SYNERGIES IN THE COMMONS:

INFORMATION SHARING IN LIMITED ENTRY FISHERIES*

Neal S. Johnson

School of Public and Environmental Affairs
and
Workshop in Political Theory and Policy Analysis
Indiana University
Bloomington, IN 47405
Phone: (812) 855-4944
Telenet: nsjohnso@ucs.indiana.edu

February 21, 1993

* This paper is a shortened version of my doctoral dissertation, written for the Department of Economics, University of Washington, Seattle. I would like to thank Yoram Barzel, Greg Ellis, Dan Huppert, and Fahad Khalil for their helpful comments.

ABSTRACT

Economic models of common property resources tend to focus on the negative externalities that exist between resource users, ignoring any cost-reducing synergies that might also exist. This paper models one such synergy that occurs in the fishery. Within the framework of a two season model, fishers repeatedly face the twin decisions of whether to continue fishing, and whether to share fish information with others. In addition, if fishers choose to share information they must also decide with whom to share. In deciding whether to share fish information, fishers weigh the expected benefits of sharing — lower search costs — against the expected costs, which include inter- and intra-seasonal stock effects, a school depletion effect, and a crowding effect. The model yields several implications, two of which are examined in this paper. First, fishers are more likely to share information if they are targeting mobile species, such as tuna, herring, and salmon, than relatively sedentary species like rockfish, lobster, and crab. Second, when vessels are privately owned we would expect information sharing cliques (ISCs) to be structured according to skill levels, with highliners forming their own clique(s) and average fishers sharing with other average fishers. We would also expect this form of clique structure when company skippers are compensated based on their own catch. Fleet managers, on the other hand, could increase fleet profits by creating ISCs comprised of heterogeneous fishers. Evidence drawn from the anthropology litererature and elsewhere strongly favors the model.

I. INTRODUCTION

Most analyses of the commons are predicated on the assumption that individuals ignore any negative impacts imposed on other resource users. These analyses are usually one-sided in the sense that synergies between members of the commons are generally ignored. Yet, for some commonly-held resources, cooperation between individuals can result in lower costs per unit output. This type of synergy exists in the fisheries for pelagic fish species such as tuna and salmon, where sharing information on the location of schools or aggregations of fish with other fishers leads to reduced search costs.

This paper examines how results from the standard common property model are altered when synergies are included in the analysis. While the application chosen for illustrative purposes is a limited entry fishery, the underlying concept is applicable to other resource regimes where each individual can impact stock levels or resource quality and where cost-reducing synergies between members of the commons are possible.

Section II of this paper models the incentives of heterogeneous fishers to share information in the presence of intertemporal stock effects. In addition to the inclusion of information sharing, the model diverges from typical common property models in two important ways. First, most fishery models specify each fisher's (or firm's) choice variable as their number of vessels (Dasgupta and Heal, 1979; Cornes and Sandler, 1983). This paper takes an alternate approach by recognizing that at the daily or seasonal level, at least, the fundamental decision faced by many fishers is whether or not to continue fishing. Instead of choosing effort at the beginning of the season, fishers continually assess the profitability of continuing the search. The second point of departure, which is closely related to the first, concerns the temporal dimensions of the problem. To accommodate the selected choice variable, the model consists of two discrete fishing seasons. Within each season, however, time is continuous, making it possible to speak of the stock level at time t in season k. This formulation allows a clearer focus on two distinct types of intertemporal stock effects: those that are *intra*seasonal versus those that are *inter*seasonal. Intraseasonal effects are related to the first-come-first-served aspect of fishing and are of concern in our model primarily because of the synergies between fishers. In addition to decreasing search costs, sharing information with others decreases stock levels faster than otherwise, resulting in fewer fish available later in the season. From the perspective of an individual fisher, this may be a cost of sharing information.

Section III examines the school depletion and crowding effects and the structure of information sharing cliques. Section IV presents evidence in support of section II and III's predictions. Section V concludes the paper.

II. HETEROGENEOUS FISHERS, INTERTEMPORAL STOCK EFFECTS AND THE INCENTIVE TO SHARE INFORMATION

This section examines the incentives faced by heterogeneous fishers to share information when faced with intraseasonal and interseasonal stock effects. For analytical ease, attention is restricted to the 2 fisher case. A two period model is employed, with each period representing a fishing season. Within each season there are 'search-harvest cycles,' or 'cycles,' for short. Harvesting takes place during each season with recruitment (stock growth) occurring between the two seasons.

The stock level at time t, $t \in [0,T]$, in season k, $k = I, II$, is denoted by $X_{k,t}$. The stock at the beginning of the first season, $X_{I,0}$, is given. The stock at the beginning of the second season is determined by a growth function:

$$X_{II,0} = G(X_{I,0} - H_{I,T}) = G(X_{I,T});\ G' \geq 0,\ G'' \leq 0, \tag{1}$$

where $H_{I,T}$ is aggregate harvest in the first season.

When not actively harvesting, each fisher continually faces two decisions: whether to continue fishing and whether to share fish information with the other fisher. If desired, fishers can choose to share information one cycle and not the next. Any commitment to share information is assumed to be credible, effectively precluding fishers from reneging on information sharing agreements after finding a school of fish. The relevant courses of action, $\mathbf{a}_i$, available to fisher i are given by

(1,1) search, share information;

(1,0) search, don't share information; and

(0,0) don't search, which obviously precludes information sharing.

If one fisher wishes to share information and the other doesn't, neither share information. Similarly, if one doesn't fish, the options available to the other are reduced to (1,0) and (0,0). For cooperative solutions, two other courses of action are also available. First, a fisher may use information from another fisher but remain idle during the search phase. Second, a fisher may search, share information when a new school is found, but may not himself harvest from a school, instead preferring to continue searching.

When a fisher chooses a course of action — to continue fishing but not share fish information, for instance — he compares the expected costs and benefits of the available alternatives and selects the one that yields him the largest net benefits. These costs and benefits include those incurred over the current search-harvest cycle, as well as any longer run intra- or interseasonal costs and benefits. Short-run (defined as one cycle) benefits are given by:

$$B_i(X_{k,t}) = P \cdot \tau_H(\alpha X^{\beta}) h_i(\alpha X^{\beta}), \tag{2}$$

where P is the exogenously given ex vessel price of fish, τ_H is the time spent harvesting from an individual school, and $h_i(\alpha X^{\beta})$ is fish catch per unit time actively spent harvesting from the school. τ_H and h_i depend on the size of each school, given by αX^{β}, where α and β are parameters associated with the schooling behavior of the particular fish species (see Johnson, 1993, for further explaination).

Expected costs are derived by assuming that the discovery of schools or aggregations of fish follows a Poisson process, with μ_i being the number of schools discovered by fisher i during a given period of searching. Fisher i's short-run expected costs will depend on whether information is shared or not. Without information sharing, expected costs are given by

$$C_i((1,0),X_{k,t}) = \frac{c_{S,i}}{X^{(1-\beta)}\mu_i} + \tau_H(\alpha X^{\beta})c_{H,i}, \tag{3}$$

where $c_{S,i}$ and $c_{H,i}$ are the costs (per unit of time) of searching and harvesting, respectively.[1] With information sharing, expected costs are

$$C_i((1,1),X_{k,t}) = \frac{c_{S,i}}{X^{(1-\beta)}\mu_A} + \tau_H(\alpha X^{\beta})c_{H,i}, \tag{4}$$

where $\mu_A = \mu_1 + \mu_2$. Given our assumptions the benefits from a search-harvest cycle are independent of μ_i and are nondecreasing in X. Also, fisher i's expected costs are strictly decreasing in μ_i (or μ_A) and are non-increasing in X.

