Enforcement and Corruption in Management of Protected Areas

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Abstract

Protected areas (PAs) are important for biodiversity conservation and can provide the benefits for current and future generations. Management effectiveness is a key factor to achieve outcomes of PAs. However, success is related to the enforcement implemented. Corruption is one of the main issues impacting and weakening enforcement. This article provides the perspective for control the corruption to get the benefit from conservation from PAs. The individual agent's behavior and social welfare will be investigated under scenarios with and without corruption. Comparisons of optimal harvesting effort, optimal enforcement, optimal PA size, and optimal wage for enforcers between cases are made to provide implications for a social planner managing a PA and corruption.

1. Introduction

The creation of protected areas (PAs) is a common conservation intervention that aims to protect species and habitats from human activity. As of 2016, approximately 15% of the Earth's land and 10% of its territorial waters are covered by national parks and other protected areas, with coverage of marine protected areas increasing by almost 300% in the last decade (UNEPWCMC, 2016). Even with this growth in coverage, much remains to ensure the protection goals of these areas which often comprises biodiversity conservation, sustainable management of fisheries, improving food and water security, and coping with climate change (UNEPWCMC, 2016). Management effectiveness is a key factor to achieve outcomes of PAs (Alban, et al., 2006). However, success is related to the enforcement implemented. Lack of enforcement is one of the reasons for PAs failing to meet their targets.

There are many issues impacting and weakening enforcement, where corruption is one. Corruption is also associated with over-exploitation of natural resources. Corruption related to illegal harvesting may occur when agents violate the regulations or laws established for a resource. Illegal harvesting of natural resources is a serious global problem causing substantial loss to societies worldwide (Mora et al. 2006, Pollnac et al. 2010). Recently, scientists have recognized corruption to be a serious concern for natural resource management (Sundstrom, 2015). Ostrom, (2005), indicated that one of the five threats to small-scale resource governance is corruption and rent-seeking. However, there has been little research investigating adequately the theoretical and empirical perspectives on these issues. Agrawal (2007) notes that there is a need for scientific analysis of the extent to which corruption may threaten the sustainability of resource governance. While corruption is widely studied, the current literature lacks an understanding of how bribery destroys enforcement of natural resource regulations. In addition, while previous literature mainly focus on the connection between law and corruption, the relationship between law and effective area protection has not been systematically studied.

With regards to marine resources, a number of studies have been conducted to examine illegal harvesting behavior based on (Becker, 1968). However these studies mainly focus on law enforcement and corruption is not dealt with. Anderson & Lee (1986) develop a model of an effort regulated fishery where harvesting in excess of the maximum effort limit is fined if detected. The profit function of a fishing vessel includes the expected fine if detected, and the cost of avoidance activities. They find that the social cost of avoidance is important for setting up optimal management programs. Charles *et al.* (1999) focus on the effectiveness of input versus output control regimes when enforcement is not perfect. Fishers maximize expected profits net of the expected fine, and their variable cost functions include avoidance costs. The authors conclude that the optimality conditions of the agents differ structurally dependent on the regulatory control used and the units of measurement under the two control regimes. Jensen, et al. (2014) study compliance and enforcement in fisheries and find that fines are costly transfers to society. They show that fines cannot help to ensure deterrence, and instead lead to increased avoidance activities with resultant decreased probability of detection.

The above mentioned studies focus on input and output management of fisheries in combination with fines, while we study PA management in a broader ecosystem service perspective, including corruption, and study how the size of PA, enforcement, effort to control corruption and fines should be decided to secure the conservation target level for society, and reduce corruption. The PAs provide conservation benefits to society but they also impose costs to agents as they may lose their preferred harvesting area. Agents will have incentives to harvest illegally if the benefit from this activity is large. Agents will also have incentives to bribe enforcers to evade fines for noncompliance. In this paper, the individual agent's behavior and social welfare will be investigated under scenarios with and without corruption. Comparisons of optimal harvesting effort, optimal enforcement, optimal PA size, and optimal wage for enforcers between cases are made to provide implications for a social planner managing a PA and corruption.

This article proceeds as follows. Section 2 describes the model of individual agent behavior and social welfare setting studies optimal effort, PA size and wage rate for enforcers. Section 3 presents the main results of the model. The article then concludes with final remarks in the section 4.

2. Model

Consider a resource with a protected area (PA) and harvesting area outside. A fraction m, $m \in (0,1)$, of the whole area is set aside as the PA, and consequently, 1 – m is the size of the outer area. When m = 0, there is no PA and m = 1 implies that the whole area is a PA.

