Observer Deployment In The Fishery and Regulatory Self-Enforcement*

William J. Furlong and Patrick M. Martin,
Department of Economics, University of Guelph, Guelph, Ontario, N1G 2W1, CANADA

Abstract. Many fisheries assign observers to vessels as a means of collecting stock data and monitoring regulatory compliance. Typically, deployment is random and the level of coverage determined in an *ad hoc* manner. This paper explores optimal observer coverage and the deployment of observers to vessels from an enforcement perspective. The central behavioural assumption is that fishery violations are motivated by profit. Violations will therefore manifest themselves in a larger than "normal" value of landings. The model employs a comparison of two distributions of landings: the first drawn from vessels with onboard observers and the second from those without observers. Strategic deployment minimizes the cost of regulatory noncompliance and may provide less biased stock data than a random deployment. Conditions under which the interests of the fleet and the regulatory agency coincide are also identified, i.e., conditions for self-enforcement. The model has the potential of being implemented with readily available data.

1. INTRODUCTION

Many countries require that vessels carry observers onboard as a condition of fishing their waters. Observers generally serve two roles. First, they gather data for stock assessment purposes and secondly, they provide a means of monitoring at-sea compliance with fishery regulations. In the United States the data collection role of observers tends to be emphasized, while in Canada and elsewhere more weight is given to the enforcement function of observers.

Although observer coverage tends to be extensive in many countries, it is not applied with uniform intensity across fisheries. For example, the northern shrimp fishery in Canada has complete or 100% coverage, while most groundfish fisheries in the same region have coverage rates ranging from five to twenty percent. There appears to be little in the way of economic justification for a particular level of coverage from an enforcement perspective. Rather, current levels tend to be justified by reference to historical levels which themselves were determined on an *ad hoc* basis.

Biologists often cite random sampling requirements to justify specific coverage levels for stock assessment purposes (see e.g., Australian Fisheries Management Authority (1995)). If, however, noncompliance is present it can be argued that random sampling yields biased inferences. Placement of an observer onboard increases the likelihood of detection and punishment for noncompliance. Onboard observers will therefore tend to deter rational violators.[1] Fishing activity in the subset of (essentially) compliant vessels with onboard observers would not be representative of activity by the remainder of the fleet if regulatory noncompliance is significant. Even though observers may have been randomly assigned to vessels, these vessels do not comprise a random sample of fleet behaviour for inference purposes. Rather, they comprise a distinct population.

This paper is concerned with several aspects of the effectiveness of onboard observers with respect to their enforcement role. Specifically, under what conditions is partial coverage optimal? If partial coverage is optimal, are there any practical ways in which the regulator can gauge what level of coverage is appropriate in a particular fishery? What deployment strategies can improve the effectiveness of a given observer expenditure?

There are several means of monitoring at-sea fishing activity (e.g., onboard observers, patrol vessels and air surveillance). Onshore inspections of vessels and landings offer an alternative to at-sea monitoring of fishing activity. At-sea and onshore monitoring are, *to some extent*, substitutable modes of enforcement. Onshore monitoring is generally less costly than at-sea monitoring. Expenditure for a single observer-day provides monitoring of a single at-sea vessel-day whereas that same expenditure dockside would provide for inspection of several vessels each of which has been at sea for many days. Although less costly, onshore monitoring is widely viewed as being incapable of detecting certain classes

*The authors gratefully acknowledge the support of the Department of Fisheries and Oceans (DFO), Conservation and Protection Branch, Ottawa, Canada. The opinions expressed here are those of the authors alone, who also bear full responsibility for any errors or omissions.

[1]For evidence on deterrence in the fishery see Sutinen and Gauvin (1988) and Furlong (1991).

of violations. By way of illustration, onshore monitoring can be very effective in detecting size or bycatch infractions, but is perceived as being incapable of detecting violations such as discarding or fishing in closures.[2]

Recently, this view has been challenged by Allard and Chouinard (1997) who propose a statistical test to infer whether discarding has taken place on vessels without observers. The test involves a comparison of samples of catch drawn from vessels with observers to that of vessels without observers. The approach assumes that vessels with onboard observers are fully compliant. Thus, data from this sample can be used to construct the length-frequency distribution of the catch *given that no discarding has occurred* which is then compared to a distribution constructed from data obtained dockside from vessels without onboard observers. Any statistically significant difference in the two distributions is attributed to discarding.

