

**Spatial distribution of effort by artisanal fishers: Exploring economic factors affecting the  
Lobster fisheries of the Corn Islands, Nicaragua**

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## 1 **Abstract**

2 Spatial distribution of fishing effort is increasingly recognised as an important consideration for fisheries  
3 management, as it can affect trends in catch rates, and be incorporated into planning of spatial management tools  
4 like marine protected areas (MPAs). One-hundred and ninety-eight household questionnaires provided a coarse  
5 indication of effort distribution of artisanal lobster fishers around the Corn Islands, and 32 semi-structured  
6 interviews with skippers were used to map individual fishing sites and describe the operating costs and revenues  
7 of typical dive and trap-fishing operations. Artisanal fisheries had ranges of up to 50 km, and had moved  
8 significantly offshore within the previous 10 years. At the scale of a 5 x 5 minute lat/long grid, trap fishing effort  
9 was highly aggregated (dispersion coefficient = 3.5), while diving had a regular dispersion (d.c. = 0.1).  
10 Descriptions of catch composition at each site showed a clear spatial pattern in the distribution of two locally-  
11 recognised types of lobster potentially indicating local stock structures. Economic information was summarised  
12 into balance sheets for typical fishers and suggested that fuel accounted for about 52 and 37% of the operating  
13 costs of dive and trap fishing captains respectively. Qualitative questions highlighted trap theft, adoption of  
14 geographical positioning system (GPS) technology and fuel costs as major factors affecting spatial behaviour.  
15 The costs and benefits of using more distant grounds were examined by testing for relationships between stated  
16 typical catch rates and distance of 90 trap-fishing grounds; and between fuel expenditure and catches in 291  
17 daily records of the activities of 3 divers. Maximum catch rates stated by trap fishers were significantly higher at  
18 more distant sites and daily catches by the divers had a positive relationship with fuel expenditure, which  
19 suggested that increasing fuel expenditure to target more distant sites would lead to higher gross revenue as well  
20 as higher net revenues, after considering variable operating costs. Thus there appears to be an economic  
21 incentive to extend the range of the fishery. However, fishers may not perceive these positive trends in catch rate  
22 with distance due to catch variability, and costs other than fuel complicate the trade-off between catch and  
23 distance.

## 24 **Keywords**

25 *Palinurus argus*, Fishing effort distribution, Corn Islands, fisheries economics, fishers' knowledge



## 26 **1 Introduction**

27 A number of authors have argued for the importance of understanding both spatial (Booth, 2000; Gillis, 2003;  
28 Hutchings and Myers, 1994; Wilen et al., 2002) and behavioural aspects (Hilborn et al., 2005; Salas and  
29 Gaertner, 2004) of fisheries. The resurgence of interest in spatially explicit management measures including  
30 Marine Protected Areas (MPAs) highlights the relevance of spatial distribution of fishing effort to fisheries  
31 management (Moustakas et al., 2006; Walters, 2000). For example the interpretation of trends in catch-per-unit-  
32 effort (CPUE) trends should take account of changes in the spatial distribution of fishing effort (Gobert and  
33 Stanisière, 1997; Jennings et al., 2001; Koslow et al., 1994; Walters, 2003).

34 Spatial effort distribution is the result of individual fishers' behaviour, which is in turn affected by various  
35 factors, some of which are highlighted here. Spatial patterns of targeted resources and habitats affect effort  
36 distribution in as far as fishers are able to perceive them (Pet-Soede et al., 2001). Fishers may maximise such  
37 knowledge by preferring familiar grounds where they can accumulate local detailed local knowledge (Begossi,  
38 2001; Rijnsdorp et al., 1998). Technical considerations may determine potential fishing areas, for example depth  
39 limits for free-diving, or smooth ground for trawling (Bene and Tewfik, 2001; Rijnsdorp et al., 1998), while  
40 technical innovations may allow more accurate navigation or monitoring of trends in catch data (Eales and  
41 Wilen, 1986). Social factors affecting effort distribution may include the activities of other fishers leading to  
42 interference competition (Gillis and Frank, 2001) and the existence of rules and institutions. Rules may be  
43 formal, like the establishment of MPAs or informal territorial arrangements established, enforced and monitored  
44 by fishers themselves (de Castro and Begossi, 1995; Schlager and Ostrom, 1992).

45 Various factors interact to determine the distance travelled to sites. Safely navigable distance varies with  
46 weather, individual risk aversion and vessel type; and determines the potential resource spaces for different  
47 fishers (Pet-Soede et al., 2001). Energy and travel-time costs increase linearly with distance travelled and are  
48 determined by fuel expenses and the opportunity cost of time, which depends on other potential activities, for  
49 example fishing at nearer sites or engaging in non-fishing activities. A "friction-of-distance" conceptual  
50 approach incorporates various distance related factors costs and predicts that evenly distributed resources will be  
51 exploited more intensively at sites nearer home ports (Caddy and Carocci, 1999). More distant sites would

52 therefore be expected to have more pristine stocks and (according to basic catch/effort models of fisheries)  
53 potentially yield higher catch rates. If such positive distance-catch rate relationship is perceived by fishers, the  
54 choice of how far to travel involves a trade off between the costs and expected higher yields.

55 In order to understand these patterns and predict the effect of proposed management strategies one must  
56 understand the social, microeconomic and natural environment in which fishers make these decisions (Aswani,  
57 1998). Wilen (Wilen, 2004) highlights a lack of models which can incorporate the complex ecological and  
58 biological feedbacks to realistically predict fishers' spatial behaviour and suggests that more ethnographic  
59 research may be necessary to describe fishers' spatial decision making.

60 In this study, a combination of rapid household questionnaires, mapping, economic analysis and qualitative  
61 stakeholder interviews were used to gain an understanding of how artisanal lobster fishers of the Corn Islands  
62 perceive and utilise the spaces of the sea around them. The objectives were to (a) describe the spatial distribution  
63 of diver and trap-fishing effort; (b) highlight factors determining distance travelled; and (c) investigate costs and  
64 benefits of distance quantitatively in terms of catch rates and fuel cost.

## 65 **2 Study area**

66 The Corn Islands lie in the Nicaraguan sector of Caribbean Sea on the most extensive portion of the Central  
67 American continental shelf. Thus, there is no natural limit to shallow fishing grounds imposed by bathymetry.  
68 The two islands are separated by about 15 km, Great Corn Island has the highest population density on the  
69 Atlantic coast of Nicaragua with a population of 7,100 residing in 10.3 km<sup>2</sup> while Lesser Corn Island, at about 5  
70 km<sup>2</sup> is much less densely populated by about 1,100 people (Ryan 1998).