We consider three different actors in this study, the agents harvesting the natural resource, the enforcer monitoring the illegal harvesting and the government controlling the corruption and the illegal harvesting if corruption exists. Each actors behave in different ways that help them to achieve their own objectives.

The individual agent may violate the PA regulation to harvest illegally, and there is a possibility that this is detected and fined. The individual agent's harvest is assumed to be a function of two inputs, e_L and e_I, the effort spent on legal (L) and illegal (I) harvesting, the stock level X and the size of the PA. Hence harvest is $h(e_L, e_I, X, m)$, with $h_{e_L} > 0$, $h_{e_I} > 0$, $h_X > 0$ and $h_m < 0$.

We assume that the PA also influences the cost function, $c(e_L, e_I, m)$, as the agent may have to reallocate to new harvesting areas or their choice of harvesting areas may be limited. The loss of access to a traditional harvesting area can lead to increased travel time to a new one, and this, in turn, leads to less time left for harvesting. Consequently, their costs may increase such that $c_m > 0$, as well as $c_{e_L} > 0$ and $c_{e_I} > 0$.

When deciding to harvest illegally, in order to reduce the likelihood of detection, the agents will exert effort a in avoidance activities. Avoidance activities can include actions taken to hide illegal harvest for example, fishers can use equipment which help them to fish inside the PA while the vessels are located in the outside areas. The avoidance cost function, $d(a, e_I, m)$, is assumed to be a function of avoidance effort, illegal harvesting effort, and the PA size, with $d_a > 0$, $d_{e_I} > 0$,and $d_m > 0$.

The enforcer monitoring the illegal harvesting and θ is the probability that an enforcer detects an agent when harvesting inside the PA. We assume that θ is a function of the enforcer's monitoring effort r, and the agents' avoidance effort, a. θ increases with monitoring effort r and decreases with the avoidance effort a of agents $\theta(r, a)$. The probability of detection is further assumed to be nonlinear so that $\theta_a < 0, \frac{\partial^2\theta}{\partial a^2} > 0, \theta_r > 0$ and $\frac{\partial^2\theta}{\partial r^2} < 0$.

2.1 Without corruption

The focus of this section is to investigate the individual agent behavior and social planner's objective in the absence of corruption. The individual agent will behave as a profit maximizing agent and decide to comply or not comply with regulations. We also assume that the agents disregard their effect on the resource stock. Each agent determines legal harvest, illegal harvest and avoidance effort in order to maximize expected net profit as follows:

$$\pi = ph(e_L, e_I, m, X) - c(e_L, e_I, m) - d(a, e_I, m) - \theta(a, r) f h(e_L, e, m, X) \qquad (1)$$

It is assumed that f is the fine per unit of production if the agent is detected violating the regulation, e.g., harvesting inside the PA. As the manager cannot clarify exactly whether the production is harvested inside or outside the PA, the fine depends on the total harvest that is found..

Without corruption, the agents allocate harvesting effort to maximize their own benefits with respect to production cost, avoidance cost and the expected fine. If the agent decides to follow the regulation, no illegal harvesting occurs, and there is no need for avoidance. The agent considers harvesting effort to maximize profit making optimal harvesting effort become $ph_{e_L} = c_{e_L}$. Optimal harvesting effort is defined by equalizing the marginal revenue and the marginal costs of harvesting.

As mentioned above, the creation of a PA with restrictions made on available harvesting area may affect the agents' production cost. The agents may have to travel further to the alternative harvesting areas. The benefit of harvesting may also decline due to this. If this benefit from legal harvesting becomes too small, the agent has incentives to engage in illegal harvesting. In addition, the PAs often help to conserve species inside the PA. The larger size and higher species abundance inside PAs may also attract more agents to harvest illegally here.

If the agent engages in illegal harvesting then the optimal allocation of effort between legal and illegal harvesting activity is determined. The agent also considers optimal avoidance effort. To find the solutions for the optimal level of e_L, e_I and a, taking the first order partial derivatives of equation (1) and setting them equal to zero, the following conditions are found:

$$ph_{e_L} = c_{e_L} + \theta f h_{e_L} \qquad (1a)$$

$$ph_{e_I} = c_{e_I} + d_{e_I} + \theta f h_{e_I} \qquad (1b)$$

$$d_a = -\theta_a f h$$

(1c)

In order to maximize profit, the agent decides to harvest legally at the effort level where marginal revenue from legal harvesting equals the total marginal cost which includes the marginal production cost for this harvest and the marginal expected fine cost. As mentioned above, if the agents harvests illegally, all production will be considered illegal. The production from legal harvesting will also be given a fine.

