FISHERY RESOURCE RECOVERY STRATEGY FOR TWO BASTARD SPECIES[1]

STRATEGIJA OBNOVE RIBNJAKA ZA DVIJE MJEŠOVITE VRSTE

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Abstract : *Some natural resources such as fisheries, forests and wild animal have been harvested until over-exploitation occurs. The purpose of this paper is to examine if we can recover such over-exploited natural resources without reducing the harvest. The basic idea is to harvest two bastard species in a specific way: the amount that is harvested is retained and only one of the two species is alternately harvested annually. We will demonstrate that under some conditions, it is possible to replenish natural resources while maintaining the existing harvest level, thus allowing the recovery to start. More specifically, we focus on a fishery case, but our methods are applicable for other natural resources.*
Key words: *over-exploitation, resource recovery, bastard species, biological model.*

Apstrakt: *Neki prirodni izvori tipa ribnjaka, šuma i divljih životinja uništavaju se zbog prekomjerne eksploatacije. Cilj ovog rada je istraživanje kako se mogu obnoviti ovi prekomjerno eksploatasini prirodni izvori, a da se pri tome ne smanji ulov. U osnovi je ideja lova dvije mješovite vrste na specifičan način: količina ulova ostaje ista, pri čemu se svake godine naizmjenično lovi jedna od ove dvije vrste. Pokazaćemo kako je pod određenim uslovima moguće popuniti prirodne izvore i održati ulov na istom nivou, i tako omogućiti početak obnove. Preciznije, fokusirali smo se na slučaj ribnjaka, ali su naše metode primjenljive i na druge prirodne izvore.*
Ključne riječi: *prekomjerna eksploatacija, obnova izvora, mješovite vrste, biološki model.*

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1. Introduction

Natural resources such as wild game animals, fisheries and forests reproduce if certain amounts of resources are left unharvested in the previous year. Recently, in the field of *Environmental Economics*, the stock of natural resources left for the next year's harvest is called '*natural capital*'. It is well known that the conservation and protection of natural resources is essential for the sustainability of human existence. In particular, natural capital that is important, threatened or vulnerable is called 'critical' natural capital and is considered to have priority in terms of conservation or protection (De Groot et al., 2003)[2].

Many renewable natural resources have suffered from over-exploitation worldwide because of the difficulty in assigning property rights. For example, for fishery resources the individual transferable quota (ITQ) system and other regulatory methods have been introduced to counter the over-exploitation of fishery resources; however, these methods have not proven effective. In the Adriatic Sea, the amount of the regulated harvest has decreased since the end of the 20th century, perhaps because of illegal fishing activities (WWF, 2008). Also, the cod population in the North Sea has decreased catastrophically because fishermen have refused to lower the amount of the total allowable catch.

These situations exist because fishermen are unwilling to reduce their landings (i.e., harvests) and/or fishery income. Thus, any fishery recovery programme aiming to reduce the current landing levels and/or fishery income faces opposition from the fishermen, despite the possibility that such programmes could increase their future landings and income. This opposition is especially evident in the following cases: when fishermen cannot (or are unwilling to) reduce their income further or when their future benefits from landings are highly discounted (e.g., they are old and do not have a successor).

[1] Some parts of this article was first presented at the 5th World Fisheries Congress held in Yokohama, Japan, October 20–24, 2008, under the title 'Economic analysis of the optimal harvest strategy for two substitutable fish stocks' . The article is recorded as a non-referred, two-page proceeding.

[2] The terms conservation and protection 'are applied for secondary nature. The difference between protection and conservation lies in whether human invention is prohibited or not. In conservation, human intervention is presumed unless it is sustainable and rational use' (quoted from Kawata (in print) with minor change).

This paper examines new methods for recovering over-exploited fishery resources while maintaining the current landings and/or fishery income. Our results are also applicable to other renewable resources. Fishery resources must be recovered at an optimal economic level to reduce the possibility of extinction and to attain the most socially beneficial use of fishery resources. Many have said that to recover our fishery resources, we must reduce the amount of fishing and/or amount of income. We will show that these beliefs are chimerical and suggest some ways to improve resource levels without worsening the current situation.

2. Review of Previous Research

2.1. Similar Research

Few studies have examined this issue from the same perspective. Kawata and Kitano (2007) investigated a resource recovery strategy for a puffer fish called 'torafugu' (*Takifugu rubripes*) that did not require reductions the landings. In this study, the basic idea is to prohibit fishing during the first half of the season. Even if fishermen sustained their previous landings levels during the latter half of the fishery season, the resource level of torafugu increased in terms of tonnage. This paper also confirmed that although torafugu will be harvested only during the latter half of the season, this change did not reduce the income of the fishermen.

However, some issues remain unresolved in Kawata and Kitano (2007). If a prohibition is in effect during the first half of the fishery season, fresh supplies of torafugu will not be available in the market. The amount of cultured torafugu would increase in the market while the supply of wild torafugu would decrease. Therefore, some consumers might become satisfied with cultured torafugu. For these consumers, a prohibition during the first half of the fishery season is not a problem. In contrast, other consumers who know the difference in the flavour of wild and cultured torafugu might want wild torafugu during the first half of the fishery season.