71 A profitable export fishery for the lobster *Palinurus argus* began in the 1970s and became the mainstay of the  
72 local economy in the 1980s (Ryan 1998). SCUBA diving for lobster was gradually been replaced by trap fishing  
73 due to safety and environmental concerns. In 2003, diving was predominantly practised by the Miskito ethnic  
74 group while most Creole fishers (and all fishers on Little Corn Island) use traps. Finfish were also fished  
75 commercially although their relatively low price led to considerably more emphasis on lobster. Commercial  
76 artisanal fishers generally operated from fibreglass or wooden skiffs 7-10 m long, powered by 40-75hp outboard  
77 engines, and crewed by 3-4 fishers. Fishers sold catches to one of 13 middlemen who passed on the catch to one

78 of the two Corn Island based companies for processing and export. The middlemen also provided fishers with  
79 fuel, dive cylinders and credit on traps, boats and engines.

80 Official statistics indicate declining catch rates across the Nicaraguan shelf in the 1990s (Adpesca, 2003). In  
81 response, a closed season on fishing lobster was imposed during May and June in 2002 and 2003 and extended  
82 to four months in 2004. Local regulations also exclude commercial fishing from within two nautical miles of the  
83 Corn Islands but lobster divers were known to still fish in this area (Pers. Comm. Corn Island Municipality).

84 Although *P. argus* was the only species targeted, local fishers clearly distinguished “red” and “white” lobster  
85 through physical and behavioural characteristics. In addition to colour differences, red or “stationary” lobsters  
86 tend on average to be heavier, are more likely to have eggs and are found in moderate numbers around the Corn  
87 Islands throughout the year in rocky habitat. White or “running” lobsters can be caught in large numbers on  
88 seagrass or gravel substrates in November to January as they pass through the area from the North (pers. comm.,  
89 various Corn Island fishers).

## 90 **3 Methods**

### 91 *3.1 Data collection interviews*

92 Two types of interviews were used to collect information on fishing techniques, costs and fishing grounds in  
93 May and June 2003. Firstly, a rapid household questionnaire, was administered to a random sample of 198  
94 fishing households stratified by community. This gave a large-sample overview of fishing activity and a coarse  
95 indication of effort distribution by the different gears. In-depth semi-structured interviews conducted  
96 opportunistically with 32 lobster fishing captains then allowed more specific mapping of individual fishing  
97 areas. The household questionnaire included questions on occupations, species targeted, gears used and boat  
98 characteristics, and a simple map of Corn Island in which the surrounding sea was divided into 24 zones related  
99 to distance and direction from the islands (Figure 1). Interviewees were asked to identify which of these zones  
100 they used for each fishing activity.

101 In-depth interviews with boat captains covered equipment used, how they selected fishing grounds, and locations  
102 of individual fishing areas. A flexible approach to mapping fishing grounds was required due to differences in

103 navigational equipment, willingness to cooperate and understanding of maps. When possible, the position of  
104 each ground was determined by positions from the fishers' own GPS (geographical positioning system) unit  
105 recorded to the nearest minute of latitude and longitude. In other cases, locations were determined by direction  
106 and the approximate distance in 'miles' (assumed to be statute miles) or travel time. Interviewees also provided  
107 some or all of the following information about each ground: approximate size and shape, local names, typical  
108 good, poor and average catch rates, time and fuel to reach, frequency and intensity of use, substrate types, depths  
109 and the typical proportion of "white lobster" caught. Depending on the length of time captains had been  
110 operating, they were asked their memories of normal, maximum and minimum distances travelled to conduct  
111 fishing now, 10 years ago, during the 1980s and during the 1970s. Information was also collected on costs of  
112 equipment, maintenance, licences, bait, fuel, tank hire (for divers) and payment to sailors. Data were organised  
113 into a hierarchical Access database, linked to a MapInfo GIS (geographical information system).

### 114 3.2 *Mapping fishing locations*

115 Twelve non-specific responses (e.g. "everywhere" or "all around") were removed from the household  
116 questionnaires. The proportion of each type of fisher from each island using each of the 24 zones was calculated  
117 and plotted using MapInfo GIS software.

118 In-depth interviews with 26 trap fishermen provided 73 locations and descriptions of fishing grounds and  
119 interviews with 7 divers provided 96. GPS positions from interviews were imported directly to MapInfo, while  
120 distances and directions were used to estimate the position of grounds in relation to a base map of the islands.  
121 Fishers who had a clear line of sight from their home beach to the ground and fishers who used GPS, were  
122 assumed to cite distances and directions directly from their home port, as they would be able to read this from  
123 the GPS display. Fishers who fished on other sides of the island from their beach and who navigated by transits  
124 (alignment of features on land) or compass bearings were assumed to state distance and direction from the point  
125 on the island when the first clear line of sight to the grounds was available. These assumptions are the most  
126 plausible interpretation of the directions recorded. Given the dimensions of Great Corn, if this assumption is  
127 incorrect it would introduce an error in site positions of up to 1.5km.

128 Interviews indicated that trap grounds extended for about a 1-mile radius around each position so the number of  
129 traps reported for each ground were assumed to be evenly distributed in a 1 mile buffer around each trap location  
130 mapped. Distribution of effort across diving grounds was determined by giving each an “attendance index”  
131 calculated as the inverse of the number of sites mapped by each diver (assuming that an equal proportion of time  
132 was spent at each). The sum of traps deployed and attendance indices were aggregated over a 5 x 5 minute  
133 lat/long grid to protect the exact location of fishing spots (Maurstad, 2002) while indicating general trends. The  
134 coefficient of dispersion (variance/mean, Begon et al., 1996) between those grid squares which included fishing  
135 was calculated to categorise the type of distribution.

### 136 3.3 *Changes in distances to fishing grounds*

137 The normal, maximum and minimum distances travelled to fishing grounds according to captains were analysed  
138 as 3 separate variables. Two-way ANOVA without replication was used to test each variable in turn for changes  
139 in time, with interviewee as a random factor and time-period (“Now”, “10 years ago”, “the 80s” and “the 70s”)  
140 as a fixed treatment effect (Sokal and Rohlf, 1981). This analysis was repeated excluding any observations  
141 detected with high residuals (1-3 observations) to check that they did not change the inference of the test. Pairs  
142 of time-periods were tested by paired t-tests with a Bonferroni correction to account for the six tests possible  
143 between 4 time-periods. A conservative probability of 0.0083 (i.e. 5% divided by 6) was therefore used to test  
144 the significance of results (Devore and Peck, 1986).

### 145 3.4 *Microeconomics of fishers*

146 Expenses and prices from interviews with fishers and middlemen were used to compile a balance sheet of a  
147 generalised trap fisher and lobster diver in 2003. To simplify capital costs (which were complicated by highly  
148 variable credit arrangements with middlemen) they were simply calculated as depreciation plus mean interest as  
149 follows:

$$150 \quad C = (V / D) + \frac{1}{2}V \times i$$



151 Where  $C$  is the capital cost of an item,  $V$  is the new price,  $l$  is the useful lifetime and  $i$  is the interest rate (5% was  
152 used<sup>1</sup>). Balance sheets were used to calculate the percentage of costs attributable to fuel for each fishery and the  
153 net income gained per pound of catch.

