch stocks within the TCI. It is believed that the TAC derived using a Schaefer biomass dynamic model (Medley 1999) is maintaining stable stocks. However, it is widely accepted that stock estimates derived from catch and effort data are inherently biased, since effort data is not adjusted to take into account changes in efficiency over time (Pascoe 1996). Nevertheless, the slight changes in efficiency over time within the conch industry do not seem to affect the results attained by the fishery dependent model, because the MSY has been corroborated by a recent visual stock assessment (Clerveaux and Danylchuk in press).

However, the lobster fishery is not managed by restrictions or limitations, and as such concerns are being aired by managers of this fishery. Their view is that lobster stocks are prone to overexploitation in the near future, based on anecdotal evidence that the fishery is in decline and effective effort is increasing (e.g. changes in gear), although at present this is not reflected by decreased landings. In effect, fishermen are maintaining landings whilst masking potential overexploitation.

Historical landing data, in conjunction with effort records and interviews with active and retired fishermen, provide an insight to the fishing industry. Reliable data and historical records relating to the fishery will help to determine whether several periods of uncharacteristic landing figures are symptomatic of changes in effective fishing effort within the fishery or other variables such as environmental factors (e.g. water temperature and currents).

The Development of Gear Type and Efficiency

Pre-1958 wooden sailing sloops 10 - 12 m in length and drawing 1.5 - 2 m of water constructed of driftwood (Doran 1958) powered by sail were used to fish the conch and lobster grounds for up to a week. Each sloop acted as a mothership for two to four small wooden, oar-powered dinghies. The dinghies were 3 - 4 m dug outs sculled by 3 m oars worked in shallow oarlocks off center on the portside of the transom. Glass buckets (water glasses) were used to first identify conch and lobster by a bowman who carefully worked an 8 m long conch hook underneath the conch and then quickly lifted the animal to the surface (Berg 1989, Doran 1958). Lobsters, on the other hand, were 'bullied' using a small net on a pole, which was placed over the lobster and scooped into the small boat.

The fishery gradually transformed from non-diving to diving with the introduction of mask, fins and snorkel in the mid. 1950s. By the end of the 1950s free diving had increased in prevalence, although conch hooks remained in use until the mid. 1970s. As alternatives to the bully, the 'toss' (a flexible wire noose on a stick) and the 'grabber' (a spring-loaded snake catcher) were introduced to catch lobster. Diving also opened up previously unexploited areas of the fishery as it enabled deeper waters to be fished (Ninnes 1994, Olsen 1985). The grabber was quickly abandoned as it damaged the lobster, thereby resulting in a reduced economic return. These two methods of fishing were quickly replaced by a more efficient method of hooking (a shark hook attached onto a 1.5 m long flexible pole), which allowed fishermen to capture lobsters from within their dens where they aggregate during the day (Bēnē 2001).

Free diving from fiberglass boats for conch and lobster aided by the use of the hook increased until it was the norm by the early 1980s (Table 1) (Nardi 1982). So far hooka and scuba which confer high fishing efficiencies, have not been used in the TCI. Their introduction is thought unlikely due to ease of enforcing these currently illegal methods of fishing.

Although changes in nominal fishing are more apparent than changes in effective effort, they have far less impact on the exploitation of a fish stock because of the law of diminishing returns (Pascoe 1996). Changes in gear on the other hand (from the use of a bully to a hook whilst fishing for lobster) and techniques (from non-diving to free diving) are believed to have increased fishermen's effectiveness to exploit the fishery.

Bënë (2001) noted that the shift to hooking is displayed by two distinct bionomic equilibrium's, resulting from two successive switches from conch to lobster and then from lobster to conch, which followed an almost perfect Cobb-Douglas indifference curve (Figure 2).

Table 1. The transition of gear in the Caribbean spiny lobster (*Panulirus argus)* and Queen Conch (*Strombus gigas)* fishery of the Turks and Caicos Islands since 1940.