For an illegal harvest strategy to be optimal, the marginal revenue from illegal harvesting equals the total marginal cost which includes the marginal cost of production, the marginal cost of avoidance and the marginal expected fine cost. For the avoidance effort, the optimal effort level is defined as that which gives the marginal benefits of avoidance effort (a reduction in the expected fine, $-\theta_a f h$) equal to the marginal cost of the avoidance effort, d_a.

One concern that should be discussed is how the agents allocate legal and illegal harvesting effort. Rearranging (1a) and (1b), the harvest rule for the agent in this case can be stated as follows:

$$\frac{c_{e_L}}{h_{e_L}} = \frac{c_{e_I}}{h_{e_I}} + \frac{d_{e_I}}{h_{e_I}} \qquad (1d)$$

From (1d), it is optimal for an agent to harvest legally and illegally at the effort levels where the marginal production cost-harvest ratio of legal harvesting equals the total marginal cost-harvest ratio of illegal harvesting. The marginal cost-harvest ratio of illegal harvesting comprises two components: the marginal production cost-harvest ratio and the marginal avoidance cost-harvest ratio. In this case, the marginal production cost-harvest ratio of legal harvesting is larger than that of illegal harvesting, which is an important condition leading to the agent's decision to harvest illegally.

With the creation of PAs, we assume that $B(m, e_I)$ are the societal benefits from conservation. These benefits include the benefits for tourism and biodiversity. $B(m, e_I)$ is assumed to be increasing and concave in the size of the PAs, $B_m > 0$, $B_{mm} < 0$, and $B(0) = 0$, and decreasing with the illegal harvesting effort $B_{e_I} < 0$. A social planner, instead of maximizing agents' expected profit, wants to maximize social welfare which includes the conservation benefit and the welfare of all members of society, with the enforcement for PAs. To obtain compliance from the agents, it is necessary to enforce the PA regulation. The enforcement cost l that a social planner has to pay, is assumed to be a function of the detection probability of illegal harvesting. We assume that $l'(\theta) > 0$ and $l''(\theta) > 0$.

For simplicity of analysis, the rents from illegal activities are included in the social welfare function. Milliman [1986], Jensen et al (2015), Milliman (1986) and Lewin and Trumbull (1990) discussed that the welfare for society is the total surplus, including the illegal surplus. In this part, we will discuss how the social planner should choose PA size and enforcement level to maximize the social welfare function.

Without corruption, the agents may choose to harvest illegally and must pay the fine if they are detected. In order to analyze society's enforcement cost function, the response function of the agent is derived to investigate how the agent reacts in the face of the manager's monitoring. The response functions can be written as $a(\theta)$ and $e_I(\theta)$ which describe the relationships between the enforcement effort and the avoidance effort and illegal harvesting effort, respectively.

Maximization of social welfare can be formulated with legal and illegal harvesting effort, PA size and enforcement effort as the control variables and stock size as the state variable.

$$\max_{e_L, e_I, m, r} \int_0^\infty \{B(m, e_I) + [ph(e_L, e_I, m, X) - c_i(e_L, e_I, m) - d(a, e_I, m)] - l(\theta)\} e^{-\delta t} \qquad (2)$$

subject to

$$\dot{X} = G(X,m) - h(e_L, e_I, m, X)\,,\ X(0) = X_0,\ X(t) \geq 0,\ 0 \leq e_L \leq e_{max} \qquad \text{(2a)}$$

Equation (2a) is the resource restriction implying steady state use of the resource where $G(X,m)$ is the natural growth function of natural stock with $G'(m) > 0$, $G''(m) > 0$. Equation (2a) is also what distinguishes the individual agent's maximization problem from society's steady-state maximization problem. The harvest function, cost function, and avoidance cost function take into account the behavioral response of agents to changes in enforcement and the corresponding effects of these variables on harvest level, operating cost and avoidance cost.

Since we are mainly concerned about the regulation compliance, the PA size, and enforcement, we only assess the optimal conditions for control variables. The current – value Hamiltonian of the problem is described as follows:

$$H = B(m, e_I) + [ph(e_L, e_I, m, X) - c(e_L, e_I, m) - d(a, e_I, m)] - l(\theta) + \lambda[G(X,m) - h(e_L, e_I, m, X)] \qquad \text{(2b)}$$

where λ is the adjoin variable measuring the marginal cost or the shadow value of the dynamic resource stock. The first order conditions are:

$$\frac{\partial H}{\partial e_L} = ph_{e_L} - c_{e_L} - \lambda h_{e_L} = 0 \qquad \text{(2c)}$$

$$\frac{\partial H}{\partial e_I} = B_{e_I} + ph_{e_I} - c_{e_I} - d_{e_I} - \lambda h_{e_I} = 0 \qquad \text{(2d)}$$

$$\frac{\partial H}{\partial m} = B_m + ph_m - c_m - d_m + \lambda[G_m - h_m] = 0 \qquad \text{(2e)}$$

$$\frac{\partial H}{\partial \theta} = B_{e_I} e_{I_\theta} + ph_{e_I} e_{I_\theta} - c_{e_I} e_{I_\theta} - (d_a a_\theta + d_{e_I} e_{I_\theta}) - l_\theta - \lambda h_{e_I} e_{i_\theta} = 0 \qquad \text{(2f)}$$