### 154 3.5 *Evaluation of distance-catch rate relationships*

155 Two separate evaluations were made of distance-catch rate relationships; one from interviews with trap fishing  
156 skippers and one from records of catch and fuel expenditure of divers. Twenty trap-fishing captains gave  
157 estimates of good, poor and/or normal catches per trip at each of 57 sites. These were converted to CPUE  
158 according to the number of traps used at each site. Catch rate and distance were square-root transformed to  
159 reduce the effect of outliers and allow regression assuming normal error distribution (Zuur et al., 2007) and  
160 regressed to test whether CPUE was higher at sites further from the islands.

161 Records of catches landed and fuel used by three lobster divers on 291 fishing days between July and December  
162 2002 were obtained from one middleman and records of historic fuel, lobster and fish prices were obtained from  
163 the records of one of the processing companies. Square-root transformed expenditure on fuel was used as a  
164 proxy for distance travelled and was regressed against square-root transformed daily catches of lobster. Changes  
165 in fuel price were not accounted for as they only fluctuated by 12% during this period (Central American  
166 Fisheries, Unpublished data). One to five days were removed from the data on each fisher due to large residuals  
167 that had a strong influence on the regression. Removal of these points had no effect on the significance of the  
168 regression and gave coefficients more indicative of typical conditions. The resultant regression equations were  
169 used along with the generalised diver balance sheet to evaluate the predicted increase in gross and net revenues  
170 for a US\$6.67 (100 Nicaraguan Cordoba) further expenditure on fuel on top of typical levels of expenditure  
171 (US\$16.7 and US\$30).

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<sup>1</sup> Some middlemen do not overtly charge interest but lend in US dollars and pay for lobsters in Nicaraguan cordobas. From the fishers perspective this leads to an effective interest rate as the Cordoba has declined at a rate of 0.767 C\$ per year over since January 2002 ([www.xe.com/ict](http://www.xe.com/ict)), which is roughly equivalent to 5%.

## 172 **4 Results**

### 173 *4.1 Spatial distribution of fishing effort*

174 Household surveys indicated that the northern zone beyond 10 miles of the island was used by the highest  
175 proportion of all types of fishers from both islands (Figure 1). No Little Corn fishers used grounds south or west  
176 of Great Corn but over 30% of Great Corn fishers utilised areas North of Little Corn suggesting that these were  
177 favourable grounds. Divers used a wider range of areas than trap fishers, with more usage of southern zones.  
178 Few commercial fishers used the zone within 2 miles of the islands and only 5-15% of divers admitted to using  
179 any of these nearshore zones.

180 Plotting of trap fishing grounds reinforced the importance of northern and eastern grounds for trap fishers  
181 indicated by the household survey, and allowed patterns to be seen at a higher resolution (Figure 2a). Trap  
182 grounds extended up to 50 km from Little Corn but the highest concentration of effort is seen 10-20 km east of  
183 Little Corn. The dispersion coefficient of trap density between 5 minute grid squares was 3.47 indicating a  
184 highly aggregated distribution of effort. Plotting diving sites and attendance indices per grid square showed  
185 individual divers ranging over a wide area in contrast to trap fishers (Figure 2b) who fished only 1-4 different  
186 grounds each. The dispersion coefficient of total attendance index was greatly less than 1 (0.10) indicating a  
187 regular distribution.

188 Interviews showed a clear distinction between the types of lobsters caught by area. Red lobster was reported to  
189 dominate catches at grounds in the east and south of the islands, while sites north and east were dominated by  
190 catches of white lobster (Figure 3).

### 191 *4.2 Factors affecting spatial effort distribution*

192 Factors affecting spatial effort distribution and fishing strategies varied between sectors. Trap fishers tended to  
193 keep to their individual grounds but move their strings of 2-10 pots between 10m and ½ mile at each setting in  
194 response to patterns of catches. Divers had knowledge of many locations and would try them in turn guided by  
195 previous experience. Some divers claimed to rotate sites to allow stocks to recover and/or to avoid repeated deep  
196 diving. Immediately after the closed season and during strong northerly winds, divers targeted concentrations of  
197 lobster close to the islands. After two or three days of fishing here, catches declined due to harvesting and the

198 lobsters moving back to deep water. Navigational tools used by fishers included landmarks, sea direction,  
199 compasses and GPS. 61% (n=28) of fishers used GPS, which they had acquired since 1992 (mean 1998). This  
200 allowed them to fish farther and in more challenging conditions, save time and fuel by easily locating grounds,  
201 and to mark traps with discrete buoys rather than flags to reduce the risk of theft. Fishers reported increased trap  
202 theft in recent years and that it was a serious concern, impelling them to fish farther offshore. 89% captains  
203 (n=9) stated that they would travel further if fuel was cheaper indicating that they were limited by fuel cost. In  
204 contrast, only 43% (n=7) said they would travel further if they had a faster boat suggesting time was only  
205 limiting for some fishers.

206 Captains were not in agreement as to whether better catches could be obtained by travelling further. Although  
207 lightly or un-fished grounds were preferred, seasonal rather than spatial variations were more apparent to fishers.  
208 Some trap fishers claimed the potential advantages of travelling to more distant grounds were offset by increased  
209 conflicts with the industrial fleet, which apparently encroached into the 26 mile zone reserved for artisanal  
210 fishers.

#### 211 *4.3 Changes distance fished in recent history*

212 Trap captains reported highly significant differences in the maximum, normal and minimum distances (p=0.000,  
213 p=0.000 and p=0.009 respectively) travelled to fishing grounds during different periods since the 1970s. All  
214 three distances had increased with time, especially during the last 10 years (Figure 6). Maximum and normal  
215 distances were significantly different between now and 10 years ago (p=0.006 and p=0.007 respectively) but not  
216 between 10 years ago and the 80s once the Bonferroni correction is applied (p=0.009 and p=0.043). The mean  
217 extension of normal fishing distance from 10 years ago to now was  $10.8 \pm 6.3$  miles (95% c.i.) while maximum  
218 distance increased by  $10.4 \pm 6.9$  miles.

#### 219 *4.4 Microeconomics of fishing operations*

220 Balance sheets based on a typical profile of lobster and trap operations estimated that fuel accounted for 52% of  
221 a lobster diving operation's total costs and 37% of costs of a lobster trap operation (see supplementary data).

#### 222 4.5 Evidence for catch rate-distance relationships

223 There was a significant positive relationship between maximum CPUE of trap grounds, as indicated by  
224 statements of “good catch” by trap fishers, and the distance of a site from the fishers home island and Great Corn  
225 Island ( $p = 0.001$ , Figure 4). “Normal” and “Bad” catches were not significantly correlated with distance ( $p =$   
226  $0.232$  and  $p = 0.562$  respectively).

227 Despite large variations in catches, there was a significant positive relationship between expenditure on fuel and  
228 total weight of lobster caught for each of the three lobster divers examined (Figure 5, Table 2). The marginal  
229 increase in daily gross margin predicted for a US\$ 6.67 (100 Nicaraguan Cordobas) increase in fuel expenditure  
230 was US\$ 11-18.67 in terms of catch value and US\$ 9.47-16.13 on daily margins for the boat captain after  
231 covering costs, payments to the diver and assistant and deductions for water weight and tax.