Year	Prevalent Type of Fishing	Prevalent Gear Type	
		Lobster Fishery	Conch Fishery
1940s	Non-diving	Bully	Conch Hook
1956	Diving	Toss & Grabber	Hand Capture
Late 1950s	Diving	Toss & Hook	Hand Capture
1960s	Diving	Toss & Hook	Hand Capture
1970s	Diving	Hook	Hand Capture
1980s	Diving	Hook (Bleach)	Hand Capture
1990s - present	Diving	Hook (Bleach)	Hand Capture

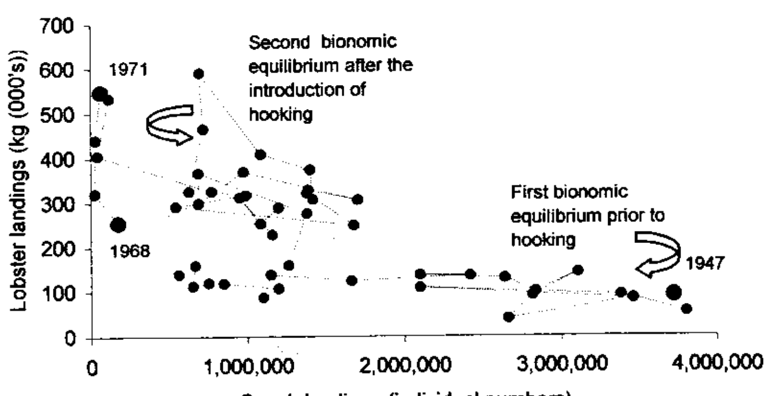

Figure 2. Phase diagram of the Caribbean Spiny Lobster (*Panulirus argus*) and Queen Conch (*Strombus gigas*) fisheries of the Turks and Caicos Islands showing two distinct bionomic phases before and after the introduction of the hook as a lobster fishing gear.

Development of Fishing Locations Over Time

Stocks are generally not evenly distributed along the seabed, and in many cases accessible areas of higher abundance are fished first to maximize return on investment (e.g. time, money) (Coppola 1996). Coppola also pointed out that fishermen have to extend their search for fish once areas of known abundance have been exploited to their full potential, venturing greater distances from port as a fishery is developed. Over time, fishing areas in the TCI have changed to reflect attempts by fishermen to increase or maintain their catches. Distant sites were explored and developed (Table 2). Until the introduction of high horsepower engines (> 40hp) in the mid. 1970s, fishermen, (in particular lobster fishermen) were restricted to fishing in close proximity to port (8 - 15 km) so as return the same day and land a high quality product. Conch fishermen, on the other hand, at times ventured further (e.g. Ambergris Cay from South Caicos) spending several days fishing and drying conch (Hesse 1977, Doran 1952).

Table 2. Fishing site development over time in the Turks and Caicos Islands Caribbean spiny lobster (*Panulirus argus*) and queen conch (*Strombus gigas*) fisheries.

	Six Hills Cay	Ambergris	Caicos Bank and the Rock	Southern Ambergris (Bush Cay)	Southern Seal Cays	Man Of War Bush	North Shore
Pre. 1970	STB/ D	U	U	STB	STB	U	U
Mid. 1970	D	LTB	U	LTB	STB	D	D
1980	D	D	D	LTB/ D	D	D_{DS}	LTB
Mid. 1980 - present day	D	D	D	LTB/ D	LTB/ D	D_{DS}	D
Distance from S. Caicos fishing community	8km	23km	31km	34km	37km	40km	40km

Key: D, Divers; U, Undeveloped; LTB, Large Trap Boats; STB, Small Trap Boats; D_{DS}, Diving still dominant but stocks are relatively depleted
Small trap boat; < 9m in length, 2 fishermen outboard engine
Large trap boat; > 9m in length, > 2 fishermen inboard engine
Divers; small boat, < 6m in length, 2–3 commercial fishermen

Since the introduction of outboard motor engines for commercial fishing vessels in the early 1950s, engine size and power have increased steadily over the years. By the middle of 1970, the sail powered sloops; seagull and low powered wooden dugout boats were replaced by vessels with fiberglass hulls with two and three cylinder engines, thereby allowing fishermen to venture further, quicker (Table 3). The increase in fishermen's fishing range and ability to carry large amounts of product increased effective fishing effort further allowing effective exploitation of the stocks. Apparent effort changed very little over time period of time.