Two types of heterogeneity will be examined: those arising from differences in skill, and those due to differences in costs. To simplify the discussion, let $\mu_1 \geq \mu_2$: if one fisher is a better searcher than the other, then it is fisher 1. Similarly, if one fisher has lower marginal costs of searching or harvesting, then it is fisher 1. Since the focus of this section is on intertemporal stock effects, school depletion and crowding effects are ignored.[2]

Let $J_{k,t,i}(X_{k,t})$ be the expected net benefits accruing to fisher i for the remainder of season k, beginning at time t. Now define $J_{k,t+,i}(X_{k,t+,i}) = J_{k,t,i}(X_{k,t}) - [B_i(X_{k,t}) - C_i(a_i,X_{k,t})]$. By defining $J_{k,t+,i}$ so that it excludes the current search-harvest cycle it's possible to write the first-period objective function for each fisher in the noncooperative cases as

---

[1] See Johnson (1993) for the derivation of (3) and (4).

[2] Note that the absence of a school depletion effect doesn't imply the absence of intertemporal stock effects. The former deals with *schools*, while the latter concerns the *total* stock. Issues related to the school depletion and crowding effects are deferred to section III.

$$\underset{a_i}{Max}\ \pi_{I,t,i} = B_i(X_{I,t}) - C_i(a_i, X_{I,t}) + J_{I,t+,i}(X_{I,t+,i}(a_i, a_{-i})) + J_{II,0,i}(X_{II,0}), \quad i = 1,2. \tag{5}$$

For the cooperative cases, the objective function is

$$\underset{a_1,a_2}{Max} \sum_{i=1}^{2} \pi_{I,t,i} = \sum_{i=1}^{2} \left[B_i(X_{I,t}) - C_i(a_i, X_{I,t}) + J_{I,t+,i}(X_{I,t+,i}(a_i, a_{-i})) + J_{II,0,i}(X_{II,0})\right]. \tag{6}$$

Note that $X_{I,t+,i}$ (and possibly $X_{II,0}$) will be influenced by the actions taken at time I,t. The intraseasonal stock effect works in the following fashion. If the two fishers are identical and they choose not to share information, then the stock level at the end of fisher i's current cycle will be the same as if they had shared information. While the cycle length has been increased for both fishers, the expected harvest over this period is the same. By contrast, if fisher 1 is a better fisher, the stock level he expects to face at the end of the current cycle will be greater if he doesn't share information. This is because fisher 2 is expected to take longer to search out and find a school if he searches on his own. Consequently, the expected harvest of fisher 2 during fisher 1's next cycle length is less than if information had been shared. To formalize this concept, let $X^s_{k,t+,i}$ denote the expected stock level at the end of fisher i's current search-harvest cycle given that information is shared. Similarly, $X^{ns}_{k,t+,i}$ is the expected stock level if information is not shared. We will say there is no intraseasonal stock effect if $X^s_{k,t+,i} = X^{ns}_{k,t+,i}$.

The One-Season Cases

This subsection examines the solution to the model beginning at time $k,t = II,0$. Define $\underline{X}^s_i$ such that $B_i(\underline{X}^s_i) = C_i((1,1),\underline{X}^s_i)$. This is the stock level at which fisher i would expect to break even if he chose to fish and share information for one more search-harvest cycle. For any stock level lower than $\underline{X}^s_i$, fishing is expected to be unprofitable for fisher i. Similarly, define $\underline{X}^{ns}_i$: $B_i(\underline{X}^{ns}_i) = C_i((1,0),\underline{X}^{ns}_i)$ as the stock level where fisher i expects to break even without information sharing.

Cooperative solution with identical fishers

For comparison purposes, first consider the cooperative solution with identical fishers. With identical fishers, $\mu_1 = \mu_2$, $c_{S,1} = c_{S,2}$, and $c_{H,1} = c_{H,2}$, so that $\underline{X}^s{}_1 = \underline{X}^s{}_2 = \underline{X}^s$. Information sharing lowers the costs of a search-harvest cycle, but not the associated benefits; hence, $B_i(X_{II,t}) - C_i((1,1),X_{II,t}) > B_i(X_{II,t}) - C_i((1,0),X_{II,t})$ for all $X_{II,t}$. A social planner would choose to have full information sharing. Given this, fishers will continue to search and harvest so long as the expected value marginal product of fishing is greater than the expected marginal cost. This will be until either $X_{II,t} \leq \underline{X}^s$ or time T is reached, whichever comes first.

Cooperative solution with heterogeneous fishers

If the heterogeneity is strictly due to differences in the ability of fishers to find schools, then $\mu_1 \neq \mu_2$. Note, however, that $\mu_1 + \mu_2 = \mu_A$, so that $\underline{X}^s{}_1 = \underline{X}^s{}_2 = \underline{X}^s$. Also, by virtue of relocation times being nil, only μ_A enters into $C_i(\mathbf{a}_i, X_{II,t})$. Consequently, whether the fishers are identical ($\mu_1 = \mu_2$) or heterogeneous ($\mu_1 \neq \mu_2$), the cooperative solution is the same as for identical fishers — with one important exception. To take an extreme example, suppose that $\mu_1 = \mu_A$ and $\mu_2 = 0$. Fisher 1 is finding schools, while fisher 2 is such a poor fisher that he could not profitably exist in the fishery by himself. Sharing information, however, increases fishery profits by increasing the aggregate benefits of each search-harvest cycle. In addition, since fisher 2 doesn't need to search, there may be additional cost savings, making this arrangement more profitable than the case where $\mu_1 = \mu_2 = ½ \mu_A$. Indeed, if there were no costs of being idle and the season length was not a binding constraint, assigning fisher 1 to do all of the searching would be the lowest cost way of harvesting $H_{II,T}$. Allowing $\mu_2 > 0$ and introducing costs of being idle modifies this conclusion (see Johnson, 1993).

The solution when the heterogeneity is strictly due to differences in the marginal costs of searching and harvesting — perhaps due to differences in foregone opportunities — follows the same line of reasoning. Consider stock levels where $\underline{X}^s_1 < X_{II,t} < \underline{X}^s_2$ and $X_{II,t} < \underline{X}^{ns}_1 < \underline{X}^{ns}_2$; fishing in the absence of information sharing is unprofitable. With information sharing, fishing is profitable for fisher 1 and unprofitable for fisher 2. The social planner would have both fishers fish and share information so long as the losses incurred by fisher 2 can be offset by the profits of fisher 1, or $B_1(X_{II,t}) - C_1((1,1),X_{II,t}) \geq B_2(X_{II,t}) - C_2((1,1),X_{II,t})$.

Non-cooperative solution

A fisher compares the net benefits of the available courses of actions. Choosing to fish and share information yields net benefits of

$$\pi^s_{II,t,i} = B(X_{II,t}) - C((1,1),X_{II,t}) + J_{II,t+,i}(X^s_{II,t+,i}). \tag{7}$$

Fishing without information sharing yields net benefits of

$$\pi^{ns}_{II,t,i} = B(X_{II,t}) - C((1,0),X_{II,t}) + J_{II,t+,i}(X^{ns}_{II,t+,i}), \tag{8}$$

whereas not fishing yields zero net benefits. Assuming that fishing is profitable, fisher i will desire to share information if $\pi^s_{II,t,i} \geq \pi^{ns}_{II,t,i}$.

As before, we analyze the two types of heterogeneity separately, beginning with non-uniform search abilities. Noting that $\underline{X}^s_1 = \underline{X}^s_2 = \underline{X} \leq \underline{X}^{ns}_1 < \underline{X}^{ns}_2$, the following results are fairly straightforward:

(i) For $X_{II,t} < \underline{X}$, $\mathbf{a}_1 = \mathbf{a}_2 = (0,0)$. Fishing is unprofitable, even when information is shared.

(ii) For $\underline{X} \leq X_{II,t} \leq \underline{X}^{ns}_1$, $\mathbf{a}_1 = \mathbf{a}_2 = (1,1)$. Fishing and not sharing information is unprofitable for both fishers, thus the only rational course of action is to share information.