## 232 5 Discussion

233 This study contributes to a growing literature demonstrating that some understanding of fishing effort  
234 distribution can be obtained by a low-tech and cost effective strategy of interviews (e.g. Hall and Close, 2007).  
235 The positions of fishing grounds may be subject to errors from misjudgement or misinformation from  
236 interviewees, ambiguous use of statute and nautical miles and the generalisation of potentially large, irregularly  
237 shaped grounds by the plotting of single positions. However, the accuracy is sufficient to show general patterns  
238 of effort distribution with a coarse 5 x 5 min grid. Such effort maps are useful for management by highlighting  
239 areas of potential conflict and heavily use, suggesting implications of proposed spatial management measures  
240 and indicating biological information about stocks. Accuracy of the patterns observed could be tested and  
241 improved by involving more fishers, checking positions at-sea while observing fishing activities and by using  
242 bathymetric charts and habitat maps to “contextually edit” fishing grounds.

243 There appeared to be some spatial segregation of the two fishing gears. Thirty-five and 40 grid squares  
244 respectively contained divers and trap fishing activity but only 15 contained both. This may be due to different  
245 ideal habitats for the two fishing methods or the result of conflicts which is felt between the two groups (Hume  
246 et al., 2005). Informal property-rights or territoriality, which have been shown to regulate fishing areas in other  
247 studies (de Castro and Begossi, 1995; Schlager and Ostrom, 1992) were not indicated by open-ended questions

248 during these interviews. However these may be difficult to elucidate without focussed study so their existence  
249 and effect on effort distribution cannot be ruled out.

250 The distinction between white and red lobster has no biological or taxonomic basis but the widely held  
251 recognition of the forms by the islanders and the clear spatial distribution trends uncovered in this study warrant  
252 further investigation. Previous studies have shown how such local classifications and mapping of local  
253 knowledge can be used to uncover the distribution of species and identify discrete stock structures with  
254 implications for management (Ames, 2004; Wroblewski, 2000).

255 Most studies of fishing effort distribution find aggregated dispersion (Jennings et al., 1999; Pet-Soede et al.,  
256 2001) as with that shown by the trap densities in this study. The regular pattern of dispersion observed for divers  
257 is therefore unexpected and usually emerges when organisms repel each other or establish territories leading  
258 them to space out evenly (Begon et al., 1996). Although fishermen have been reported to have territories  
259 (Acheson, 1975; de Castro and Begossi, 1995) examples usually concern fixed gears and territoriality between  
260 divers who use sites intermittently seems unlikely. One diver described how he usually spent half of his time at  
261 one site, almost half at his next 3 most popular and only made occasional visits to others. This level of detail was  
262 not available for most divers, necessitating the assumption that a diver spreads effort evenly between his sites.  
263 Temporal distribution of diver effort between sites could be found through a logbook study as was conducted  
264 with artisanal fishers in Kenya (Obura, 2001) and would be expected to increase the variance and thus the  
265 dispersion coefficient of diver effort. In addition perceptions of dispersion patterns are determined by the scale at  
266 which they are examined (Levin, 1992). If divers focus on smaller grounds (e.g. individual rocks) than trap  
267 fishers, examination on a smaller spatial scale than the 5 x 5 minute grid used here may have shown a more  
268 aggregated distribution.

269 The historic extension of fishing ranges observed in these fisheries is a typical phenomenon of fisheries as they  
270 become overexploited in nearshore grounds (Caddy and Carocci, 1999). Extension of ranges *per se* do not  
271 indicate overexploitation, as they are likely due to changes in any factors affecting distance costs. For example  
272 technological improvement (e.g. GPS) can allow fishing at greater distances while trap fishers were impelled to  
273 travel further to avoid theft of traps. However, in the case of Corn Island, declining CPUE trends are coupled  
274 with an increase in the maximum range from 14 to 24 miles as over 10 years (Figure 6) which would result in a

275 doubling of the potential resource space available to fishers. Area fished is important in the interpretation of  
276 CPUE trends (Gobert and Stanisière, 1997; Jennings et al., 2001; Koslow et al., 1994) so when increasing fishing  
277 areas is accounted for in Corn Islands, the long-term declines of lobster stocks around Corn Island may be more  
278 severe than perceived by fishers or CPUE statistics. Given that extension of ranges is likely to occur in  
279 developing fisheries, detection of catch trends by fishers or managers may be hidden by CPUE ‘hyperstability’  
280 (Hilborn and Walters, 1992) if range extension buffers CPUE from declines in stocks. It is therefore important  
281 that fisheries managers are aware of trends in spatial effort distribution.

282 There was evidence that catch rates were higher at more distant sites in both the trap and dive fishery. The  
283 significant relationship found between fuel expenditure and catch for lobster divers predicts that there is an  
284 economic incentive for divers to focus on grounds farther from home. However, the costs associated with  
285 distance do not only involve fuel and other financial factors, but also non-monetary costs and incentives  
286 (Jennings et al., 2001). Bene and Tewfik (2001) for example, found that divers in the Turks and Caicos did not  
287 behave according to economic predictions due to social and technical factors like peer-pressure and diving  
288 ability. The qualitative results of this study suggest that the decision on how far to travel is affected by  
289 familiarity with grounds, conflicts with vessels from other islands, fuel cost, safety and opportunity costs of  
290 travel time. Figure 7a shows a conceptual model of costs associated with distance for a Corn Island trap  
291 fisherman considering five of the factors discussed during the in-depth interviews and described by simple  
292 functional relationships with distance. The aggregate cost-distance function which incorporates all of these  
293 factors (Figure 7b) is much more complicated than a simple fuel cost – catch rate relationship. Thus,  
294 appreciating how fishers’ make spatial decisions requires a flexible and interdisciplinary approach that can cope  
295 with the complexity of factors which may be missed by solely reductionist economic modelling.

296 In addition, even if a straightforward fuel cost - catch trade off did accurately represent fishers’ decision making,  
297 it is questionable whether fishers could perceive generalised relationships like those in Figure 5 given the  
298 variability experienced in catches and the impact of seasons and individual ground characteristics. In response to  
299 the question, “Do you catch more fish when you go further?” fishers typically said that sometimes catches were  
300 higher but that they could also be lower. Artisanal fishers elsewhere have been shown to be unable to discern  
301 spatial variation in catch rates in order to maximise their returns (Oostenbrugge et al., 2001; Pet-Soede et al.,

302 2001). It was also mentioned on many occasions that grounds are fished cyclically, one diver claiming he used  
303 most of his grounds only once per year. In this scenario, although a generalised trend of greater catches at more  
304 distant grounds may be observed, it would be of little practical use for day-to-day decision making if divers  
305 selected grounds on the basis of those which had not been fished recently, irrespective of distance.