One limitation of the Allard and Chouinard analysis is their focus on the single violation of discarding which fails to capture potential substitutability across violations. Further, their discussion of observer coverage levels only considers its sampling properties, and ignores the direct benefit of deterrence achievable from a purposive deployment.

The present study suggests how the Allard and Chouinard approach can be generalized to all violations. This generalization is based on the assumption that violations are motivated by profit. The conditions for optimal partial coverage are developed. A comparison of distributions of landings from vessels with and without observers then provides a means of inferring the proportion of total landings that are attributable to noncompliance. This is a readily available measure that can be used by the regulator to determine coverage levels. Finally, a strategic deployment rule that assigns observers to vessels where the expected benefit of enforcement is greatest is formulated. The fleetwide level of noncompliance is thereby minimized for any given level of observer expenditure. Thus, the model in this paper addresses the optimal allocation of observer resources *to* and *within* the fishery.

An overriding objective in this paper is to advance the case for efficient observer deployment that can be readily implemented by the regulatory agency. As such, the present paper does not develop a rigourous theoretical model. Rather, the emphasis is on developing an effective framework for practical enforcement operations.

The next section presents a simple model of optimal observer coverage. Despite its simplicity, the model establishes the precise circumstances under which a partial coverage regime would be optimal. It also clarifies why a strategic as opposed to random deployment of observers is a necessary condition for an optimal partial coverage regime. A subsequent section discusses how the model can be implemented with readily available data. A funding arrangement in which the interests of the fleet and the regulatory agency are incentive compatible is proposed. Finally, we propose some test statistics for implementation.

2. OPTIMAL OBSERVER COVERAGE

The optimal level of observer coverage obtains when the benefits net of costs are maximized. The following discussion captures in a simple way the conditions under which partial coverage is optimal, and when it is not. This model focuses on the enforcement function of observers and then discusses the implications for data collection.

Let b represent the number of observers and N the size of the fleet.[3] It follows that, $b \leq N$ and b/N is the level of observer coverage. Also, let the total cost of the observer program be represented by the function $C(b)$. The costs of observers are readily measurable. The fixed cost of the infrastructure is represented by c_o -- this would include recruitment, training, etc. The variable cost of an additional observer is assumed constant at c per observer day. The cost function is therefore given by:

$$C(b) = c_o + cb .$$

The benefits of observers are considerably more involved. The intermediate output of an observer is deterrence of illegal activity which presumably translates into a more productive stock that ultimately yields a greater resource rent. The resource rent is therefore a function of the number of observers and represented by the function $R(b)$. It is assumed that resource rent is increasing in the level of observer coverage (i.e., $R' > 0$ for all $b \leq N$) because more observers generate more regulatory compliance thereby bringing the harvest closer to its optimal level and composition.

[2] Anderson (1989) provides an in-depth discussion of the degree of substitutability between these two forms of monitoring and questions whether the loss in compliance benefits warrants the cost savings in substituting at-sea monitoring for dockside inspections.

[3] Strictly, speaking, b refers to the number of observer sea-days and N refers to the number of at-sea fishing days for the fleet. For economy of language, the terms observer and observer sea-days are used synonymously as are vessels and vessel sea-days.

The optimal number of observers maximizes *R(b) - C(b)*. This yields the usual first order condition for an interior solution where the marginal benefit of an observer equals the marginal cost (i.e., $R' - c = 0$).

For the moment, assume all *N* vessels have the same propensity for noncompliance (i.e., each commits the same number and type of violations when no observer is present). The impact on resource rent from an additional observer is therefore constant at R' per vessel and is independent of the vessel. If $R' > c$, complete coverage is optimal (i.e., $b^* = b_{max} = N$). If, however, $R' < c$, zero coverage is optimal. Partial coverage would only be optimal if $R' = c$ for some level of observer coverage less than b_{max}. This can occur when either *c* increases in the number of observers, R' decreases in the number of observers or both. At least one of the assumptions in the simple model must therefore be relaxed to obtain partial coverage as an optimum.