The social planner will decide the optimal harvesting effort interpreted in (2c), the optimal enforcement needed (2d), the optimal size of the PA (2e), and the optimal detection probability (enforcement) in the presence of illegal harvesting (2f).

In (2c), the optimal legal harvesting effort that the social planner wants the agents to exert in order to maximize social welfare equals the level where marginal revenue from legal harvest equals the total marginal cost of legal harvest plus the marginal cost of taking the social planner's objective into account, λh_{e_L}. The equation (2d), as Jensen, et al., (2014) mentioned, can be interpreted as condition for the optimal enforcement for illegal harvesting.

Equation (2e) can be rearranged as $-ph_m + c_m + d_m = B_m + \lambda(G_m - h_m)$. This indicates that the optimal PA size for maximizing social welfare is set up so that the marginal loss for agent caused by PA equals the marginal benefit of PA by increasing biodiversity and the stock size. The optimal detection probability is defined based on (2f) by equalizing the aggregate marginal benefit from enforcement for society by reducing the illegal harvesting $B_{e_I} e_{I_\theta} + ph_{e_I} e_{I_\theta} - c_{e_I} e_{I_\theta} - (d_a a_\theta + d_{e_I} e_{I_\theta}) - \lambda h_{e_I} e_{i_\theta}$ to the marginal cost of the enforcement, l_θ.

2.2 With corruption

Rational individuals seeking to best combine the resources they have in their power in order to produce profits may resort to rent-seeking and corruption. Thus, instead of complying with a regulation, agents may have an incentive to bribe enforcers in order to avoid paying a fine for illegal harvesting. There are two ways that agents may bribe enforcers. Agents can pay an *ex-ante* bribe to the enforcer for letting them harvest without complying with the regulation. In this case, agents do not spend time and effort on avoidance activities and thereby circumvent this potential cost. Alternatively, the agents may pay an *ex-post* bribe to the enforcer when they are detected violating regulations, in order to avoid paying the fine. They will negotiate with the enforcer for a bribe that is smaller than the fine. In this case, their expected profit function will include the production cost, the avoidance cost, and a bribe. It should be noted that the motivation of agents does not change with the regulation. They will still try to maximize profit, but have to take into account the constraints imposed by the regulatory regime. In the following we derive the agents' behavior in each case and investigate how corruption affects natural resources.

2.2.1 Ex-ante bribery

The choice of an agent regarding *ex-ante* bribery depends on whether the agents have access to enforcers *ex-ante*. If *ex-ante* bribery is made possible by the enforcer, the size of the bribe that an agent must pay in exchange for not being monitored will be negotiated. We assume that the size of the bribe is R. Paying a bribe to the enforcer may help the agent reduce the avoidance cost. Thus costs in this case only include the production cost and the bribe.

The corruption is controlled by the effort to detect the bribe. If the bribe is discovered, we assume that there is no transfer between agents and enforcers and fines on both agents and enforcers are imposed. We further assume that the fine imposed on an agent and on an enforcer caught engaging in bribery is proportional to the bribe. The agent will have to pay the fine for violating the regulation and for engaging in bribery while the enforcer only pays the fine for bribery engagement. We assume the probability of detecting bribery is α, and $0 < \alpha < 1$, and s, with $0 < s < 1$, is the fine rate imposed on an agent and an enforcer caught engaging in bribery. Thus the fine imposed on the agent and enforcer if detected to be engaging in bribery is sR.

Since the agent faces the government's control of corruption, the agent's expected cost from bribery is $\alpha(fh + sR) + (1 - \alpha)R$, where the first term is the fine for illegal harvesting and the fine for bribery if detected ($\alpha = 1$). The second term is expected bribe, provided the corruption is not detected ($\alpha = 0$).

The agent will decide to offer a bribe if the expected cost of corruption is smaller than the sum of the avoidance cost and the expected fine for bribery in the case without corruption;

$\alpha(fh + sR) + (1-\alpha)R < d + \theta fh$. The size of the bribe affecting the agent's decision to offer an *ex-ante* bribe is as follows:

$$R < \frac{d+(\theta-\alpha)fh}{1-\alpha(1-s)} \qquad (3a)$$

An *ex-ante* bribe must satisfy condition (3a). The bribe can increase with an increase in the detection probability and the fine rate for illegal harvesting. The *ex-ante* corruption may therefore be deterred if the fine rate and the detection probability of illegal fishing are sufficiently high.