## 306 **6 Conclusion**

307 This study has used low-tech combined interview and GIS approaches to collect fishers' knowledge on the  
308 distribution of fishing effort around the Corn Islands and the related economics offering a cost-effective means  
309 to monitor fishing effort distribution and reconstruct past trends.. Trap fishing effort had a highly aggregated  
310 dispersion while diving was regularly dispersed, perhaps because of the greater mobility and number of sites  
311 used by divers. Although fuel is a major part of fishers' costs, the range of the artisanal lobster fleet has,  
312 typically of many fisheries, expanded in recent years in response to higher CPUE at more distant sites, trap theft  
313 from nearshore grounds and new navigational technology. This expansion of range suggests that declines in  
314 lobster stocks may be more severe than perceived by declines in CPUE, and could impact the economic viability  
315 or profitability of operations. Spatial management measures, which are growing in popularity, should be  
316 considered in the light of existing spatial organisation of the fishery. Description of such organisation, can  
317 contribute to management planning by allowing spatial measures to incorporate existing patterns, and also help  
318 conventional stock assessment and management to take account of non-uniform fishing effort distribution.  
319 Understanding the factors underlying spatial effort distribution will help to predict the impact of MPAs on  
320 fishers and resources in terms of displacement of fishing effort, although there are likely to be a complex range  
321 of interacting factors that can only be appreciated by an interdisciplinary approach.

## 322 **Acknowledgements**

323 Fishers, traders and residents of Corn Island are gratefully acknowledged for their assistance, cooperation and  
324 knowledge, especially Norma Dixon, Jose Manuel Alvarez and Melody Taylor. Clarence Gonzalez assisted with  
325 in depth interviews. Ulrika Gunnartz, Jessenia Bello, Karen Joseph and students from URACCAN conducted the  
326 bulk of the household survey. Ivan Weir and Bob Foster-Smith advised on research, John Bythell and Michael



327 Daw provided advice on data analysis, Beatrice Crona assisted with preparation of figures. This study was part  
328 of 'Reefmap Nicaragua' funded by Rufford Small Grants, the Royal Geographical Society, Newcastle University  
329 and supported by MARENA. Tim Daw was supported by an NERC studentship and travel grant. The manuscript  
330 was substantially improved by the comments of two anonymous reviewers.

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414 **Figure Captions**

415 Figure 1. Percentage use of zones around the Corn Islands by different types of lobster fishers from the two  
416 islands.

417 Figure 2. Lobster fishing effort intensity from in-depth interviews with skippers per 5x5 minute lat/long grid. (a)  
418 Trap density as a result of fishing by 12 Little Corn Island and 14 Great Corn island trap fishers. One grid square  
419 contained markedly higher density of 17 traps/km<sup>2</sup> (b) Lobster diver attendance by 7 Great Corn Island divers.  
420 Attendance indices assume divers spread effort evenly between their own sites.

421 Figure 3. Relative distribution of red and white lobsters on the lobster fishing grounds around the Corn Islands.  
422 Shaded boxes and numbers indicate mean percentage white lobster reported for grounds in each 5x5 minute  
423 lat/long grid square.

424 Figure 4. ‘Good’, ‘normal’ and ‘poor’ catch rates reported by skippers at individual sites plotted against distance  
425 from skippers’ home island. The regression line and equation is shown for good catches, for which there was a  
426 significant relationship.

427 Figure 5. Actual catches and fitted regressions of daily lobster catch against expenditure on fuel by 3 Corn Island  
428 divers between July and December 2002.

429 Figure 6. “Maximum”, “Minimum” and “Normal” distances of fishing sites from home quoted by Corn Island  
430 lobster trap fishermen for the past 35 years. Bars indicate mean response ±S.E. Number of responses indicated  
431 on each bar.

432 Figure 7. (a) Conceptual diagram of the relationship between cost and distance for a lobster trap fisherman based  
433 on factors described in qualitative interviews and simple functional relationships. (b) Aggregate function of total  
434 costs with distance arrived at by summing costs in figure a; asymptotically increasing relationship of catch  
435 revenue with distance; and net benefits calculated as the difference between costs and revenue.

Tables

1

2 Table 1. Distribution of sample of fishers by home island, ethnic group and fishing gear

|                                | Total | Island     |             | Ethnic group |                   |         | Main fishing gear |        |          |
|--------------------------------|-------|------------|-------------|--------------|-------------------|---------|-------------------|--------|----------|
|                                |       | Great Corn | Little Corn | Miskito      | Creole & Garifuna | Mestizo | Traps             | Diving | Handline |
| Approx No fishers <sup>1</sup> | 1700  | 1290       | 430         | 306          | 1230              | 151     | 560               | 80     | 460      |
| Household interviews           | 198   | 139        | 59          | 43           | 129               | 22      | 152               | 38     | 5        |
| Fishing areas used             | 196   | 158        | 38          | 91           | 104               | 1       | 60                | 115    | 21       |
| In depth interviews & mapping  | 33    | 24         | 16          | 7            | 26                | 0       | 25                | 7      | 1        |
| Information on costs           | 16    | 8          | 8           | 4            | 12                | 0       | 11                | 3      | 0        |

<sup>1</sup> Calculated by multiplying government figures from ADPESCA (2003) up to total fishing population estimate of 1700

3

4 Table 2. Regression relationships found between daily expenditure on fuel and weight of catch for three Corn Island lobster divers  
5 between July and December 2002 (Equations in the form:  $\sqrt{\text{catch}} = a \times \sqrt{\text{fuel expenditure}} + B$ )

| Diver | n               | Gradient (a) | Intercept (B) | Significance |
|-------|-----------------|--------------|---------------|--------------|
| 1     | 94 (2 removed)  | 0.0740       | 2.18          | p = 0.010    |
| 2     | 96 (5 removed)  | 0.0911       | 3.00          | p = 0.012    |
| 3     | 101 (1 removed) | 0.1113       | 1.42          | p < 0.001    |