It is important, therefore, to consider the feasibility of carrying out resource recovery activities while maintaining landing levels and not restricting the first half of the fishing season. Suppose there are other fish that could be substituted for the target fish. Furthermore, suppose that both of these two fishes cannot be harvested during the first half of the fishery season. In such a case, if we harvest one of these two fishes alternately on an annual basis, one of two fish can always be supplied.

Kawata (2003) revealed that torafugu and another type of puffer fish called 'karasu' (*T. chinensis)* are substitutable. We will examine whether resource recovery is possible without closing the first half of the fishing season. Specifically, we suggest that torafugu and karasu be harvested in alternate annual intervals. Moreover, because few biological parameters such as carrying capacity and intrinsic growth rate are not available, we built a simple model and examined several situations.

2.2. Characterization of This Research

One of the most-used mathematical models of renewable natural resources is the Schaefer model, in which the Verhust-Pearl logistic equation is used for the growth function and the Cobb-Douglas production function is assumed as the harvest rate (Clark, 2005). Because the Hamiltonian of the Schaefer model is linear in the control variable, the combination of bang-bang control and singular control will provide optimal control.

When the current population is above the optimum size, we should harvest at the maximum feasible harvest rate. On the other hand, when the population is below the optimum level, we should prohibit harvesting until the population recovers to this level. The combination of bang-bang and singular controls is the fastest method to realise the optimum population.

This paper deals with a situation in which fishery resources have decreased. If the Schaefer model is applicable to our case, the best method of resource recovery is a fishing ban led by bang-bang control. In real circumstances, though, the possibility that fishermen will agree to a fishing ban until the resource level recovers to the optimal level is unlikely. Therefore, this paper proposes the second-best method in that, although the efficiency of recovery is low and more time is required compared with bang-bang control, our proposal is more feasible and all fishermen will likely agree with this recovery strategy.

3. Analysis

3.1. Assumptions and Conditions

Suppose we have two goods, fishes I and II, equally substitutable. This implies that consumers will notice minor differences between fishes I and II in terms of usage, price and taste. There is, however, a clear difference between the habitats of these fishes, and fishermen can conduct separate activities to obtain these two fishes. In addition, suppose that the resource levels of both fishes are below desirable levels and that the attainment of their respective N^{MSY} is the resource recovery criterion, whereby the growth function is provided as a concave function and N^{MSY} is the resource level at which the maximum sustainable yield is attainable.

<u>Assumption 1</u>

Fishes I and II are homogeneous: Values of the biological parameters are the same.

<u>Assumption 2</u>

The daily harvest is the same throughout the season.

Set the first time period at 0, where both fishes I and II increase to annual levels and sustainable harvests are attained. Fishes I and II are indicated as superscripts, while period t is a subscript. Thus, the landings for fishes I and II can be denoted as H^I and H^{II}, respectively. Furthermore, we have $H^I = F(N^I_0)$ and $H^{II} = F(N^{II}_0)$. Odd (even) values of $t > 0$ indicate the harvesting of only fish I (II), where the total amount of landings from fish I (II) equals $H^I + H^{II}$. For simplicity, we assume that the total amount of fishing at period 0, denoted as $H^I + H^{II}$, is constant until the resource levels recover.

Under these assumptions, the conditions that should be satisfied so that resource recovery can begin are as follows:

Condition I (condition for fish I)

$N^I_1 < N^I_3$ should be attained at period t.

Condition II (condition for fish II)

$N^{II}_1 < N^{II}_3$ should be attained at period t.

These conditions are required for the following reasons. When the population is below N^{MSY}, the growth rate is an increasing function of the population. As assumed above, the total fishing harvest is constant during the resource recovery period, which is equal to $H^I + H^{II} = F(N^I_0) + F(N^{II}_0)$. Therefore, if the resource level at period $t = 3$ is more than the level at time 0, the proliferation of fishes I and II at time $t = 3$ is more than the population of fishes H^I and H^{II}.

3.2. Base Case

Suppose the growth function is concave and the marginal growth rate diminishes. More specifically, the growth function is a logistic equation, which is a quadratic function. The dynamics of the fishery resource level are summarized in Table 1. Because we assumed the amounts of growth $F(N^I_0)$ and $F(N^{II}_0)$ equalled H^I and H^{II}, it follows that the resource levels at the beginning of period 0 and levels at the beginning of period 1 coincide— $N^I_0 = N^I_1$ and $N^{II}_0 = N^{II}_1$. At period 1, only fish I are harvested and the amount is $H^I + H^{II}$. Therefore, at the beginning of period 2, resource levels of fishes I and II are $N^I_2 = N^I_1 - H^{II}$ and $N^{II}_2 = N^{II}_1 + H^{II}$. At period 2, only fish II are harvested and the amount is $H^I + H^{II}$. Therefore, at the beginning of period 3, resource levels of fishes I and II are $N^I_3 = N^I_1 + F(N^I_2) - H^{II}$ and $N^{II}_3 = N^{II}_1 + F(N^{II}_2) - H^I$.