For the enforcer, he or she may accept the bribe if the expected benefit from corruption is larger than the wage, thus $w + (1-\alpha)R - \alpha sR > w$. The rule for the enforcer's acceptance of a bribe requires:

$$\alpha < \frac{1}{1+s} \qquad (3c)$$

While the bribe level is the main concern of agent when deciding whether to offer a bribe, this rule shows that the bribe level does not affect the enforcer's acceptance of bribery. The enforcer is mainly concerned with the bribery detection probability and the fine rate for corruption.

Given the corruption detection probability a, the expected profit of an individual agent is as follows:

$$\pi = ph(e_L, e_I, m, X) - c(e_L, e_I, m) - [\alpha(fh + sR) + (1-\alpha)R] \qquad (4)$$

The third component on the right hand side, as mentioned above, consists of the expected bribe and expected fines for illegal harvesting and for engaging in corruption. The first order condition for legal and illegal harvesting effort, respectively, are:

$$ph_{e_L} = c_{e_L} + \alpha f h_{e_L} \qquad (4a)$$

$$ph_{e_I} = c_{e_I} + \alpha f h_{e_I} \qquad (4b)$$

The agent chooses the legal/illegal fishing effort by equating the marginal return from legal/illegal harvesting to the total marginal cost including the marginal legal/illegal production cost and marginal expected fine. To investigate the agent's allocation between legal and illegal harvesting, (4a) and (4b) are re-arranged. The following rule is given for harvesting activities:

$$\frac{c_{e_L}}{h_{e_L}} = \frac{c_{e_I}}{h_{e_I}} \qquad (4c)$$

In the optimization problem of the agent in (4c), the marginal production cost-harvest ratio of legal harvesting equals to that of illegal harvesting. .

Following Amacher, et al., (2012), the enforcer's incentive to accept a bribe and probability he or she detects the illegal harvesting depends on the enforcer's wage. Thus the wage is the instrument for government to control the enforcer and it determines the total enforcement cost. With the *ex-ante* corruption, as mentioned above, enforcement has no effect on the agent's illegal activity, agent will not pay for the activity to avoid the enforcer's monitoring. However, the control of corruption may lead to a change in the agent's and enforcer's behavior since both the agents and the enforcers will pay the fine if detected. The bribe and the fine are the transfer between the agent, the enforcer and the government so they are not included in the social welfare function. Corruption reduces social welfare as it increases the cost of monitoring. The social planner has to choose the optimal level of legal and illegal harvesting[1] effort, PA size, and the enforcer's wage in order to maximize social welfare and reduce corruption. The social welfare function will be defined as follows:

$$\max_{e_L,m,r} \int_0^{\infty} \{B(m,e_I) + [ph(e_L,e_I,m,X) - c(e_L,e_I,m)] - g(\alpha)\} e^{-\delta t} \quad (5)$$

subject to

$$\dot{X} = G(X,m) - h(e_L,e_I,m,X)\ ,\ X(0) = X_0,\ \ X(t) \geq 0,\ \ 0 \leq e_L \leq e_{max} \quad (5a)$$

The current-value of Hamiltonian is defined as:

$$H = B(m,e_I) + [ph(e_L,e_I,m,X) - c(e_L,e_I,m)] - g(\alpha) + \lambda[G(X,m) - h(e_L,e_I,m,X)] \quad (5b)$$

The optimal conditions for this maximization are:

$$\frac{\partial H}{\partial e_L} = ph_{e_L} - c_{e_L} - \lambda h_{e_L} = 0$$

(5c)

$$\frac{\partial H}{\partial e_I} = B_{e_I} + ph_{e_I} - c_{e_I} - \lambda h_{e_I} = 0$$

(5d)

$$\frac{\partial H}{\partial m} = B_m + ph_m - c_m + \lambda[G_m - h_m] = 0$$

(5e)

$$\frac{\partial H}{\partial w} = B_{e_I}e_{I_w} + ph_{e_I}e_{I_w} - c_{e_I}e_{I_w} - g_\alpha \alpha_w - \lambda h_{e_I}e_{i_w} = 0$$

(5f)

Compared to without corruption case the enforcement needed for illegal harvesting in this case is bigger, the wage for enforcer due to this is also higher. The increase in the wage for the enforcers may lead to lower probabilities of accepting bribery and reduces the loss of biodiversity from PA at the margin ($B_{e_I}e_{I_w}$). The wage rate for enforcers is defined by equalizing marginal benefits from enforcement (comprising reduction in bribes and illegal harvesting) for society $B_{e_I}e_{I_w} + ph_{e_I}e_{I_w} - c_{e_I}e_{I_w} - \lambda h_{e_I}e_{i_w}$ to the enforcer's wage marginal cost $g_\alpha \alpha_w$.