As discussed above, it is reasonable to expect the cost of placing an observer on an additional vessel to be approximately constant once the program infrastructure has been established. On the other hand, the benefit of an additional observer is unlikely to be constant; the assumption that all vessel operators have the same propensity for violations is not compelling. Some are simply more law-abiding than others. Some are more risk averse than others. Some perceive greater gains from violations and less risk of punishment than others. Whatever the reason, the enforcement benefit of assigning an observer to a vessel is not independent of the vessel or operator.

Now, suppose the propensity to violate does indeed vary across vessels but that the assignment of observers to vessels is nonetheless random. The full or zero coverage solution still obtains as the optimum. The only modification is in interpretation: R' is now the *average* or *expected* benefit of compliance but it is still a constant that is independent of the number of observers. This follows because a fully compliant vessel is just as likely to be assigned an observer as is the most flagrant violator. On the other hand, suppose that observers are strategically assigned to vessels. Certain vessel operators have reputations, fishery officers have information or suspicions about others. This intelligence is used in a partial coverage regime to strategically assign observers to those vessels suspected of noncompliant behaviour. The first few observers are assigned to those vessels expected to violate the most. Additional observers are assigned to vessels according to fishery officers' descending expectation of violations. Stated otherwise, R' is decreasing in the level of observer coverage. Partial coverage can therefore be optimal.[4]

Note that in either the simple story of a constant R' across vessels or the equivalent random deployment of observers, partial coverage of (for example) 20% can be *expected* to generate deterrence of exactly 20% of total violations. In the strategic deployment regime, 20% coverage would deter more than 20% of total noncompliance. Firstly, vessels with the highest propensity to violate would be assigned observers. Secondly, there is an incentive for vessels without observers to reduce noncompliance in order to decrease the likelihood of being assigned an observer on future trips.

The above discussion underlines the conflict between enforcement staff and biologists in their views of observers according to their roles as "watch dogs" or "information gatherers", respectively. Enforcement seeks a purposive deployment, biological assessment promotes a random assignment. It can be argued that stock assessment data may be more accurate with a strategic deployment than a random one. Placement of an observer onboard is hypothesized to change fishing behaviour to being more compliant with regulations. Use of data drawn from this sample of vessels to infer catch statistics for the observerless and, therefore, noncompliant fleet is highly suspect. A strategic deployment minimizes the difference in behaviour between the two samples since it eliminates the most serious violators. Data drawn from vessels that have been assigned observers in a strategic manner are therefore less biased than data drawn from a sample of randomly selected vessels.

Maximization of enforcement benefits requires that observers be assigned to those vessels that are most likely to be noncompliant. As discussed above, enforcement staff no doubt have some intelligence on who the violators are. This intelligence is likely to be accurate for the handful of hardcore violators, but thereafter becomes blurry and crude and is then more of a guessing game (i.e., an essentially random allocation). A means of obtaining a more finely tuned ranking of violators for purposes of observer deployment is required.

3. IMPLEMENTATION FRAMEWORK

Direct measurement of the benefits of onboard observers is highly problematic. First, an estimate of the number and

[4] R' may also be decreasing if the marginal cost of noncompliance is increasing. That is to say, the marginal loss in rent increases the further the harvest is from its optimum. We ignore this biological stock effect so that we may better focus on enforcement considerations.

type of violations deterred would have to be obtained. Second, the impact on the stock from these reduced violations would have to be quantified. Finally, the increase in the resource rent from the stock effect would have to be estimated. Are these measurable? In principle, yes, but only with data that are free of limitations and imperfections. As anyone working in fisheries is well aware, this is highly unlikely to be the case.

Violations data are particularly problematic. Measurement of any illegal activity is subject to a reporting error. The proportion of total offences that is unreported varies considerably with the type of offence (e.g., compare motor vehicle theft with assault). In the fishery, there is ample evidence that the proportion of unreported violations is very high. There have been some attempts to estimate the extent of fishery violations (e.g., Blewett et al (1985) and Sutinen et al (1990)). These, however, are occasional studies that employ a survey methodology which is incapable of providing current, ongoing, and consistent data at a reasonable cost. Dependable violations data remain a black hole in regulatory enforcement in the fishery. Any attempt to *directly* measure the enforcement benefits of observers is, at best, subject to scepticism.

In the present context, there is an alternative to using direct violation data. Fisheries violations are committed to increase profits.[5] Violations will therefore manifest themselves in larger than normal profits. Vessels with atypically high profits are more likely to have been engaging in illegal activities than those with unusually low profits, *ceteris paribus*. Can this relationship between profits and noncompliance be identified? Actual profits may be even more difficult to measure than violations. However, increased profits from many fishery violations generally result from increased revenue or, equivalently, value of landings.