6

Figure 1

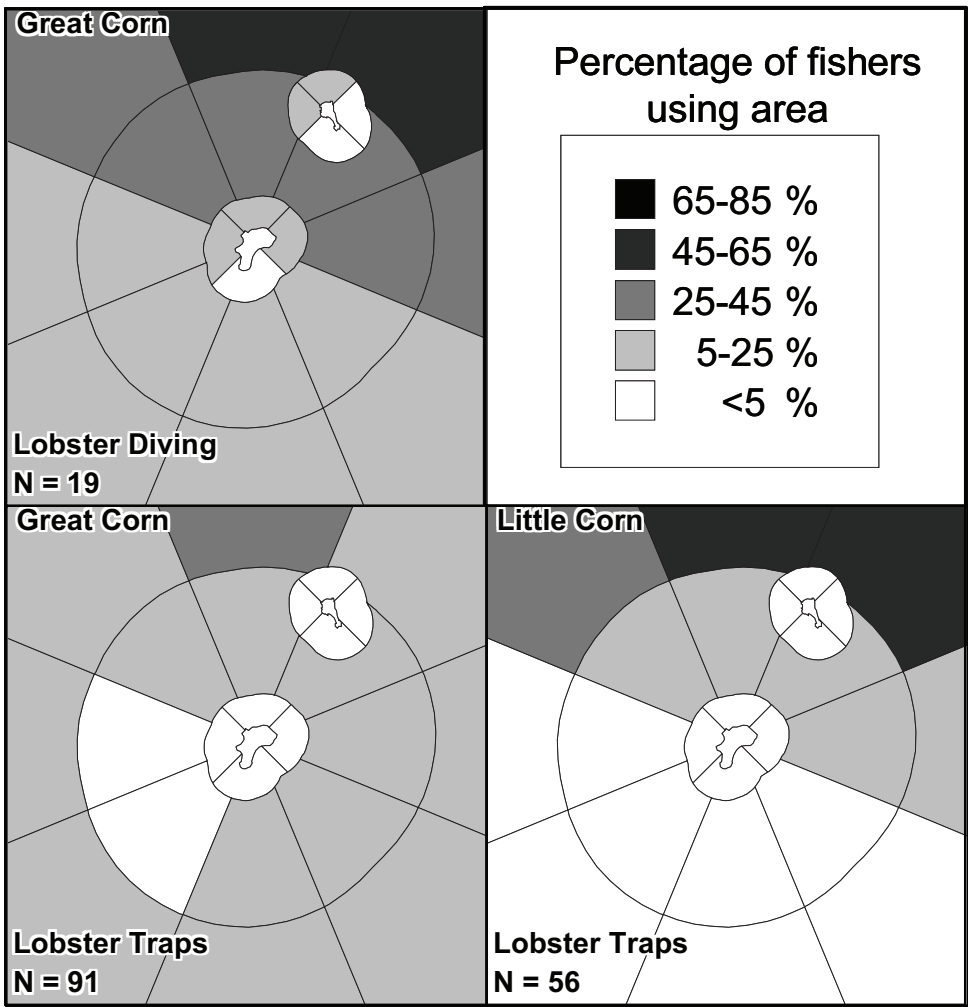
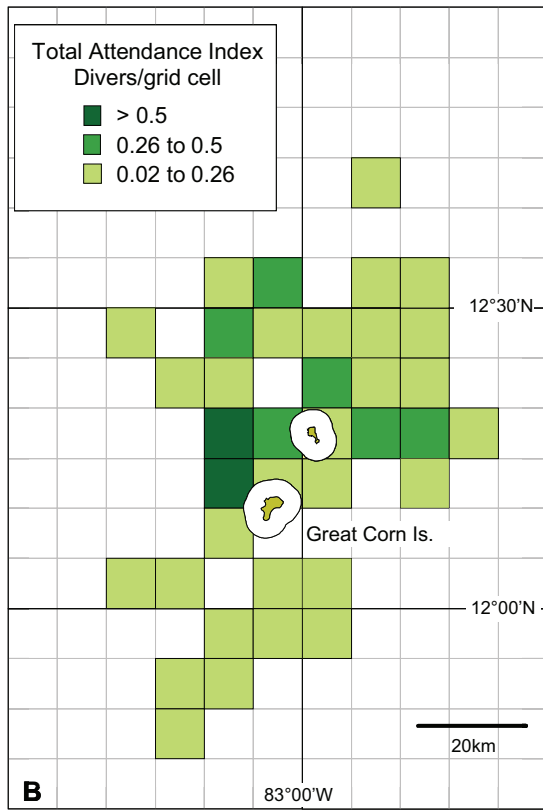
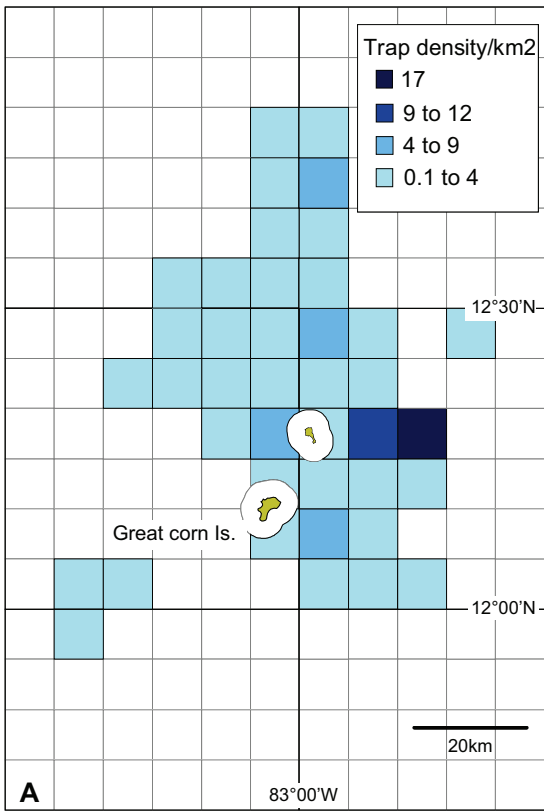