2.2.2 Ex-post bribery

While the ex-ante bribery has an effect on the monitoring that leads to noncompliance of the agent, the ex-post bribery cannot help the agent reduce the avoidance cost. The motivation to

[1] The social planner does not like illegal harvesting, but cannot deter it completely due to the cost involved.

choose this kind of bribery is that the agent believes the probability of detection is low. We assume that b, with $0 < b < 1$, is the bargaining power of the enforcer, and that the bargaining outcome is efficient for both the agent and the enforcer. The bribery in this case will depend on the catch and it is assumed as, bfh. The expected fine for the agent and the enforcer if detected engaging in bribery is, $sbfh$.

For the enforcer, he will accept the ex-post bribery if his benefit from accepting the ex-post bribery is larger than his wage, $w + (1 - \alpha)bfh - \alpha sbfh > w$. The bribery detection probability will affect enforcer's decision. As the ex-ante bribery case, when the bribery detection probability satisfies condition, $\alpha < 1/(1 + s)$, the enforcer will accept the ex-post bribery.

The agent's expected profit function is as follows:

$$\pi = ph(e_L, e_I, m, X) - c(e_L, e_I, m) - d(a, e_I, m) - \theta[\alpha(1 + sb) + (1 - \alpha)b]fh \quad (7)$$

The fourth component in the profit function is the expected fine for the individual agent. If the agent is not detected violating the regulation ($\theta = 0$ and $\alpha = 0$), no bribe is transferred, the expected fines are zero. If the agent is detected violating the regulation ($\theta = 1$), and pays the bribe, but the bribery is not detected ($\alpha = 0$), then the expected fine for violation of the regulation is bfh. If the agent is detected violating the regulation ($\theta = 1$), and caught engaging in bribery ($\alpha = 1$), the total expected fine is $(1 + sb)fh$.

Let $[\alpha(1 + sb) + (1 - \alpha)b] = \omega$, clearly $\omega < 1$. From the first order conditions of the profit maximization we obtain:

$$ph_{e_L} = c_{e_L} + \omega\theta f h_{e_L} \quad (7a)$$

$$ph_{e_I} = c_{e_I} + d_{e_I} + \omega\theta f h_{e_I} \quad (7b)$$

$$d_a = -\omega f h \theta_a \quad (7c)$$

The total marginal cost for legal harvesting in the ex-post bribery case is smaller than that of ex-ante bribery case, however the total marginal cost for illegal harvesting is higher as a consequence of avoidance activities and the probability of detection. So the optimal legal harvesting effort is larger while the optimal illegal harvesting effort is smaller for ex-post bribery compared to those for ex-ante bribery.

Rearrange (7a) and (7b), we have the harvest rule for legal and illegal harvesting:

$$\frac{c_{e_L}}{h_{e_L}} = \frac{c_{e_I}}{h_{e_I}} + \frac{d_{e_I}}{h_{e_I}} \quad (7d)$$

In the optimization of the agent, the marginal production cost-harvest ration of legal harvesting is equal to the total marginal cost-harvest ratio which is the sum of the marginal production cost – harvest ratio and the marginal avoidance cost-harvest ratio as the case without corruption. Different from ex-ante bribery where the marginal production cost is the same for legal and illegal harvesting, in this case, the marginal production cost-harvest ratio of legal harvest is also higher than that of illegal fishing.

The agent's preference regarding ex-ante or ex-post corruption should be investigated in order to understand the motivation of an agent when offering a bribe. With the analysis of marginal cost-harvest ratio above, clearly the agent' choice between ex-ante and ex-post bribery depends on the comparison of the marginal production cost-harvest ratio between legal and illegal harvesting. However, it also depends on the detection probability for illegal harvesting. Thus the agent decides to choose ex-post bribery instead of ex-ante bribery if the extra cost from ex-post bribery is smaller than that of ex-ante bribery, $d + \omega f h < \alpha(fh + sR) + (1-\alpha)R$. The condition for the agent to choose ex-post bribery instead of ex-ante bribery is:

$$\theta < \frac{\alpha(fh+sR)+(1-\alpha)R-d}{\omega fh} \qquad (6a)$$

Regarding the social planner, in order to maximize the social welfare, he will consider how the bribery detection will influence illegal harvesting. The optimal social welfare function is as follows:

$$\max_{e_L,m,r} \int_0^\infty \{B(m,e_I) + [ph(e_L,e_I,m,X) - c(e_L,e_I,m) - d(a,e_I,m)] - \theta g(\alpha)\}e^{-\delta t} \qquad (8)$$

subject to

$$\dot{X} = G(X,m) - h(e_L,e_I,m,X)\ ,\ X(0) = X_0,\ X(t) \geq 0,\ 0 \leq e_L \leq e_{max} \qquad (8a)$$