There are two potential exceptions to the landings-noncompliance relationship. The first is is due to highgrading. When an individual quota is in place, highgrading may result in a lower value of landings on a particular trip, even though there is an expectation of increased future profit. Highgrading increases the value per tonne of catch but may also decrease total tonnage, thereby preserving some quota for future (presumably more valuable) catch. Although, the value of landings on this particular trip is actually lower, the value of landings from future trips are expected to be larger so that overall profits are maximized.

The second exception to the landings-noncompliance relationship is that some violations may result in increased profits through a reduction in costs as opposed to an increase in revenue. *A priori*, it is not clear if increased revenues or decreased costs offer a better explanation of most illegal activity in the fishery. The present framework would however capture this cost effect if it is specified in terms of *landings per unit effort* instead of simple landings. For ease of exposition, we continue our discussion in terms of "landings".

The linkage between landings and noncompliance therefore suggests that unusually high landings can be employed as a proxy variable to signal the probability of noncompliance. Now, consider a particular fishery defined by species, season, area, vessel size and gear. In other words, control for a host of factors that may help explain differences in landings across vessel trips. This is achieved by temporal, areal, and tonnage class standardization. Despite this normalization, the value of landings nonetheless can be expected to vary across vessel trips because there are still three factors for which we have not yet controlled: productivity differences, luck and the propensity to violate. An example of the variation in landings by trip is given by the arbitrary frequency distribution depicted in Figure 1 where the mean value of landings is V_o.

Appearance of a vessel in the upper tail of the distribution may be attributable to luck on that particular trip, relatively more productive fishers, or a greater level of noncompliance. If luck is the cause, consistent reappearance in the upper tail of the distribution on future trips is unlikely. Since luck is random, appearance in the lower tail should be equally likely as appearance in the upper tail for the normal distribution depicted in Figure 1. If a certain vessel is identified as having a disproportionate frequency of upper tail appearances, some enforcement action is warranted (i.e., placement of an observer onboard). On the other hand, differences in productivity due to differences in expertise may also explain a unusually frequent upper tail appearance. If this is the case, then the vessel should continue to report relatively high landings with an observer onboard -- reassignment of the observer to another vessel would then be warranted. If noncompliance is the explanation for frequent upper tail appearances, the relatively high value of landings will disappear (on average) when an observer is assigned to that vessel. In summary, all three scenarios provide information that can be used to construct a profile of each vessel's history and provide a ranking of the likelihood of noncompliance across vessels. We denote this ranking P^i for the probability of noncompliance by the i^{th} vessel.

[5]There are, of course, some violations that do not result in increased profits (e.g., administrative infractions or inhumane killing of seals). However, the majority of violations relevant in this context are solely motivated by profit.

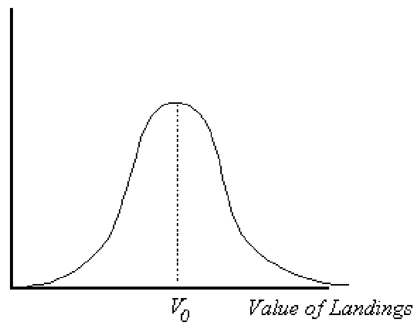

Figure 1

The approach has limitations for enforcement. It is unlikely to provide information that would not stand up to the rigours of court evidence. Further, the model does not (in its present form) identify which violations are being committed — unusually high landings may be attributable to many small violations or to a single serious infraction. Of course, the model can be modified to target a specific infraction in a manner similar to Allard and Chouinard (1997).

Now, let's address optimal coverage levels. Separate distributions of the value of landings can be constructed for those vessels with observers onboard and those without. For illustration purposes, two arbitrary distributions are presented in Figure 2. The differences in both the means and the variances of these distributions are relevant for policy purposes.