The truly interesting situations occur when the stock level is large enough for at least one fisher to be profitable. As in the previous section, a fisher will want to share information if $\pi^s_{II,t,i} \geq \pi^{ns}_{II,t,i}$. With heterogeneity caused by differences in search abilities, $X^s_{II,t+,1} < X^{ns}_{II,t+,1}$ (or, equivalently,

$X^{s}_{II,t+,2} > X^{ns}_{II,t+,2}$). Fisher 2 will want to share information; not only are costs lower under information sharing, but the stock level at the beginning of his next cycle is larger than if information weren't shared. Whether information is shared therefore depends upon fisher 1. By sharing information, fisher 1 expects to face a lower stock level at the beginning of his next search-harvest cycle. Consequently, fisher 1 will only share information if

$$C_1((1,0),X_{II,t,1}) - C_1((1,1),X_{II,t,1}) \geq J_{II,t+,1}(X^{ns}_{II,t+,1}) - J_{II,t+,1}(X^{s}_{II,t+,1}). \tag{9}$$

Equation (9) says that a fisher will share information if the reduction in search costs (the left-hand side) are greater than the decrease in future profits due to the intraseasonal stock effect (the right-hand side).

One of the more interesting results concerns the impact of changes in τ_H on the incentive to share information. Increasing τ_H does not alter the left-hand side (LHS) of (9) but will affect the right-hand side (RHS) through its impact on $X_{II,t+,1}$.[3] Differentiating the RHS with respect to τ_H yields

$$\left(\frac{\partial J_{II,t+,1}}{\partial X_{II,t+,1}}\frac{\partial X^{ns}_{II,t+,1}}{\partial \tau_H}\right)_{X_{II,t+,1}=X^{ns}_{II,t+,1}} - \left(\frac{\partial J_{II,t+,1}}{\partial X_{II,t+,1}}\frac{\partial X^{s}_{II,t+,1}}{\partial \tau_H}\right)_{X_{II,t+,1}=X^{s}_{II,t+,1}}. \tag{10}$$

In general, (10) cannot be signed without knowing the sign of $\partial^2 J_{II,t+}/\partial(X_{II,t+,1})^2$. If season length is a nonbinding constraint, $\partial^2 J_{II,t+,1}/\partial(X_{II,t+,1})^2$ is conjectured to be non-negative. If it were to equal zero, (10) would be positive since $\partial X^{s}_{II,t+,1}/\partial\tau_H < \partial X^{ns}_{II,t+,1}/\partial\tau_H < 0$; information sharing would be less likely. On the other hand, if $\partial^2 J_{II,t+,1}/\partial(X_{II,t+,1})^2 > 0$, it's possible that (10) would be negative, in which case information sharing would be *more* likely. Practically speaking, however, $J_{II,t+,1}$ is likely to be relatively linear in $X_{II,t+,1}$ over the relevant range, so that we would predict that information that is 'long lived' (has a greater τ_H) is less likely to be shared. For example, information sharing is more

[3] This can be seen by examining equations (3) and (4). While the costs of a search-harvest cycle increase, the increase is the same regardless of whether information is shared or not. Of course, with crowding or school depletion a factor, τ_H itself would be a function of whether information was shared or not.

likely when the targeted species are salmon than when they are rockfish.

When the heterogeneity arises from differing marginal costs, $\underline{X}^s{}_1 < \underline{X}^s{}_2$, and $\underline{X}^{ns}{}_1 < \underline{X}^{ns}{}_2$. In addition, $X^s{}_{II,t+,i} = X^{ns}{}_{II,t+,i}$, meaning there is no intraseasonal stock effect on either fisher from sharing information so long as it's profitable for both fishers to fish without sharing information. More specifically, it may be profitable for fisher 1 but not fisher 2 to fish without sharing information. In this situation, there is an intraseasonal stock effect from sharing information with fisher 2 because it allows fisher 2 to harvest when he would otherwise have quit fishing. Fisher 1 can form an entry barrier by not sharing information, keeping fisher 2 out of the fishery. For stock levels above $\underline{X}^{ns}{}_2$, however, there will be full information sharing.

In summary, as the stock is drawn down it's possible that fishers will go from sharing information, to not sharing, and then back to sharing. This differs from the cooperative solution in two ways. First, the cooperative solution calls for full information sharing at all stock levels. Second, in the absence of side payments, fisher 2 will have to fish if he wishes to share information. In the cooperative solution it was possible that the fisher who was poorer at searching would only be used to harvest. This form of specialization is not possible under the non-cooperative solution.

In all of the cases discussed above, greater initial stock levels increase fishery profits either by increasing the net benefits of each search-harvest cycle or by increasing the number of cycles, so that $\partial J^c{}_{II,t,0} / \partial X_{II,0} > 0$, and $\partial J^{nc}{}_{II,t,0} / \partial X_{II,0} > 0$.

The Two-Season Cases

To obtain a situation with a large divergence from the socially optimal outcome it's necessary to include either crowding, school depletion, or interseasonal stock effects in the model. This subsection focuses on the interseasonal stock effect.

Cooperative solution

Not surprisingly, the optimal course of action in the first season is similar to that during the second season, the only difference being that the effect on future stocks must be accounted for when deciding when to cease fishing. As before, fishing will stop when

$$\sum_{i=1}^{2}\left[B_i(X_{I,t}) - C_i((1,1),X_{I,t})\right] < \sum_{i=1}^{2}\delta\left[J_{II,0,i}(X_{II,0}(X_{I,t})) - J_{II,0,i}(X_{II,0}(X^s_{I,t+,i}))\right]. \tag{11}$$

The social planner also has the option of either idling one of the fishers while the other continues fishing or having one specialize in searching.

Non-cooperative solution

Much of the behavior in the two-season non-cooperative case with heterogeneous fishers is comparable to that found in the one-season model. Attention here will be restricted to the stock level at which the fishers would cease information sharing and/or fishing. Each type of heterogeneity will be considered separately.

Consider the case where the heterogeneity between fishers 1 and 2 arises from differences in search abilities. As in the one-season model, fisher 2 will want to share information since it decreases his search costs and results in a higher post-cycle stock level compared to the no-sharing case. When information sharing and fishing cease therefore depends on fisher 1. Let $\underline{X}_I^{ns}$ be the value for $X_{I,t}$ which solves

$$B_1(X_{I,t}) - C_1((1,0),X_{I,t}) = \delta\left[J_{II,0,1}(X_{II,0}(X_{I,t})) - J_{II,0,1}(X_{II,0}(X_{I,t} - \tau_H h_1))\right]. \tag{12}$$

For contrast, compare this to the version of the cooperative case where there is full information sharing and no specialization in searching or harvesting. If $J_{II,0,i}$ were linear in $X_{II,0}$, fishing would cease when the stock falls below $X^c_{I,T}$, which is the stock level that solves

$$B_1(X_{I,t}) - C_1((1,1),X_{I,t}) = \sum_{i=1}^{2} \delta\left[J_{II,0,i}(X_{II,0}(X_{I,t})) - J_{II,0,i}(X_{II,0}(X_{I,t} - \tau_H h_1))\right]. \quad \textbf{(13)}$$

With no synergies present, the LHSs of (12) and (13) would be identical. Since the RHS of (12) is less than the RHS of (13), this implies $\underline{X}_I^{ns} < X^c_{I,T}$. Notice, however, that the degree of depletion below $X^c_{I,T}$ will depend on fisher 2's share of period *II* profits.

When synergies are allowed, both the LHS and the RHS of (12) will be lower than the respective LHS and RHS of (13), creating the possibility that $\underline{X}_I^{ns} \geq X^c_{I,T}$. Fishing would end when $X_{I,t} < \min(X^c_{I,T}, \underline{X}_I^{ns})$.

The analysis of the case where fishers differ in their search and harvest costs parallels previously obtained results. First, there is no intraseasonal stock effect for stock levels where both fishers would find it profitable to fish without sharing information; therefore, information will be shared. Second, the cost-reducing synergies between the fishers may allow an outcome equal to the cooperative solution, both in terms of the stock level at the end of season *I* and the existence of information sharing. In contrast to the cooperative solution, however, there is no possibility for specialization in searching or harvesting. While it's important to note this result, it's equally important to note that there are incentives present to secure binding contracts that would allow specialization.