Figure 2 - colour

1



2



Figure 4

1

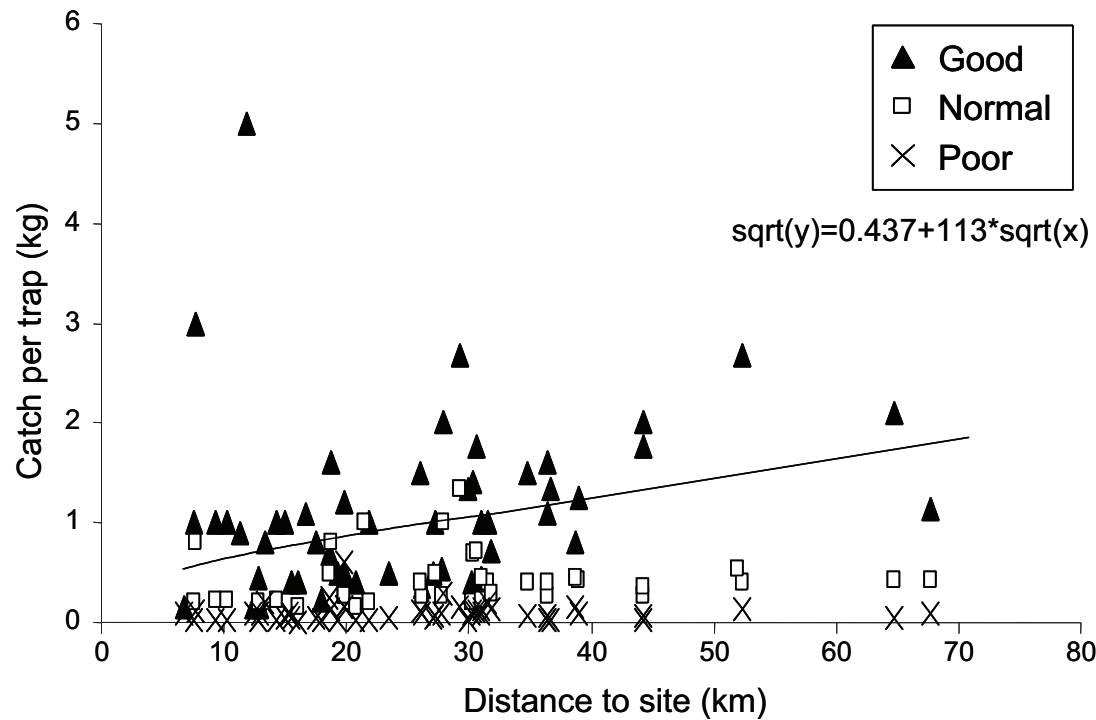




Figure 5 - colour

1

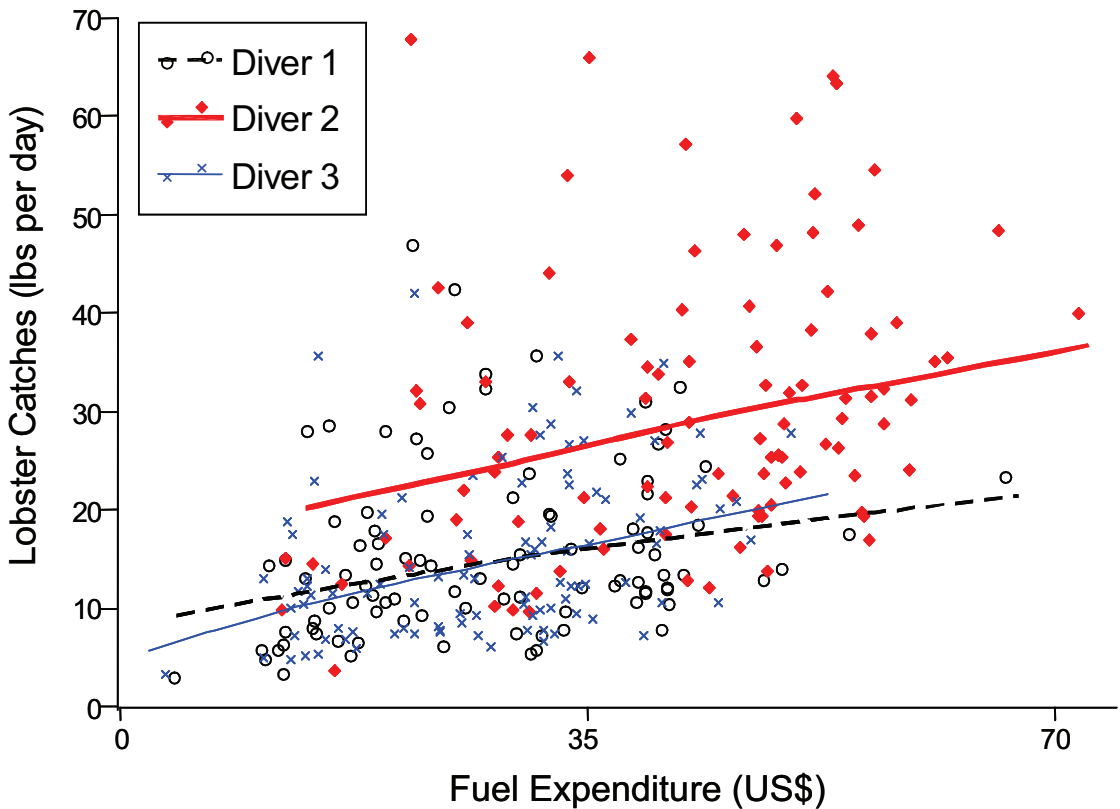


Figure 6

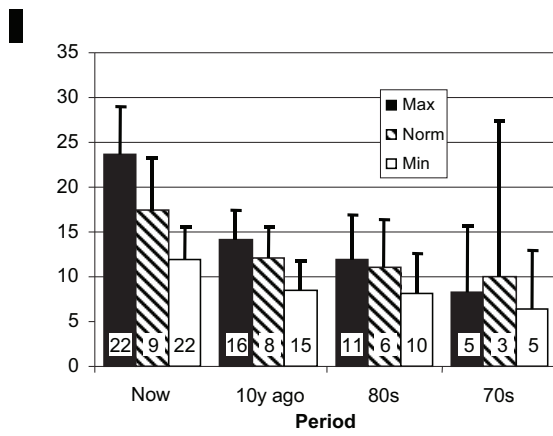


Figure 7

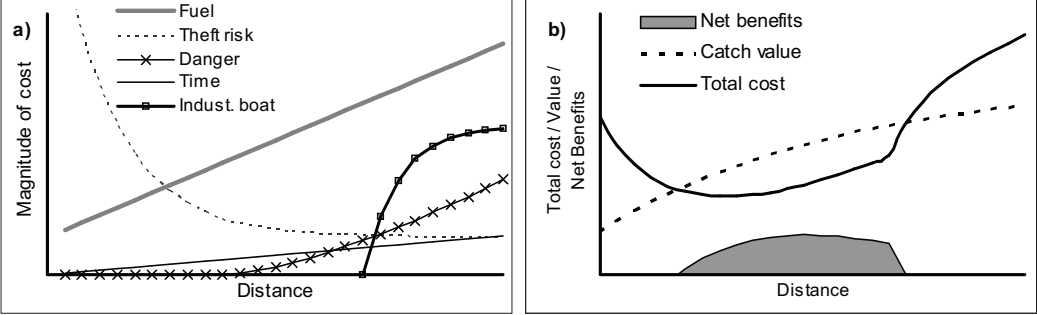


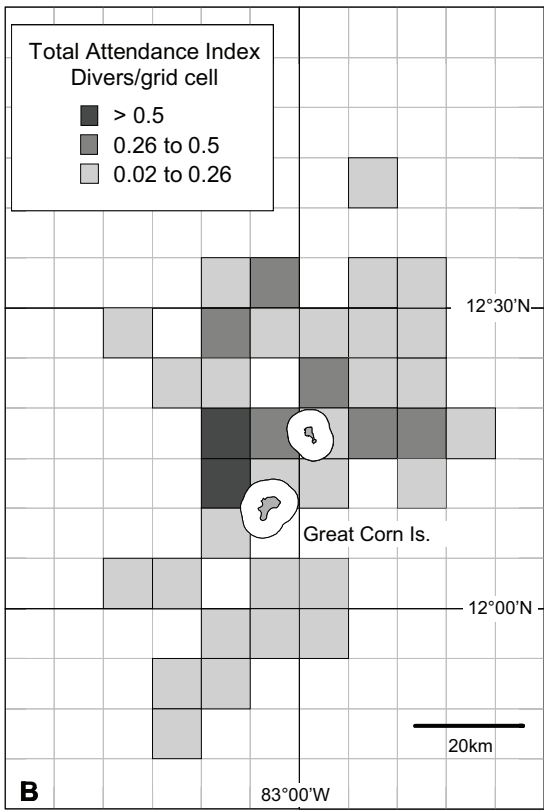
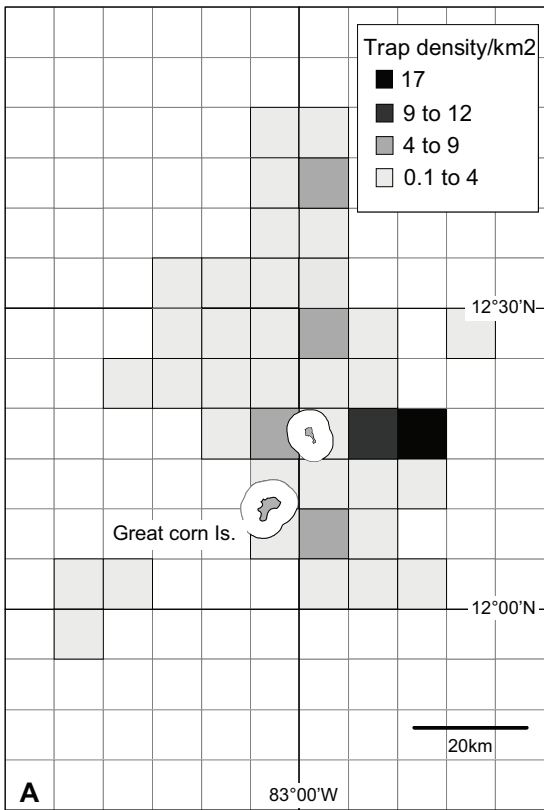
Table 1. Generalised balance sheets for lobster dive and trap fishing captains fishing from Corn Island in 2003. Values are reported in Nicaraguan Cordobas (in 2003 15C\$=1USD)

| INPUT VARIABLES/PARAMETERS      | DIVER            | TRAP FISHER      |
|---------------------------------|------------------|------------------|
| Distance fished (Mi)            | 14               | 17.4             |
| Trips per week                  | 6                | 3                |
| NoTraps                         |                  | 300              |
| Dive Tanks/Traps per Day        | 11               | 100              |
| No of Sailors                   |                  | 2                |
| Lobster Catch (lbs/day)         | 20 lbs           | 20 lbs           |
| Lobster Price                   | C\$ 137          | C\$ 137          |
| Mixed Fuel Price                | C\$ 48           | C\$ 48           |
| Bait Price (per sack)           |                  | C\$ 275          |
| Bait usage (trap months/sack)   |                  | 150              |
| Tender/Sailor Pay (/lb lobster) | C\$ 12           | C\$ 10           |
| Travel Fuel (gal/mile)          | 0.3              | 0.3              |
| Fishing fuel (gal/trip)         | 8                | 8                |
| Price per tank                  | C\$ 15           |                  |
| InterestRate                    | 5%               | 5%               |
| Exchange rate                   | C\$ 15           | C\$ 15           |
| Months of Veda                  | 2                | 2                |
| Licence Cost (/month)           | C\$ 300          | C\$ 300          |
| Boat Licence (/year)            | C\$ 900          | C\$ 900          |
| Boat Maintenance (/year)        | C\$ 6,000        | C\$ 6,000        |
| Engine Rebuild (/occasion)      | C\$ 7,500        | C\$ 7,500        |
| Engine Rebuild frequency (yrs)  | 3.25             | 3.25             |
| Alcaldia tax                    | 1.5%             | 1.5%             |
| Deduction for water             | 5%               | 5%               |
| Boat cost                       | C\$ 82,500       | C\$ 82,500       |
| Boat lifespan                   | 25               | 25.0 yrs         |
| Engine Cost                     | C\$ 64,500       | C\$ 64,500       |
| Engine lifespan                 | 6.5              | 6.5 yrs          |
| Trap Cost                       |                  | C\$ 225          |
| Trap Lifespan                   |                  | 1.5 yrs          |
| Trap loss per year              |                  | 50               |
| <b>TRIP BALANCE</b>             |                  |                  |