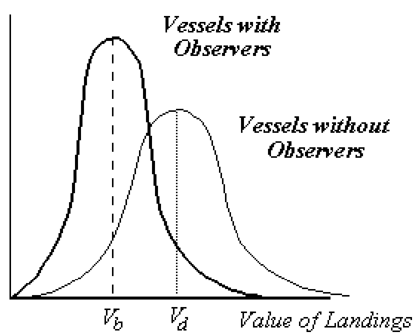

Figure 2

Standard statistical tests can be conducted to test whether or not these distributions are drawn from the same population. If the tests fail to reject the null hypothesis of identical distributions then noncompliance is insignificant and random assignment of observers to vessels would yield unbiased estimates for stock assessment purposes. On the other hand, if the tests reject the hypothesis of identical distributions then the vessels without observers are engaging in illegal fishing activity that is not represented by the subset of vessels with observers. Random assignment yields biased inferences. A purposive or strategic deployment is appropriate. We now discuss the implications of different distributions.

3.1 The difference in the means

In Figure 2, V_b denotes the mean value of landings for vessels with observers onboard and V_d the mean for those without onboard observers (i.e., landings are reported dockside only). The difference in these means yields important and useful information for the enforcement authority.

The distribution of luck and expertise can be assumed independent of whether or not a vessel has an observer onboard. The difference between V_b and V_d is therefore entirely attributable to violations. It is assumed that $V_d > V_b$, otherwise it might be argued that the observer program is not productive from an enforcement perspective. The expected return from an additional observer measured in terms of reduced landings from increased compliance is $V_d - V_b$. Further, if there are N_d vessels in this fishery without observers then the value of landings attributable to noncompliance in this fishery (denoted V_{nc}) is

$$V_{nc} = N_d(V_d - V_b).$$

The greater is the value of landings attributable to violations, the stronger is the case for increased levels of coverage, *ceteris paribus*.

One could also calculate ρ the proportion of total landings attributable to violations by dividing V_{nc} by the total value of landings, i.e.,

$$\rho = V_{nc} /(N_n V_n + N_b V_b).$$

where N_b is the number of vessels with observers.

Although the difference in mean landings $V_d - V_b$ is directly related to the true marginal benefit of observer coverage (i.e., R' discussed above), they are not identical. V_{nc} is a market measure of violations that understates the full social cost. It measures the value of current harvest attributable to violations. It does not incorporate the foregone value of future harvests from a greater than optimal current harvest (i.e., the cost of exceeding the optimal TAC). Even if V_{nc} is an insignificant proportion of total landings, the full social costs may still be significant. Although V_{nc} does not measure the full social cost of illegal fishing, it can nonetheless serve as a practical indicator of the benefits of enforcement resource allocation. The larger is ρ the stronger is the case for increased coverage levels. Also, a comparison of ρ across different fisheries serve as a guide for relative coverage levels.

3.2 The difference in the variances

Suppose statistical tests reject the null hypothesis of identical means, i.e., there is evidence that $V_d - V_b > 0$. Is this sufficient to justify some partial level of observer coverage? Not necessarily. Suppose each vessel has the same propensity to violate, so that any vessel without an observer increases its landings by the same amount $V_d - V_b$. The optimal coverage level would then be zero or complete. Since everyone commits the same violations, if it pays to put an observer on one vessel, it pays to put them on all vessels. As discussed above, only if the propensity to violate differs across vessels would partial coverage be optimal (again, we are ignoring the stock effect).

Whether the propensity to violate is constant or differs across vessels is a testable proposition. If all vessels without observers violate to the same extent, the distribution of their landings is equivalent to the distribution of landings by vessels with observers shifted up by a constant, $V_d - V_b$. Although the mean increases, the variance remains constant. On the other hand, if the propensity to violate differs across vessels, then both the mean and the variance will increase. Therefore a partial coverage regime would be optimal only if both the mean and variance of the observerless trips are greater than that of trips with observers.

4. SELF-ENFORCEMENT

In some observer programs the cost of the program is borne by the regulatory agency. In others, the fishers pay the cost. In this case the cost is either distributed on a fleetwide average cost basis or it is entirely borne by those vessel assigned observers. An interesting policy implication arises when the observer program is financed by the entire fleet as opposed to a regime where only vessels carrying observers bear the cost. If the regulator announces that it will employ estimates of ρ as the criterion for determination of observer coverage levels, then industry has an incentive to ensure that observers are assigned to those vessels with the highest propensity to violate. For any given coverage level, landings due to violations would be minimized if observers are assigned to the relatively more severe violators. The resulting decrease in total illegal landings can then be used to justify a lower coverage level and hence lower cost for the fleet. Thus, the interests of the regulator and the regulated coincide insofar as deployment of a given number of observers to vessels is concerned.