Table 3. Fishermen of the Turks and Caicos Islands have increased their effectiveness over time at exploiting the fish stocks by changing hull composition and increasing engine size, allowing increased load capacity, speed and range.

Year	Prevalent Propulsion method	Hull material
1940	Sail/oars	Driftwood, dug out canoes
1950	2.5-6hp Seagull engine introduced	Locally made wooden boats, first imported fiberglass hull
1960	18hp	Wood/Fibreglass
1970	40hp	Wood/Fibreglass
1975	55hp	Wood/Fibreglass
1985	65-70hp	Wood/Fibreglass
1990	70-75hp	Wood/Fibreglass
1995	85-90hp	Wood/Fibreglass/buoyant foam
2000	85-90hp (lobster fishing)	Wood/Fibreglass/buoyant foam
2000	105-200hp (conch fishing)	Wood/Fibreglass/buoyant foam

Source: Department of Environment and Coastal Resources commercial fishing vessel licence application forms, historical records and interviews with commercial fishermen.

Effect of Increasing Fishing Efficiency

A simple surplus production model (Fox) was used to model the effects of increasing fishing efficiency using lobster catch and effort data from the mid. 1960s encompassing both pre- and post-hooking years (1966 - 2000) whilst also taking into account the changes in distance traveled from fishing centres over time. The data was then compared to the years when hooking was not as prevalent and there were no significant changes in fishing location (1966 - 1980).

The results indicate that a MSY of 491,650 kg would be obtained at an apparent effort level of 25,000 man-days, had effective fishing effort remained constant, as in pre-prevalent hooking years (1966 - 1980). However, an increase in effective effort causes a shift in the Fox model with the MSY rising more steeply and reaching a lower MSY value of 354,576 kg at 20,000 man-days of apparent effort (Figure 3). The ratio of fishermen to a fishing vessel was also investigated however there was no significant change in this ratio as the fishery developed. The implication here is that this potential area of increasing effective effort is actually static.

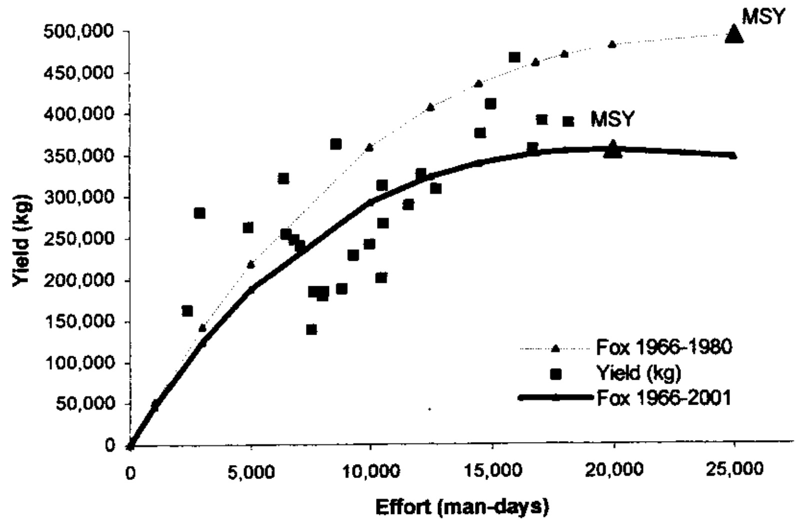

Figure 3. Maximum sustainable yield plot from a Fox surplus production model for the Turks and Caicos Islands Caribbean spiny lobster (*Panulirus argus*) fishery illustrating how a change in gear (the introduction of the hook in 1980) results in a decrease in the maximum sustainable yield which could also be attained by a reduced nominal effort (man - days).