| <b>Trip Revenue</b>             |                  |                  |
| Net Catch                       | C\$ 19           | C\$ 19           |
| Revenue                         | C\$ 2,603        | C\$ 2,603        |
| <b>Variable Costs</b>           |                  |                  |
| Fuel                            | C\$ 586          | C\$ 635          |
| Dive Tanks                      | C\$ 165          |                  |
| Pay to tender/divers            | C\$ 228          | C\$ 400          |
| 1.5% Alcaldia tax               | C\$ 39           | C\$ 39           |
| <b>TOTAL TRIP COSTS</b>         | <b>C\$ 1,018</b> | <b>C\$ 1,074</b> |

|                                   |                   |                   |
|-----------------------------------|-------------------|-------------------|
| <b>Margins</b>                    |                   |                   |
| Total Trip Margin                 | C\$ 1,585         | C\$ 1,529         |
| Share to Capn & Diver each        | C\$ 793           |                   |
| <b>ANNUAL COSTS</b>               |                   |                   |
| <b>Fixed Costs</b>                |                   |                   |
| Fishing Licence                   | C\$ 3,000         | C\$ 3,000         |
| Boat Licence                      | C\$ 900           | C\$ 900           |
| Boat Maintenance                  | C\$ 6,000         | C\$ 6,000         |
| Engine Rebuild                    | C\$ 2,308         | C\$ 2,308         |
| <b>TOTAL ANNUAL FIXED COSTS</b>   | <b>C\$ 12,208</b> | <b>C\$ 12,208</b> |
| <b>Capital Costs</b>              |                   |                   |
| Boat depreciation                 | C\$ 3,300         | C\$ 3,300         |
| Boat mean interest                | C\$ 2,063         | C\$ 2,063         |
| Engine depreciation               | C\$ 9,923         | C\$ 9,923         |
| Engine mean interest              | C\$ 1,613         | C\$ 1,613         |
| Trap depreciation                 |                   | C\$ 45,000        |
| Trap mean interest                |                   | C\$ 1,688         |
| <b>TOTAL ANNUAL CAPITAL COSTS</b> | <b>C\$ 16,898</b> | <b>C\$ 63,586</b> |
| <b>Other</b>                      |                   |                   |
| Bait                              |                   | C\$ 5,500         |
| <b>ANNUAL BALANCE</b>             |                   |                   |
| No. Trips Per Year                | 260               | 130               |
| Annual Gross Margin (Capn)        | C\$ 206,096       | C\$ 198,821       |
| Annual Fixed & Capital Costs      | C\$ 29,106        | C\$ 81,293        |
| Annual Net Income                 | C\$ 176,990       | C\$ 117,528       |
| Annual spending on fuel           | C\$ 152,256       | C\$ 82,493        |
| Annual spending variable costs    | C\$ 264,588       | C\$ 139,569       |
| Fuel as % of all costs            | 52%               | 37%               |

Figure 2 - greyscale

1



2

Figure 5 - greyscale

1