Discussion

The tragedy of the commons is not a foregone conclusion in one-period fishery models. By assuming no crowding or school depletion effects and by specifying the decision variable as whether or not to continue fishing, the preceding analyses have arrived at results that run counter to those obtained from some static, one-period common property resource models. Under all scenarios examined, fishers cease fishing when the expected value marginal product of effort is no longer greater than its expected marginal cost. Any divergences from the socially optimal solution in the one-season model were found to arise from the withholding of fish information among fishers. These inefficiencies, however, do not result in lower than optimal ending stock levels. Indeed, it's possible to end up with too *large* of an ending stock! This latter result was found to occur when fishers had differing marginal costs of searching and harvesting.

In contrast to the season *II* results, the stock in season *I* may be overfished due to an interseasonal stock effect. The mechanism by which this occurs is fairly straightforward: by leaving a fish or school in the sea to grow until season *II*, both fisher 1 and fisher 2's second period profits increase. Unfortunately, each fisher only considers the impact of his harvesting on his own profits, thereby creating a negative externality. Without synergies between fishers, overfishing will occur in season *I*. However, this overfishing can be lessened or eliminated entirely if there are significant cost savings from sharing information on school location. While fishers still only compare their own expected benefits to their own expected costs, they also realize that they have some control over the harvesting conducted by others, which, in turn, does affect their own costs and benefits.

III. THE STRUCTURE OF INFORMATION SHARING CLIQUES

Section II assumed there were no school depletion or crowding effects, allowing a clearer focus on the intertemporal stock effects. These assumptions are relaxed in this section as attention is shifted to the structure and dynamics of information sharing cliques (ISCs) or 'code groups.' To simplify the analysis, stocks are assumed to be exogenously determined, so that any intertemporal stock effects are eliminated. This is a reasonable assumption in many fisheries where regulators limit harvests through the use of seasonal closures, total allowable catch, or quotas. It's an even more reasonable assumption in small artisinal fisheries where fishers exploit a relatively small proportion of a migratory or mobile stock.

The emphasis of this section is on the size and composition of ISCs and the implicit contractual arrangements between clique members. The structure of ISCs is addressed from three perspectives. First, if a fleet manager was faced with a regulated season length and was constrained to use the code group form of organization, how would he organize the fleet's vessels? Would vessels of similar ability be assigned to work together, or would each code group consist of both 'highliners' and average fishers? Second, in the absence of organizational constraints, how would the fleet manager organize the fleet's vessels? Finally, if vessels were individually owned and operated, how would the fishers choose to structure their code groups? Would they choose an arrangement similar to one of those chosen by the fleet manager, or would they arrange themselves differently? As shown below, there may be a divergence between the structure of fleet manager-designed and skipper-designed code groups, with the divergence partially attributable to the means by which fishers are compensated for their efforts. In most fisheries skippers and their crew members are compensated based on their vessels' harvest. Alternative contractual arrangements between the fleet manager and skippers are possible which would induce fishers to form code groups of the same structure as chosen by the fleet manager. Unfortunately, these alternative contracts may also induce shirking and a less desirable outcome.

The optimal size for a code group depends on the magnitude of the school depletion and crowding effects, which in turn depend on the size and number of fish schools on the fishing ground. As a consequence, desired clique size may change as stocks fluctuate. However, if restructuring code groups is costly fishers may opt to maintain the 'wrong' clique size for some period of time, raising the question of whether alternative means of mitigating the school depletion and crowding effects are possible. This issue is examined in more depth in Johnson (1993).

5.2 The fleet manager's problem

Suppose the N vessels in a fishery could be partitioned into company fleets based on vessel ownership, and that each fleet is under the control of a manager who faces the task of directing or coordinating the activities of his company's vessels. The stock level is exogenously given and is assumed to be known by the fleet manager, making the problem distinct from those analyzed by Mangel and Clark (1983), where uncertain stock levels is the primary reason for sharing fish information. All vessels are assumed to have the same harvest efficiency, but differ in their search efficiency, as reflected by their μ_is.

The analysis below proceeds on the assumption that all vessels are on the fishing ground for the same length of time, T. This may either be due to unfavorable weather conditions or the imposition of seasonal closures by a regulator to prevent overfishing. Alternatively, the regulator could specify that the fishery will be closed when some total allowable catch (TAC) is achieved. In either case, all vessels would be on the fishing ground for approximately the same length of time. The fleet manager seeks to maximize fleet profits subject to this time constraint. In passing, we note that the analysis and conclusions might be altered if the regulator imposed individual quotas, in which case the fleet manager would wish to minimize costs subject to the harvest constraint.

Fleet manager-designed code groups

Suppose the fleet manager was constrained to assign vessels to code groups. Vessels share information within their code group but do not share information across code groups. Code group members search for schools and, once one is discovered, all code group vessels relocate to the school, where they harvest until the school is either lost or depleted.

In placing the fleet's vessels in code groups, the fleet manager must decide on the number of code groups as well as the size and composition of each group. If the manager was just interested in discovering the largest number of schools (or if each school were instantly harvested), the composition of the code groups would not matter since making each vessel its own code group or placing all vessels in a single code group would not affect the expected number of schools discovered. This is evident since

$$E[Number\ \ of\ schools\ \ discovered] = \sum_{i=1}^{N} TX^{(1-\beta)}\mu_i = TX^{(1-\beta)}\mu_f\ , \tag{14}$$

where μ_f is the sum of the fleet vessels' μ_is. Introducing harvest times and the possibility of a school being exploited by two or more vessels alters this conclusion. Since time spent harvesting is not spent searching, the members of a code group cease producing information on new school locations when they are actively harvesting from a school. The composition of code groups will consequently affect the number of schools discovered and harvested.

Consider a simplified version of the problem where $\tau_{TR} = 0$. If vessels only differ in their search efficiency, the benefits of a search-harvest cycle to a vessel in the k^{th} code group is given by

$$B_k(m_k,X) = \tau_H(m_k,X) \cdot h(m_k,X) \cdot P \tag{15}$$

and its costs by

$$C_k(m_k,\mu_k,X) = \tau_S(\mu_k,X)c_S + \tau_H(m_k,X)c_H. \tag{16}$$

Profits per time period are therefore

$$\frac{\pi_k}{t} = \frac{\tau_H(m_k,X)\left[h(m_k,X)P - c_H\right] - \tau_S(\mu_k,X)c_S}{\tau_H(m_k,X) + \tau_S(\mu_k,X)} \tag{17}$$

Initially assume that the number of code groups is fixed at q. The fleet manager's objective is to choose μ_k and m_k to maximize the fleet's profits:

$$\underset{\mu_k, m_k}{Max}\ \Pi_f = \sum_{k=1}^{q} m_k T \frac{\pi_k}{t}, \tag{18}$$

subject to the constraints

$$\sum_{k=1}^{q} \mu_k = \mu_f; \quad \mu_k \geq 0,$$

$$\sum_{k=1}^{q} m_k = N; \quad m_k \geq 0. \tag{19}$$

Treating τ_S as being deterministic, the Lagrangian for this problem can be written as

$$\mathcal{L} = T\sum_{k=1}^{q} m_k \frac{\tau_H(m_k,X)[h(m_k,X)P - c_H] - \tau_S(\mu_k,X)c_S}{\tau_H(m_k,X) + \tau_s(\mu_k,X)}$$

$$+\lambda_1\left[\mu_f - \sum_{k=1}^{q}\mu_k\right] + \lambda_2\left[N - \sum_{k=1}^{q} m_k\right] + \sum_{k=1}^{q}\nu_k(\mu_k) + \sum_{k=1}^{q}\gamma_k(m_k). \tag{20}$$