The current value of Hamiltonian for this problem may be expressed as follows:

$$H = B(m,e_I) + [ph(e_L,e_I,m,X) - c(e_L,e_I,m) - d(a,e_I,m)] - \theta g(\alpha) + \lambda[G(X,m) - h(e_L,e_I,m,X)] \qquad (8b)$$

The optimality conditions for the control variables are:

$$\frac{\partial H}{\partial e_L} = ph_{e_L} - c_{e_L} - \lambda h_{e_L} = 0$$

(8c) $\frac{\partial H}{\partial e_I} = B_{e_I} + ph_{e_I} - c_{e_I} - d_{e_I} - \lambda h_{e_I} = 0$

(8d)

$$\frac{\partial H}{\partial m} = B_m + ph_m - c_m - d_m + \lambda[G_m - h_m] = 0$$

(8e)

$$\frac{\partial H}{\partial w} = B_{e_I}e_{I_w} + ph_{e_I}e_{I_w} - c_{e_I}e_{I_w} - \left(d_a a_w + d_{e_I}e_{I_w}\right) - (\theta_w g + \theta g_\alpha \alpha_w) - \lambda h_{e_I}e_{i_w} = 0$$

(8f)

The optimal size of PA is the same as under no corruption but it is smaller than that of ex-ante bribery case due to the presence of the agent's marginal avoidance cost with respect to the PA size. The illegal harvesting effort is smaller than that of ex-ante bribery due to the higher marginal cost so the optimal wage for enforcer is also smaller compared to that ex-ante bribery.

3. Main results

To provide management implications for the social planner, the findings from the model should be summarized and discussed. From the models presented above, we are able to derive main results for the individual agent and enforcer's behavior, and the social planner's objectives.

3.1 Individual agent behavior

In order to analyze agent behavior in the different cases, the comparisons of optimal legal harvesting effort and illegal harvesting effort are made. From the solutions to an agent's profit maximization, the result 1 regarding individual agent behavior can be stated as follows:

Result 1.

Result 1.1: *The corruption affects the natural resources in such a way that it can make the marginal cost of illegal harvest of an individual agent decrease which, in turn, leads to an increase in the illegal harvesting effort. The ex-ante bribery imposes the most serious threat to the resources as the marginal cost is smaller compared to non-corruption and ex-post bribery. This makes the illegal harvesting effort for ex-ante bribery become the biggest.*

Comparison of the total marginal cost for illegal harvesting between no corruption, ex-ante bribery and ex-post bribery in equations (1b), (4b) and (7b), it indicates that the total marginal cost for illegal harvesting for the ex-ante is the smallest. The illegal harvesting effort due to this is highest for this case. The increase in harvesting effort without control, for the long term, may lead to overexploitation. The corruption thus has directly contributed to the degradation of natural resources that needs specific regulations and appropriate management for natural resources.

Result 1.2: *For no corruption and ex-post bribery cases, the increase in the detection probability for illegal harvesting and fine rate leads to an increase in avoidance effort, thus the detection probability and the fine may be complements. The fine rate should be higher when the probability of detection is lower and vice adverse.*

With ex-ante bribery, there will be no avoidance activity from the agent and no detection of illegal harvesting from the enforcer. However under no corruption and ex-post bribery cases, the agent has to pay for avoidance effort in relation to the enforcement of the regulation. Both the detection probability and fine rate for illegal harvesting can make the expected cost for agent increase (see equation (1b) and (7b)), so they will influence the illegal harvesting activity. Jensen, et al., (2014) concludes that it is not always to set the fine as high as possible since it can make the agent increase the avoidance effort. The fine rate for bribery and the bribery detection probability thus can be complementary to save the resource for the government. If the enforcement effort increases, the fine rate may decrease and vice averse.