5. THE NONCOMPLIANCE INDEX

Landings from vessels with observers and from vessels without observers form two distinct samples. The statistical question of interest is whether the two samples can be considered to have been drawn from the same population (given the relevant standardization). If statistics such as the mean and variance are the same for the two sampled populations it is unlikely that serious fishing violations are occurring. (The other possibility, that onboard observers do not curtail violations, is assumed not to be the case). The greater the divergence in the sample statistics of landings from vessels with and without onboard observers, the more likely it is that violations are occurring in the absence of an onboard observer. In this case there is an economic rationale for onboard observers. Assume that is indeed the case. Implementation of strategic deployment requires a ranking of the likelihood of noncompliance across vessels (i.e., P^i discussed above).

There are some well-established statistical procedures for constructing such a ranking — see for example the discussions of the Rank Sum Test and the Median Test in Mood et al (1974).[6] The following suggests two intuitive and practical ways in which this ranking might be constructed -- however, their full statistical properties have not been fully explored.

First, the difference in the means of the sample populations for the fleet in a particular fishery, $V_d - V_b$, could be compared to the difference in means for the i^{th} (normalized) vessel, $v_d^i - v_b^i$. If $v_d^i - v_b^i > V_d - V_b$ it is more likely that the i*th* vessel has violated fishery regulations than a vessel for which the inequality is reversed. The enforcement agency could then rank vessels by the difference and place observers on those vessels where the difference is the greatest (and hence the likelihood of noncompliance is greatest). In addition, as new information is forthcoming from future landings (both with and without observer placements), the means of both populations for the fishing fleet and for a particular vessel would be updated.

$$[v_d^i - v_b^i] - [V_d - V_b]$$

Another candidate for ranking vessels by likelihood of violation is the product of a vessel's mean place in the cumulative distribution function (CDF) for landings without observers and one minus its mean place in the CDF for landings with an onboard observer. For example, suppose that a particular vessel has mean observerless landings that are greater than 70 percent of all other vessels without observers, and its mean observer landings are only 40 percent greater than that of other vessels also with observers. The product, .7 x (1 - .4) = .42, would indicate a higher

[6] An extended discussion of the application of these tests in the context of observer deployment can be found in Furlong and Martin (1999).

propensity for violating behaviour than a vessel with the opposite ranking (and hence an index value of .4 x (1 - .7) = .12). The distribution for observerless landings is generated by differences in both noncompliance and productivity across vessels, while the distribution of observer landings is generated only by differences in productivity. Thus, the index adjusts a vessel's placement in the first distribution to reflect its placement in the second where violations have been deterred.

The above suggests two *ad hoc* ways of constructing noncompliance indices based upon the distributions of landings for vessels with and without observers. The objective is to illustrate that such an index can be constructed with dockside data and without much statistical expertise.

6. CONCLUSION

Onboard observers provide two distinct services: collection of data for stock assessment and at-sea monitoring of regulatory compliance. This paper addresses optimal observer coverage levels and deployment of observers across vessels. Central to this study is the proposition that data from vessels with onboard observers can be compared to data from vessels without onboard observers to infer regulatory noncompliance by the latter group. In particular, it is argued that most violations are motivated by profit and will therefore manifest themselves in above normal levels of profit or, equivalently, landings. There is therefore a positive relationship between value of landings and noncompliance. Since landings are observable dockside, once the relationship between landings and noncompliance is known, illegal behaviour can be inferred from landings data only. Thus, differences in mean landings between vessels with and without observers can be attributed to noncompliance once other possible explanations have been filtered out (e.g., luck, productivity differences, fishing capacity, etc.).

Optimal observer coverage in a fishery may be zero, partial or complete. It is argued that partial coverage can be justified when there are differences in the propensity to violate across vessels. This is equivalent to a difference in the variances for the two landings distributions. The partial coverage regime requires that observers be assigned to those vessels which are believed to have the highest propensities for noncompliance. Strategic deployment of observers to vessels requires that an index which ranks each vessel's likelihood of noncompliance be developed. Two methods of constructing this index are proposed.