Since there are q code groups, the manager has $2q$ choice variables. If μ_k and m_k are treated as continuous choice variables, the Kuhn-Tucker maximum conditions are

$$\frac{\partial\mathcal{L}}{\partial\mu_k} = m_k T\frac{\partial\tau_S}{\partial\mu_k}\left[\frac{-c_S}{\tau_H+\tau_S} - \frac{\tau_H[h\cdot P - c_H] - \tau_S c_S}{(\tau_H+\tau_S)^2}\right] - \lambda_1 + \nu_k$$

$$= \frac{-m_k T}{(\tau_H+\tau_S)^2}\frac{\partial\tau_S}{\partial\mu_k}[\tau_H c_S + \tau_H[h\cdot P - c_H]] - \lambda_1 + \nu_k = 0 \quad \forall\ k = 1,\ldots,q, \tag{21}$$

$$\frac{\partial\mathcal{L}}{\partial m_k} = \frac{\pi_k}{t} + T\frac{\partial\tau_H}{\partial m_k}\left[\frac{hP - c_H}{\tau_H+\tau_S} - \frac{\tau_H[hP - c_H] - \tau_S c_S}{(\tau_H+\tau_S)^2}\right] + \frac{\partial h}{\partial m_k}\frac{\tau_H P}{\tau_H+\tau_S} - \lambda_2 + \gamma_k = 0$$

$$= \frac{\pi_k}{t} + \frac{T}{(\tau_H+\tau_S)^2}\frac{\partial\tau_H}{\partial m_k}[\tau_S[hP - c_H] + \tau_S c_S] + \frac{\partial h}{\partial m_k}\frac{\tau_H P}{\tau_H+\tau_S} - \lambda_2 + \gamma_k = 0 \quad \forall\ k = 1,\ldots,q, \tag{22}$$

$$\frac{\partial\mathcal{L}}{\partial\nu_k} = \mu_k \geq 0; \ \frac{\partial\mathcal{L}}{\partial\gamma_k} = m_k \geq 0;$$

$$\nu_k \geq 0; \quad \gamma_k \geq 0; \ \nu_k[\mu_k] = 0; \ \gamma_k[m_k] = 0 \quad \forall\ k = 1,\ldots,q. \tag{23}$$

In general, there is no guarantee that there will be an interior solution to this problem. Instead, it's quite possible that the fleet manager should leave some code groups empty, or even place all vessels in a single code group. Since the number of code groups, q, is also a choice variable, the fleet manager can first solve for the general structure of a code group assuming an interior solution, and then use this solution in deciding on the optimal number of code groups. If a corner solution is optimal, it will be picked up by this procedure.

For an interior solution, the first order conditions can be satisfied by setting $m_k = m^*$ and $\mu_k = \mu^*$ for all $k = 1,\ldots, q$. Essentially, all code groups should be of the same size and have the same search efficiency.[4] The intuition behind this result is straightforward. If all of the fleet's vessels just searched for schools they would find $X^{(1-\beta)}\mu_f$ schools per time period. Upon finding a school, however, all members of a code group cease searching for a period of time as they harvest from the newly discovered school. If the best search vessels (the highliners) were assigned to the same code group, many of them would experience more non-search time than other vessels. The fleet manager could do better by reassigning these vessels to code groups where their skills in searching could be more beneficially utilized.

The above interior solution was derived under the assumption that the number of code groups was fixed. Still treating μ_k and m_k (and hence μ^* and m^*) as continuous choice variables, the manager chooses the number of code groups, q, to solve

$$\underset{q}{Max}\ \Pi_f = N \cdot T \frac{\tau_H(N/q,X)\left[h(N/q,X)P - c_H\right] - \tau_S(\mu_f/q,X)c_S}{\tau_H(N/q,X) + \tau_s(\mu_f/q,X)} \tag{24}$$

subject to the constraint that $1 \leq q \leq N$. The Lagrangian for this problem is

$$\mathcal{L} = \Pi_f + \lambda_1(q-1) + \lambda_2(N-q), \tag{25}$$

[4] Practically speaking, μ_k and m_k are not continuous variables but can only take on a finite number of values. The intent here is to characterize the nature of the solution.

with first order conditions

$$\frac{\partial \mathcal{L}}{\partial q} = N \cdot T \frac{-\frac{\partial \tau_H}{\partial m}\frac{N}{q^2}(hP - c_H) - P\tau_H \frac{\partial h}{\partial m}\frac{N}{q^2} + \frac{\partial \tau_S}{\partial \mu}\frac{\mu_f}{q^2}}{\tau_H + \tau_S}$$

$$+ \frac{\Pi_f}{\tau_H + \tau_S}\left[\frac{\partial \tau_H}{\partial m}\frac{N}{q^2} + \frac{\partial \tau_S}{\partial \mu}\frac{\mu_f}{q^2}\right] + \lambda_1 - \lambda_2 = 0 \qquad \textbf{(26)}$$

and

$$\frac{\partial \mathcal{L}}{\partial \lambda_1} = q - 1 \geq 0; \; \frac{\partial \mathcal{L}}{\partial \lambda_2} = N - q \geq 0; \qquad \textbf{(27)}$$

$$\lambda_1[1 - q] = 0; \; \lambda_2[N - q] = 0; \quad 1 \leq q \leq N; \; \lambda_1 \geq 0; \; \lambda_2 \geq 0.$$

Since the solution will most likely involve non-integer values, the manager must use the solution to (26) and (27) to approximate the optimal q. If there were no school depletion or crowding effects, $\partial \tau_H/\partial m = \partial h/\partial m = 0$ while $\partial \tau_S/\partial \mu < 0$. To satisfy the equality in (26) thus requires $\lambda_1 - \lambda_2 > 0$, which, from (27) can only be satisfied if $\lambda_1 > 0$. Using the complementary slackness conditions, this implies $q = 1$. With no school depletion or crowding effects, all vessels should be placed in one code group. Using similar reasoning, if the school depletion and crowding effects were large enough, the optimal arrangement would be to place each vessel in its own code group.

Skipper-designed code groups

In many fisheries, vessels are individually owned and operated. While the skippers have the option of forming 'well balanced' code groups identical to what a fleet manager would specify, the incentives in place make this outcome unlikely, as will be seen in this section.

Initially assume that skippers and their crew receive a share of their vessels' harvest and that side payments between vessels are impractical. Fisher i's profits for the season are given by

$$\pi_i = T\frac{\tau_H(m_k,X)[h(m_k,X)P - c_H] - \tau_S(\mu_k,X)c_S}{\tau_H(m_k,X) + \tau_S(\mu_k,X)} \tag{28}$$

To get an idea of how skippers would organize their code groups, suppose that fisher i could choose both the size of his code group, m_k, as well as its search efficiency, μ_k. Differentiating (28) with respect to μ_k and m_k yields

$$\begin{aligned}\frac{\partial \pi_i}{\partial \mu_k} &= T\frac{\partial \tau_S}{\partial \mu_k}\left[\frac{-c_S}{\tau_H+\tau_S} - \frac{\tau_H[h \cdot P - c_H] - \tau_S c_S}{(\tau_H+\tau_S)^2}\right] \\ &= \frac{-T}{(\tau_H+\tau_S)^2}\frac{\partial \tau_S}{\partial \mu_k}[\tau_H c_S + \tau_H[h \cdot P - c_H]] > 0\end{aligned} \tag{29}$$

and

$$\begin{aligned}\frac{\partial \pi_i}{\partial m_k} &= T\frac{\partial \tau_H}{\partial m_k}\left[\frac{hP - c_H}{\tau_H+\tau_S} - \frac{\tau_H[hP - c_H] - \tau_S c_S}{(\tau_H+\tau_S)^2}\right] + \frac{\partial h}{\partial m_k}\frac{\tau_H P}{\tau_H+\tau_S} \\ &= \frac{T}{(\tau_H+\tau_S)^2}\frac{\partial \tau_H}{\partial m_k}[\tau_S[hP - c_H] + \tau_S c_S] + \frac{\partial h}{\partial m_k}\frac{\tau_H P}{\tau_H+\tau_S} < 0.\end{aligned} \tag{30}$$

Equation (29) says that fisher i would like to be in a code group with high search efficiency so as to decrease his search costs. At the same time, (30) says he would also like the size of the code group to be limited to reduce the crowding and school depletion effects. These twin goals can be achieved by associating with good searchers or highliners, i.e., those with high μ_is. However, unless the fishery is comprised of just one code group, it will be impossible for all vessels to associate with highliners. The highliners, however, will have first choice on with whom to form a code group. Consequently, the model predicts that highliners will choose to form code groups with other highliners. This is generally supported by anecdotal evidence. In the Southeast Alaska salmon troll fishery, for example, the best fishers form code groups among themselves, with fishers of lesser ability forming code groups comprised of fishers of similar ability (personal communication with Don Smith, owner of the Dixie II). Orbach (1977) echoes this observation by noting a similar form of organization in the tuna fishery, though he postulates that associating with highliners may partially be motivated by an interest in improving one's social status:

> [S]tatus may be gained by the implicit knowledge that a particular skipper is a confidant of other high-status skippers. In many cases, especially company code groups, this social stock is worth more to the skippers than is the 'economic stock' whose value may tend to be increased through the more efficient search procedures which more complete cooperation might produce. (Orbach, 1977:117-118)

He further observes

> While complete information transfer would certainly change the distribution of the catch somewhat, it would almost certainly increase the efficiency of the industry as a whole. The main reason that information is distributed in the manner described above is competition between the individual skippers — both for the resource itself *and* for the status gained relative to the other skippers and crews in the fleet.
>
> The effects of this system are important for the owners of the boats and their shore-side managers. Especially in the cases of large company fleets, whose skippers are normatively sharing a code group, the system leads to considerable corporate inefficiency. Loyalty to the company is almost always overridden by status-seeking and other loyalties to friends, relatives, and the skipper's own crew. (Orbach, 1977:121)

Orbach is not explicit regarding who gains from an increase in the 'economic stock.' It appears, however, that this value accrues to the company as a whole, not just to the individual vessel. So, despite the company-organized code groups being more efficient (profitable) from the company's perspective, the highliners, or high-status skippers, find it individually more profitable to associate with other highliners and, to a degree, exclude average fishers from their information sharing network.

From the preceding discussion it should be clear that there can be a divergence between how a company would like to organize its vessels and how the skippers of those vessels actually organize. The reason appears to lie in the form of compensation for skippers and their crew. Typically, the skipper and crew receive shares based on vessel output as opposed to fleet output. Since fishing is a hazardous undertaking, basing compensation on fleet output is likely to produce shirking among crew members and even among skippers. Furthermore, by the very nature of fishing, monitoring of individual vessels by the fleet manager is difficult. While catch and the number of schools discovered is in principle observable, the stochastic nature of fishing provides a built-in excuse for skippers not meeting expectations. Basing compensation on vessel performance can eliminate this incentive to shirk, but carries with it a loss in efficiency in the use and production of fish information.

IV. EMPIRICAL ANALYSIS

This section examines two predictions that arise from sections II and III:

Prediction 1: Information sharing will decrease with

- An increase in τ_H. This is due to an increase in the intertemporal stock effects (see section II), as well as an increase in the more immediate school depletion effect (see section III).
- An increase in the school depletion effect. We would expect to observe this with more sedentary species (where τ_H would be greater) and with gear technology capable of harvesting a large percentage of a school (such as purse seiners).
- An increase in the crowding effect (see section III). This is a function of the dispersal of the fish species (compact schools or small niches) and the harvesting technology.

Prediction 2: Members of an information sharing clique will have approximately equal skill levels (see section III).

Data

Most of the evidence in support of the model was gleaned from numerous ethnological studies of fishing communities. Table 1 summarizes these studies; a more detailed presentation can be found in Johnson (1993). Each of the species discussed in these cases was placed into one of three categories based on its relative mobility. Category *I* consists of the relatively mobile schooling species, such as tuna, herring, and salmon. Similarly, category *III* comprised the relatively immobile species such as clams, lobsters, crabs and rockfish. Species which were judged to fall somewhere between these two categories, such as migratory groundfish species, were classified as category *II* species.

Accounting for the influences arising from differing gear types and other factors related to the school depletion and crowding effects is more problematic, partially due to the strong correlation between a species category and the gear employed to harvest the species in that category. For example, gear capable of harvesting an entire school, such as a purse seine, is only used to catch schooling species, whereas pots are only used for crabs and lobsters. In addition, some gear types also take time to relocate. To try to capture these factors, three subcategories (*A*, *B*, and *C*) were created within each species category, with category *B* being the default category. Classification of the cases into these categories was rather subjective, being based on a number of factors including gear type, the number of other fishers, and the existing stock levels. Each case was placed in subcategory *B* unless the evidence indicated a lesser (subcategory *A*) or greater (subcategory *C*) probability of observing school depletion or crowding effects than the typical case in that species category, under the assumption that there would be full information sharing. For example, for the mobile species, trolling was judged to be less likely to lead to lead to these effects than, say, drift nets or trawlers, whereas purse seines were judged to be more likely to lead to crowding and school depletion. Similarly, for category *II*, recreational party boats were placed in subcategory *A* whereas larger trawlers were placed in subcategory *C*. Table 2 summarizes the categorization of the cases.

To complete the data set, each case was categorized according to the level of information sharing reported. The *Y*(es) category was for fisheries where the majority of fishers participated in some form of information sharing and the information was valuable. If information was shared but it was not clear that the information was valuable — perhaps due to lengthy relocation times — the case was placed in the *L*(ittle) category. Also placed in this category were the few cases where the information sharing tended to be restricted to a few fishers. A case was assigned to the *N*(one) category if information was not shared. This categorization is included in Table 2 and is presented in a cross classification format in Table 3.

Analysis

Casual scrutiny of Table 2 or 3 reveals that as we move from category *I* to category *II* and then to category *III*, information is less likely to be shared. In addition, within the categories, especially *II*, the subcategories *A*, *B*, and *C* seem to have some partial explanatory value. While the evidence appears to support the proposition concerning information sharing, care must be taken since there was some degree of arbitrariness in how each observation was categorized. In particular, observations assigned to information sharing category *L* and/or species category *II* could have been assigned to other categories by another researcher. It is unlikely, however, that a species classified into *I* would be classified by someone else as being in *III* and *vice versa*. Similarly, it's unlikely that a case classified as *Y* would be reclassified as *N*.

To statistically examine our prediction that fishers targeting more mobile fish species are more likely to share information than those targeting less mobile species, the data in Table 3 were reclassified in various ways into 2×2 contingency tables. This yielded thirteen 2×2 tables of the general form shown in Table 4. Due to the small sample size, we employ Fisher's exact test for 2×2 contingency tables (Everitt, 1977). Fisher's test relies on the exact probability distribution of the observed frequencies which, for fixed marginal totals, is the hypergeometric distribution. Under the null hypothesis of no association, and with marginal totals given, the probability (P) of obtaining a particular arrangement of a, b, c, and d, is:

$$P = \frac{(a+b)!\,(c+d)!\,((a+c)!\,(b+d)!}{a!\,b!\,c!\,d!\,N!} \tag{31}$$

Equation (31) is used to find the probability of the observed frequencies, as well as all other arrangements that give as much or more evidence for a positive relationship between species mobility and information sharing. In obtaining the alternate arrangements, the marginal totals are held constant. For example, suppose a reclassification yields $\{(a,b),(c,d)\} = \{(9,5),(2,7)\}$. Equation (31) would be used to calculate the probability of observing this set of frequencies, as well as the two arrangements $\{(10,4),(1,8)\}$ and $\{(11,3),(0,9)\}$. This procedure yields the probabilities 0.0533, 0.0066, and 0.0003, respectively, for a total probability of 0.0602. If our chosen significance lever was 0.10, we would reject the null hypothesis of no relationship between species mobility and information sharing in favor of the alternate hypothesis that there is a positive relationship between the two categories. Note that an advantage of Fisher's test over the chi-square test is that it indicates the direction of departure from the null hypothesis.

Table 5 presents the results of applying Fisher's exact test to the 13 rearrangements. Note that the above example is arrangement # 10. Two of the arrangements, # 6 and # 7, might be called worst case scenarios. These assume that the reclassification takes place in such a manner as to be *against* the model's predictions. For example, *(I,L)* would be reclassified as *(I,N)*; *(II,Y)* is reclassified as *(III,Y)*; and all cases classified as *(II,L)* would be reclassified as either being in *(I,N)* or *(III,Y)*.

In all of the 13 different ways that the data were arranged and tested, the direction of the association between fishery classification and information sharing is right; in all but three, it is significant at least at the 0.10 level. Eight of the arrangements are significant at the 0.001 level. Not surprisingly, the weakest results are from the worst case analyses. Taken as a set, these results strongly favor the model.