DISCUSSION

Despite concerns which has been raised about surplus production models overestimating stocks and their unpredictability to identify potential changes of the catchability of inputs (Cunningham, 1980), surplus production models are commonly used as a management tool in many fisheries throughout the world (Coppola 1996; Sparre 1992). The reasoning for this is that in contrast to most analytical models, the data requirements are less demanding and can be met with reasonable yield and effort estimates/values being attained over several years (Sparre 1992).

An underlying assumption in the short run catch-effort relationship is that catch in one year is a linear function of effective fishing effort (Coppola 1996, Cunningham 1980) given by:

$$C = qEB$$

where C is the catch, q is the catchability coefficient, E is effort and B is the stock biomass.

A change in gear has the potential to increase both apparent and effective effort exerted upon a stock (Figure 2). The two binomial equilibrium observed in the fishery is a result of an increase in effective fishing effort (e.g. hooking), that led to an increase in apparent effort (e.g. man-days). A shift to free-diving and hooking in the late 1950s and early 1960s increased the effectiveness of fishermen to catch lobsters, hence increasing profit and attracting more fishermen into the lobster industry. As the lobster stocks became depleted, fishermen diverted their effort to fishing conch, thereby producing the second bionomic equilibrium.

Furthermore, the change in fishing gear increased the level of the catchability coefficient (q) thereby increasing fisherman's effectiveness at exploiting the lobster stocks. However, lobster landings remained higher in the second bionomic equilibrium than previously, although apparent effort (man-days) declined to previous levels. This phenomenon may provide misleading CPUE information (i.e. abundance of the stock is high). The short-term benefit was the maintenance of high landings at a similar apparent effort level, but larger long-term MSYs were sacrificed.

There has been an increasing trend in the use of reference points for fisheries management, particularly with those that maximize yield (Caddy 1995) (e.g. effort at the MSY (E_{msy})). Increasingly, the use of fishing effort as a reference point would imply that at some point effort would be curbed at the reference level to provide optimum benefit to the resource users. One fishery management tool widely used to achieve this objective (effort reduction) is by exclusion (e.g. limiting the number of individuals allowed to enter the fishery).

The success of limited licence entry programs on a global scale has been quite variable (Austin 1986). Limiting the number of licensed fishermen itself may not prevent biological overfishing, as pointed out by Austin (1986), because only the apparent effort has been managed, and this in fact may have negligible impact on stock protection and management. Nevertheless, if used in conjunction with attempts to limit effective effort such as technology creep, limiting the number of licenses can assist in achieving biological and economic objectives.

It has been suggested that nominal or apparent fishing effort will only be a true reflection of fishing mortality so long as the catchability coefficient remains constant (Cunningham 1980):

$$F = qf$$

where F, is fishing mortality, q is catchability coefficient and f is nominal/apparent fishing effort. However, the catchability coefficient does not remain constant due to changes in efficiency, temporal and spatial scales (Tewfik 2000). As such, nominal/apparent effort would need to be periodically standardized and factored to take into account increasing effective effort within the fishery.

CONCLUSION

Effective and nominal efforts within the TCI fishery are significantly different. Technology creep has over time increased the effectiveness of exploiting the fisheries (e.g. the lobster stocks by shifting the MSY to a lower level of equilibrium). The creep in effective fishing effort caused by changes in gear requires careful management to prevent over exploitation.

It is imperative that fishery managers have a good understanding of the levels of effective and nominal effort being exerted in their fisheries in order to choose the most appropriate manner in which to manage the fishery. If this is not the case, ineffective effort reduction schemes will do little to protect either the economic or biological sustainability of the fishery and may in actual fact be expensive and detrimental.