The model developed in this paper bears a resemblance to the state-dependent enforcement literature that was first proposed in the context of tax evasion and further refined in the environmental literature — see for example, Landsberger and Meilijson (1982), Greenberg (1984), Russell (1986) and Harford (1991, 1993). The core proposition in that literature is to use an individual's history of noncompliance to determine assignment to one of various groups which are subject to differing intensities of enforcement. Thus, detection of noncompliance today has an additional cost of increased likelihood of detection and severity of punishment in the future. This is analagous to an increased likelihood of having an observer placed on your vessel. The state-dependent literature is cast in a two-period game theoretic context in which there are two or three enforcement categories. The model implicit in the present paper is an infinite time horizon with a continuum of categories as characterized by the index ranking probabilities of noncompliance. It would appear to be a generalization of the state-dependent model.

The present paper is policy-oriented in nature. It discusses practical means of judging optimal coverage levels as well as effective deployment of resources that can be readily implemented. There is a richer theoretical model behind this discussion. It investigates the "captain's problem" of choosing a particular intensity of noncompliance. A model in which captains have different discount rates or marginal rates of substitution between legal and illegal landings can generate differences in noncompliance decisions. In making this decision, a captain takes the fleetwide coverage level as given, and infers the likelihood of being assigned an observer on future trips based upon one's individual placement in the fleetwide distribution of landings. The regulator knows the relationship between individual intensity of noncompliance and coverage levels. It then uses this relationship in choosing the observer coverage level that maximizes net benefits.

7. REFERENCES

Allard, J. and G.A. Chouinard, A Strategy to Detect Fish Discarding by Combining Onboard and Onshore Sampling, *Canadian Journal of Fisheries and Aquatic Sciences*, 54, 2955- 2963, 1997.

.

Anderson, L.G., Enforcement Issues in Selecting Fisheries Management Policy, *Marine Resource Economics*, 6, 261-277, 1989.

Australian Fisheries Management Authority, A Review of the Australian Fisheries Management Observer Program, unpublished report prepared for the Australian Fisheries Management Authority, 1995.

Blewett, E., W.J. Furlong and P.Toews, Canada's Experience in Measuring the Deterrent Effect of Fisheries Law Enforcement, in *Fisheries Law Enforcement: Programs, Problems and Evaluation*, J. Sutinen and T. Hennessey, eds., Marine Technical Report 93. Kingston, University of Rhode Island, 1985.

Furlong, W.J., The Deterrent Effect of Regulatory Enforcement in the Fishery, *Land Economics*, 67 (1), 116-129, 1991.

Furlong, W.J. and P.M. Martin, A Statistical Model of Optimal Observer Coverage and Deployment, Technical Report prepared for the Conservation and Protection Branch, Department of Fisheries and Oceans, Government of Canada.

Greenberg, J., Avoiding Tax Avoidance: A Repeated Game-Theoretic Approach, *Journal of Economic Theory*, 32, 1-13, 1984.

Harford, J.D., Measurement Error and State-Dependent Pollution Control Enforcement, *Journal of Environmental Economics and Management* 21, 67-81, 1991.

__________, Improving on the Steady State in the State-Dependent Enforcement of Pollution Control, *Journal of Environmental Economics and Management* 24, 133-138, 1993.

Landsberger, M. and I. Meilijson, Incentive Generating State-Dependent Penalty System, *Journal of Public Economics*, 19, 333-352, 1982.

Mood, A.M., F.A. Graybill and D.C. Boes, *Introduction to the Theory of Statistics*, Third Edition, New York: McGraw-Hill, 1974.

Parsons, L.S., Ensuring Compliance: Fisheries Enforcement, Chapter 19 in *Management of Marine Fisheries in Canada*, Canadian Bulletin of Fisheries and Aquatic Sciences 225, 625-653, 1993.

Russell, C.S., W. Harrington and W.J. Vaughan, *Enforcing Pollution Control Law*, Resources for the Future, Washington, D.C., 1986.

Sutinen, J. and J. Gauvin, An Econometric Study of Regulatory Enforcement and Compliance in the Commercial Inshore Lobster Fishery in Massachusetts, in *Rights Based Fishing*, P.A. Neher, R. Arnason and N. Mollet (eds), Boston: Kluwer Academic Publishers, 1988.

Sutinen, J., A. Rieser and J. Gauvin, Measuring and Explaining Noncompliance in Federally Managed Fisheries, *Ocean Development and International Law*, 21, 335-372, 1990.