Comparative case studies and equality of clique members

Several of the case studies provide what might be termed 'comparative evidence' in support of the model. That is, a specific case may have presented evidence on more than one fish species/location/gear combination. This section summarizes this evidence on a case by case basis.[5]

Eastern U.S. and Canadian in-shore fisheries, circa 1873. In this case it was found that lower stock levels led to a switch from information sharing to no information sharing.

Bering Sea pollock fishery. Larger vessels, which would presumably experience larger school depletion and crowding effects if information were shared, only share information when they have reached vessel harvest capacity. Smaller trawlers, on the other hand, sometimes share information in small cliques. Unexplored is why the larger Japanese vessels are reportedly more willing to share information than the similarly sized American vessels. This may be a function of the contract between a vessel's skipper and his company and clearly is deserving of further inquiry.

Clamming on Long Island. Information is sometimes transmitted from commercial clammers to recreational clammers. Since individual recreational clammers do not harvest a large quantity of clams, the intertemporal stock effects are relatively small when compared to the impact of sharing information with other commercial clammers. Not surprisingly, information is not shared between commercial clammers.

Lobster fisheries. Palmer (1991a) presents a good comparative study of the lobstering ports of 'Middle Harbor' and 'Southern Harbor.' It was found that lobstermen in Southern Harbor were willing to share information, whereas those in Middle Harbor were not. Notably, the competition for the resource was greater in Middle Harbor, so we would expect greater school depletion and crowding effects compared to Southern Harbor.

Fishing in a Brazilian coastal village. In this fishery, the willingness to share information was a direct function of the species targeted. Information on the location of rockfish was not shared while information on schooling species was freely shared.

Structure of code groups. Several studies explicitly reported that information sharing tended to

[5] Each of the cases mentioned below can be found in Johnson (1993).

be only between fishers of approximately equal ability, in agreement with section III's predictions. These include the SE Alaska salmon troll fishery (Smith, 1992), various west coast fisheries (Stuster, 1978), and the Maine lobster fisheries (Acheson, 1988).

V. SUMMARY

Using the microeconomics paradigm, the observed pattern of information sharing in different fisheries has been shown to be consistent with fishers weighing the expected benefits and costs of their actions, and pursuing a profit-maximizing course of action. Fishers targeting more mobile species, such as tuna, salmon, and herring, are more likely to share information and form information sharing cliques than those fishers targeting relatively sedentary species like lobster, crabs, and rockfish. Harvest technologies, the general level of competition, and stock levels also play predictable roles in influencing information sharing. Increasing a fisher's ability to harvest an entire school, increased competition, and lower stock levels all lead to a reduced likelihood that information will be shared.

The structure of the information sharing cliques was also examined. The heterogeneity of fishers and the compensation mechanism for skippers and their crew creates a divergence between how a fleet manager would organize his vessels and how individually owned vessels are organized. While it may be possible for fishers to form 'well-balanced' code groups, the presence of transaction costs and shirking make it a less attractive arrangement. As a consequence, individually owned vessels, and even some company-owned vessels, form code groups based on skill level, with highliners associating with other highliners and average fishers associating with other average fishers.

References

Acheson, James. 1988. The Lobster Gangs of Maine. Hanover, NH: University Press of New England.

Alaska Fishermen's Journal. January, 1992.

Andersen, Raoul R. 1972. Hunt and deceive: information management in Newfoundland deep-sea trawler fishing, pp. 120-140. *In*: Raoul Andersen and Cato Wadel (eds.) North Atlantic Fishermen: Anthropological Essays on Modern Fishing. University of Toronto Press.

Brown, Gardner M., Jr. 1991. Personal communication.

Colton, Chris. 1992. Personal communication.

Cornes, Richard, and Todd Sandler. 1983. On commons and tragedies. *American Economic Review* 73(4):787-792.

Dasgupta, Partha, and Geoffrey Heal. 1979. Exonomic Theory and Exhaustible Resources. Cambridge: Cambridge University Press.

Ellis, Carolyn. 1986. Fisher Folk. Lexington, Kentucky: The University Press of Kentucky.

Everitt, B. S. 1977. The Analysis of Contingency Tables. London: Chapman and Hall.

Forman, Shepard. 1967. Cognition and the catch: the location of fishing spots in a Brazilian coastal village. *Ethnology* 6(4):417-426.

Furia, Lisa. 1992. Personal communication.

Gatewood, John B. 1984a. Cooperation, competition, and synergy: information-sharing groups among Southeast Alaskan salmon seiners. *American Ethnologist* 11(2):350-370.

Goodlad, C. Alexander. 1972. Old and trusted, new and unknown: technological confrontation in the Shetland herring fishery. *In*: Raoul Andersen and Cato Wadel (eds.) North Atlantic Fishermen: Anthropological Essays on Modern Fishing. University of Toronto Press.

Hodges, Hart. 1992. Personal communication.

Johnson, Neal S. Synergies in the commons: information sharing in limited entry fisheries. Ph.D. dissertation. Department of Economics, University of Washington, Seattle.

Löfgren, Orvar. 1972. Resource management and family firms: Swedish west coast fishermen, pp. 82-103. *In*: Raoul Andersen and Cato Wadel (eds.) North Atlantic Fishermen: Anthropological Essays on Modern Fishing. University of Toronto Press.

Mangel, Marc, and Colin W. Clark. 1983. Uncertainty, search, and information in fisheries. *J. Cons. int. Explor. Mer* 41:93-103.

Maril, Robert Lee. 1983. Texas Shrimpers. College Station, Texas: Texas A&M University Press.

McCay, Bonnie. 1987. The culture of the commoners: historical observations on Old and New World fisheries, pp. 195-216. *In*: Bonnie J. McCay and James M. Acheson (eds.) The Question of the Commons: the Culture and Ecology of Communal Resources. Tucson, Arizona: The University of Arizona Press.

Nelson, Richard. 1989. The Island Within. San Francisco: North Point Press.

Orbach, Michael K. 1977. Hunters, Seamen, and Entrepreneurs: The Tuna Seinermen of San Diego. University of California Press: Berkeley, CA.

Orth, Geoffrey C. 1987. Fishing in Alaska, and the sharing of information. *American Ethnologist* 14(2):377-379.

Palmer, Craig T. 1990. Telling the truth (up to a point): radio communication among Maine lobstermen. *Human Organization* 49(2):157-163.

Palmer, Craig T. 1991a. Kin-selection, reciprocal altruism, and information sharing among Maine Lobstermen. *Ethology and Sociobiology* 12:221-235.

Rhodes, Eduardo. 1992. Personal communication.

Smith, Don. 1992. Personal communication.

Stiles, Geoffrey. 1972. Fishermen, wives and radios: aspects of communication in a Newfoundland fishing community, pp. 35-60. *In*: Raoul Andersen and Cato Wadel (eds.) North Atlantic Fishermen: Anthropological Essays on Modern Fishing. University of Toronto Press.

Stuster, Jack. 1978. Where "Mabel" may mean "sea bass." *Natural History* 87(9):65-71.

Table 1. Information sharing in fisheries: summary of case studies.

Species	Gear type	Location	Information sharing?	Source
Herring	Drift net	Shetland	Yes, but relocation times are long	Goodlad (1972)
	Purse seine	"	Yes	"
Herring	Trawler	Sweden's west coast	Yes	Löfgren (1972)
Herring sac roe	Purse seine	Sitka Sound, Alaska	No need for information sharing; fishers often 'co-op' the catch	Alaska Fishermen's Journal (1992), Nelson (1989), and Smith (1992)
Salmon - coho and king (chinook)	Troll	SE Alaska	Yes; fishers may belong to more than one code group, which are comprised of fishers of equal ability	Furia (1992), and Smith (1992)
	"	Northern California	Yes	Stuster (1978)
Salmon	Gillnet	SE Alaska	Yes	Orth (1987)
	"	Cook Inlet, Alaska	Yes	Orth (1987)

Table 1 (continued). Information sharing in fisheries: summary of case studies.