Result 1.3: *The choice of agent between ex-ante or ex-post bribery in the concern to maximize its profit depends on the marginal production cost-harvest ratio of illegal and legal harvesting and the detection probability for illegal harvesting. The agent can choose ex-ante bribery even when* *its production cost-harvest ratio of illegal harvesting equals to that of legal harvesting. But agent only can choose ex-post bribery when its production cost-harvest ratio of illegal harvesting is smaller than that of legal harvesting.*

From (4c) and (7d), the production cost of illegal harvesting is different from that of legal harvesting. With the ex-post bribery, the agent still has to spend effort on avoidance activity. Only when the marginal production cost of illegal harvesting is smaller than that of legal harvesting, agent may get benefit from illegal harvesting and have the incentive to offer ex-post bribery to the enforcer.

Result 1.4: *Even with effort control the corruption, bribery may not be deterred toward the agent. For ex-post bribery, the agents will pay the bribe if this bribe is smaller than the fine. For ex-ante bribery, if magnitude of the bribe leads to* $R < \frac{d+(\theta-\alpha)fh}{1-\alpha(1-s)}$ *, the expected marginal cost of illegal harvest activity, in this case, is lower compared to that in the case without corruption.*

2.2 Enforcer

Corruption affects the enforcer behavior in the way that the enforcer may accept the bribe and invest zero effort in enforcing the regulation. Note from (3c) that the acceptance of enforcers toward ex-ante and ex-post bribe depends on the bribery detection probability. We are thus can state the below result.

Result 2: *The bribe is just the lump sum payment of agent to enforcer and will not impact the acceptance of enforcers. The enforcer will accept any size of bribe as long as the bribery detection probability does not exceed* $\alpha < 1/(1+s)$. *The government thus can use bribery detection effort and bribery fine rate complementarily to control the corruption.*

The higher the bribery detection and the fine for bribery, the lower the probability that the agent offers a bribe and the lower the probability that enforcer accepts the bribe.

3.3 The social welfare

For the social planner, with the objective to maximize social welfare, following results are found:

Result 3:

Result 3.1: *The optimal PA size under no corruption and ex-post bribery is smaller than that of ex-ante bribery case.*

The optimal PA size under no corruption and ex-post bribery is defined by equalizing the marginal benefit of PA including marginal increase for society benefit and a marginal increase for stock size ($B_m + \lambda[G_m - h_m]$) to the marginal loss for agent caused by the PA ($-ph_m + c_m + d_m$).

With ex-ante bribery, the optimal PA size is defined by:

$$B_m + \lambda[G_m - h_m] = -ph_m + c_m$$

The agent does not have to pay for avoidance activity so the marginal cost for the PA size is smaller, which again leads to the optimal PA size being larger.

Result 3.2: *The optimal wage rate for the enforcer is larger in the case of ex-ante bribery compared to that of the case of ex-post bribery. This means that it is not always optimal to set the high wage rate for enforcers to prevent them engaging in bribery.*

The agents have a higher probability to pay the ex-ante bribery since their marginal cost of illegal harvest will be smaller compared to ex-post corruption and without corruption cases Thus to avoid the enforcer accepting the bribe, the wage for enforcer should be higher.

As the same, the marginal loss for society from creating a PA is bigger in the ex-ante case compared to those of other cases. The wage for enforcers is also different between in the ex-post bribery and ex-ante bribery. In order to attain maximization social welfare, the optimal wage rate of enforcer in the case of ex-post bribery is smaller than that of ex-ante bribery.

Result 3.3: *The PA size and the wage rate for enforcers are instruments that may work together to help the government achieve maximum social welfare and reduce illegal harvesting and corruption. The increase in illegal harvesting leads to the need for more conservation and enforcement. Thus the increase in PAs size needs the higher enforcers' wage rate.*

Conclusion remarks

This article discusses corruption and enforcement system for PAs and investigate how individual agent behaves and how government can control the corruption to achieve the optimal social welfare. The individual agent behavior is examined to investigate how individual agent choose the optimal legal and illegal harvest and the avoidance effort for enforcement from government. The condition for the enforcer's decision to accept the bribe is also examined. The maximization of social welfare is analyzed to find out the optimal enforcement for illegal harvesting, the optimal PA size and the optimal wage for enforcers that help the government achieve the objective to maximize biodiversity conservation and benefits for stakeholders. The social planner would put more effort to avoid the ex-ante bribery since it can lead to the degradation of natural resource due to the absence of monitoring. The article provides the perspective for control the corruption to get the benefit from conservation from PAs. The negative impact of corruption on natural resources requires appropriate enforcement and design of PAs.

Acknowledgements

The authors express gratitude to financial assistance provided by The Norwegian Agency for Development Cooperation (NORAD) through NORHED project QZA-0485 SRV-13/0010 "Incorporating Climate Change into Ecosystem Approaches to Fisheries and Aquaculture Management in Sri Lanka and Vietnam",

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