LITERATURE CITED

Austin, C.B. 1986. How to measure the potential advantages of limited entry. *Proceedings of the Gulf and Caribbean Fisheries Institute* **39**:12-22.

Bĕnĕ, C. and A. Tewfik. 2001. *Analysis of fishing effort allocation and fishermen behaviour through a system approach.* Research paper 155. Centre for Economics and Management of Aquatic Resources. University of Portsmouth. United Kingdom. 29 pp.

Berg, C.J. and D.A. Olsen. 1989. *Conservation and Management of Queen Conch (Strombus gigas) fisheries in the Caribbean.* Pages 421-442 in: J.F. Caddy (ed.) Marine invertebrates fisheries; their assessment and management. John Wiley & Sons. New York, New York USA..

Caddy, J.F. and R. Mahon. 1995. *Reference points for fisheries management.* FAO Fish. Tech. Paper 347. Food and Agriculture Organization. Rome, Italy. 83 pp.

Clerveaux, W. and A. Danylchuk. 2003. Visual assessment of Queen Conch (*Strombus gigas*) stocks in the Turks and Caicos Islands. *Proceedings of the Gulf and Caribbean Fisheries Institute* **54**:250-258.

Coppola, G. and S. Pascoe. 1996. *A surplus production model with a non-linear catch-effort relationship.* Research paper 105. Centre for Economics and Management of Aquatic Resources. University of Portsmouth. United Kingdom. 15 pp.

Cunningham, S. and D. Witmarsh. 1980. *Fishing effort and fisheries policy.* 2nd ed. Research paper 6. Centre for Economics and Management of Aquatic Resources. University of Portsmouth. United Kingdom. 12 pp.

Doran, E. 1958. The Caicos conch trade. *Geographic Review* **48**:388-401.

Hesse, C.O. and K. Hesse. 1977. Conch industry in the Turks and Caicos Islands. *Underwater Naturalist* **10**:4-9.

King, M. 1995. *Fisheries Biology and Management.* Fishing News Books. Oxford, United Kingdom. 341 pp.

Medley, P.A.H. and C.H. Ninnes. 1999. A stock assessment for the conch (*Strombus gigas* L.) Fishery in the Turks and Caicos Islands. *Bulletin of Marine Science* **64**(3):399-406.

Nardi, G.C. 1982. An analysis of the queen conch fishery of the Turks and Caicos Islands, with a review of a new, multi-purpose dock receipt. M.S. Thesis. State University of New York, Stony Brook, New York USA. 47 pp.

Ninnes, C. 1994. *A review of the Turks and Caicos fisheries for Strombus gigas* L. Pages 67-72 in: R.S. Appeldoorn and B. Rodriquez, (eds.) *Queen Conch Biology, Fisheries and Mariculture*. Fundacion Cientifica Los Roques, Caracas, Venezuela.

Olsen, D. A. 1985. *Turks and Caicos Fisheries Assessment*. Final report on FAO project TCI/83/002. FAO. Rome, Italy. 94 pp.

Pascoe, S. and C. Robinson. 1996. Measuring changes in technical efficiency over time using catch and stock information. *Fisheries Research* **28**:305-319.

Sadler, H.E. 1997. *Turks Islands Landfall, A History of the Turks and Caicos Islands*. United Cooperative Printers Ltd. Kingston, Jamaica. 300 pp.

Seijo, J.C., Defeo, O. and S. Salas. 1998. *Fisheries bioeconomics: theory, modelling and management*. FAO Fisheries Technical Paper 368. FAO. Rome, Italy. 108 pp.

Sparre, P. and S.C. Venema. 1992 . *Introduction to tropical fish stock assessment, part one-manual*. FAO Fisheries Technical Paper 306/1 - Rev 1. FAO. Rome, Italy. 376 pp.

Tewfik, A. [2000]. Improvements to the use of catch per unit effort as an index of abundance: increased management capacity in small-scale fisheries. Ph.D. thesis proposal summary. Department of Biology, McGill University. Canada. Unpubl. MS.