Species	Gear type	Location	Information sharing?	Source
Salmon - pink, chum and sockeye	Purse seine	SE Alaska	Yes, but only before an opening; not all fishers participate.	Gatewood (1984a)
			Yes, both before and during an opening; all fishers belong to at least one code group.	Orth (1987)
Atlantic salmon	Drift net	Newfoundland	No useful information shared	Stiles (1972)
Sea bass	Dragger	West coast of U.S.	Yes	Stuster (1978)
Swordfish	Harpoon	"	Yes	"
Tuna - albacore	Trolling	"	Yes, 'optimal' code group size of 12 boats	"
Tuna - skipjack and yellowfin	Purse seine	Eastern tropical Pacific	Yes, fishers often participate in more than one code group	Orbach (1977)
Various bottom fish species (i.e., sole)	Dragger	West coast of U.S.	No	Stuster (1978)

Table 1 (continued). Information sharing in fisheries: summary of case studies.

Species	Gear type	Location	Information sharing?	Source
Black cod	Longline	SE Alaska	Minimal	Smith (1992)
Cod	Longline	Newfoundland	Information on exploitative strategy not shared; catch information is shared	Stiles (1972)
Halibut	Longline	SE Alaska	No	Smith (1992)
	"	Newfoundland	Information on exploitative strategy not shared; catch information is shared	Stiles (1972)
Grey sole	Seine	Newfoundland	Yes, but information is distorted	Stiles (1972)
Bottom fish (cod, flounder, sole, redfish, and haddock)	Trawler	Gulf of St. Lawrence and the Grand Banks	Some; information sharing cliques appear to be small	Andersen (1972)
Clams		Long Island	No	Rhodes (1992)
			Only between commercial and recreational clammers	Colton (1992)

Table 1 (continued). Information sharing in fisheries: summary of case studies.

Species	Gear type	Location	Information sharing?	Source
Crab	Scrapes and pots	Chesapeake Bay	Only on well-known fishing areas; not shared on unknown areas	Ellis (1986)
Crab		West coast of U.S.	No	Stuster (1978)
Lobster	Lobster pots	Maine	Rare and only among lobstermen of similar ability	Acheson (1988)
"	"	'Middle Harbor,' ME	No	Palmer (1990, 1991a)
"	"	'Southern Harbor,' ME	Yes, though limited participation	"
"	"	Long Island	No	Colton (1992)
"	"	Sweden's west coast	No	Löfgren (1972)
Shrimp	Trawler	Texas	Yes, among 'friends'	Maril (1983)
Rock fish	Handline from log rafts	Coqueiral, Brazil	No	Forman (1967)
Miscellaneous schooling species	"	"	Yes	"

Table 1 (continued). Information sharing in fisheries: summary of case studies.

Species	Gear type	Location	Information sharing?	Source
Various species, including cod	Handlines, haul seines and gillnets	Eastern U.S. and Canadian in-shore fisheries - c.1873	At high stock levels - Yes At low stock levels - No	McCay (1987)
Pollock	Small trawlers. (U.S.)	Bering Sea	Seldom; limited to between vessels selling to the same cannery	Hodges (1992)
	Large trawlers, factory trawlers (U.S.)	"	Only when capacity has been reached	"
	Large trawlers (Japanese)	Bering Sea 'Donut Hole'	Yes	"
Party boats	Recreational	Washington state	Yes	Personal observation
Party boats	"	Long Island	Yes	Colton (1992)
Various species, including leopard sharks, sole	Dragger	West coast of U.S.	None or rare	Stuster (1978)
African wildlife safaris		Africa	Yes	Brown (1991)

Table 2. Categorization of case studies.

Category	Cases	Information sharing category
IA	Salmon; troll; SE Alaska	Y
	Salmon; troll; N. California	Y
	Tuna (albacore); troll; west coast of U.S.	Y
	Various schooling species; handlines; Coqueiral, Brazil	Y
IB	Herring; drift net; Shetland	Y
	Herring; trawler; Sweden	Y
	Salmon; gillnet; SE Alaska & Cook Inlet; Alaska	Y
	Salmon; drift net; Newfoundland	L
	Swordfish; harpoon; west coast of U.S.	Y
	Sea bass; trawler; west coast of U.S.	Y
	Shrimp; trawler; Texas	Y
IC	Herring; purse seine; Shetland	Y
	Salmon; purse seine; SE Alaska	Y
	Tuna; purse seine; eastern tropical Pacific	Y
IIA	Various species; recreational party boats; RI and WA	Y
	Various species, including cod, high stock levels; handlines, haul seines, gillnets, Eastern U.S. and Can.	Y
IIB	Cod; longline; Newfoundland	L
	Halibut; longline; Newfoundland	L
	Pollack; small trawlers (U.S.); Bering Sea	L
	Various species, including cod, low stock levels; handlines, haul seines, gillnets; Eastern U.S. and Can.	N
	Various species, including leopard sharks and sole; trawler; west coast of U.S.	N
	Various bottomfish, including cod, flounder, sole, redfish and haddock; trawler; Newfoundland	L
	Various bottomfish; trawler; west coast of U.S.	N
IIC	Grey sole; Danish seine; Newfoundland	L
	Pollack; large trawlers (Japanese); Bering Sea	Y
	Pollack; large/factory trawlers (U.S.); Bering Sea	N
	Black cod; longline; SE Alaska	L
	Halibut; longline; SE Alaska	N

Table 2 (continued). Categorization of case studies.

Category	Cases	Information sharing category
IIIA	Crab; Chesapeake Bay	N
	Crab; west coast of U.S.	N
	Lobster; Maine (Acheson)	L
	Lobster; Middle Harbor, ME (Palmer)	N
	Lobster; Southern Harbor, ME (Palmer)	L
	Lobster; Rhode Island	N
	Lobster; west coast of Sweden	N
IIIB	Clams; Long Island	N
	Rock fish; handlines; Coqueiral, Brazil	N

Table 3. Cross classification of data.

		Information sharing category Y	L	N	Total
I	A	4	0	0	4
	B	6	1	0	7
	C	3	0	0	3
Total I		13	1	0	14
II	A	2	0	0	2
	B	0	4	3	7
	C	1	2	2	5
Total II		3	6	5	14
III	A	0	2	5	7
	B	0	0	2	2
Total III		0	2	7	9
Total		16	9	12	37

Table 4. General 2 × 2 contingency table.

		Information sharing category *Yes*	*No*	
Species category	*Mobile*	a	b	$a + b$
	Sedentary	c	d	$c + d$
		$a + c$	$b + d$	$N = a + b + c + d$

Table 5. Tests of association using Fisher's exact test for 2 × 2 contingency tables.

Arrangement #	Grouping	*I(#Y, #N); III(#Y, #N)*	*P*
1	Delete all cases categorized as *II* and/or *L*	(13,0);(0,7)	1.29E-05
	Delete all L; partition II		
2	*IIA,B,C* → *III*	(13,0);(3,12)	1.50E-05
3	*IIA* → *I; IIB,C* → *III*	(15,0);(1,12)	4.27E-07
4	*IIA,B* → *I; IIC* → *III*	(15,3);(1,9)	2.73E-04
5	*IIA,B,C* → *III*	(16,5);(0,7)	6.69E-04
	Worst case scenarios		
6	*IL* → *IN; IIY* → *IIIY; IIL* → *IN*	(13,12);(5,7)	0.4070
7	*IL* → *IN; IIY* → *IIIY; IIL* → *IIIY*	(13,6);(11,7)	0.4516

Pairwise comparisons between *I*, *II*, and *III*

	i,j	c_i*(#Y, #N)*; c_j*(#Y, #N)*	*P*
	All *L* → *Y*		
8	*I, II*	(14,0);(9,5)	0.0204
9	*I, III*	(14,0);(2,7)	1.47E-04
10	*II, III*	(9,5);(2,7)	0.0602
	All *L* → *N*		
11	*I, II*	(13,1);(3,11)	1.71E-04
12	*I, III*	(13,1);(0,9)	1.22E-05
13	*II, III*	(3,11);(0,9)	0.2055