Table 1. Dynamics of the resource levels

	FISH I		FISH II	
Period	**Resource level**	**Landing**	**Resource level**	**Landing**
beginning of period 0	N^I_0		N^{II}_0	
period 0	$N^I_0 + F(N^I_0)$ $= N^I_0 + H^I$	H^I	$N^{II}_0 + F(N^{II}_0)$ $= N^{II}_0 + H^{II}$	H^{II}
end of period 0 = beginning of period 1	$N^I_1(=N^I_0)$		$N^{II}_1(=N^{II}_0)$	
period 1	$N^I_1 + F(N^I_1)$ $= N^I_1 + H^I$	$H^I + H^{II}$	$N^{II}_1 + F(N^{II}_1)$ $= N^{II}_1 + H^{II}$	0
end of period 1 = beginning of period 2	$N^I_2 = N^I_1 - H^{II}$		$N^{II}_2 = N^{II}_1 + H^{II}$	
period 2	$N^I_1 - H^{II} + F(N^I_2)$	0	$N^{II}_1 + H^{II} + F(N^{II}_2)$	$H^I + H^{II}$
end of period 2 = beginning of period 3	$N^I_1 + F(N^I_2) - H^{II}$		$N^{II}_1 + F(N^{II}_2) - H^I$	

Note:

Suppose the landings of fishes I and II at period 0 are H^I and H^{II}, which satisfies sustainable resource levels. After period 1, if period t has an odd value, only fishes I are harvested. The total amount of landings with fish I equal $H^I + H^{II}$. If t is an even number, the above applies to fish II.

Based on the equation at the beginning of period 3, if conditions 3 and 4 are satisfied, the resource levels of fishes I and II should recover. That is, the equivalents of conditions I and II are as follows:

Condition III

For the recovery of fish I (where $N^I_1 < N^I_3$ is satisfied), $F(N^I_2) > H^{II}$ is necessary.

Condition IV

For the recovery of fish II (where $N^{II}_1 < N^{II}_3$ is satisfied), $F(N^{II}_2) > HI$ is necessary.

From the above, the follow is derived:

Proposition 1

Under assumptions 1 and 2, if $N^I_1 \leq N^{II}_1$, then fish I will become extinct.

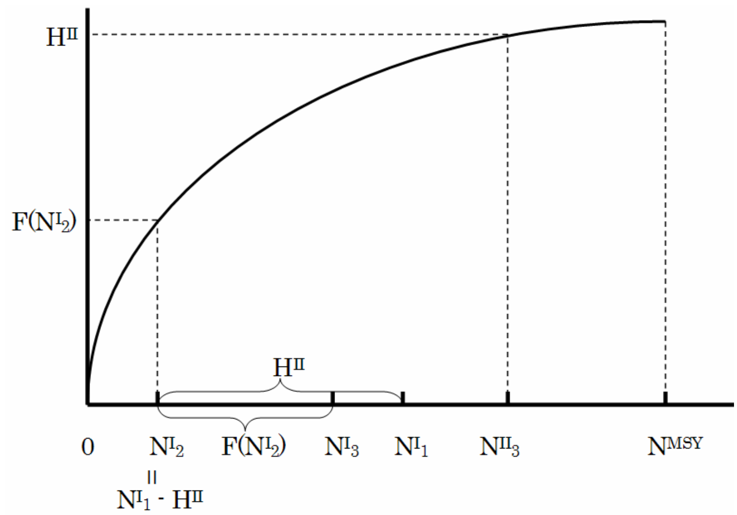

Fig. 1 Diagonal explanation of proposition 1

Proof

From Table 1, the resource level at the beginning of period 2 is $N^{I}_{2} = N^{I}_{1} - H^{II}$. Then it follows that $N^{I}_{2} < N^{I}_{1}$. We also assume that $N^{I}_{1} \leq N^{II}_{1}$. Therefore, $N^{I}_{2} < N^{I}_{1} < N^{II}_{1}$. Because $N^{I}_{2} < N^{II}_{1}$ and assumption 1 is given, we have $F(N^{I}_{2}) < F(N^{II}_{1}) = H^{II}$. From Table 1, the resource level at the beginning of period 3 is $N^{I}_{3} = N^{I}_{1} + F(N^{I}_{2}) - H^{II}$. Because $F(N^{I}_{2}) < H^{II}$, it follows that $N^{I}_{3} < N^{I}_{1}$ and the growth also decreases. On the other hand, the harvest is constant throughout the recovery periods and the resource level approaches zero in the long run (see Fig. 1).

Next, we suppose $N^{I}_{1} > N^{II}_{1}$. Then it can be easily shown the following.

<u>Proposition 2</u>

Under the assumptions 1 and 2, if $N^{I}_{1} > N^{II}_{1}$, then conditions I and II will not be satisfied simultaneously.

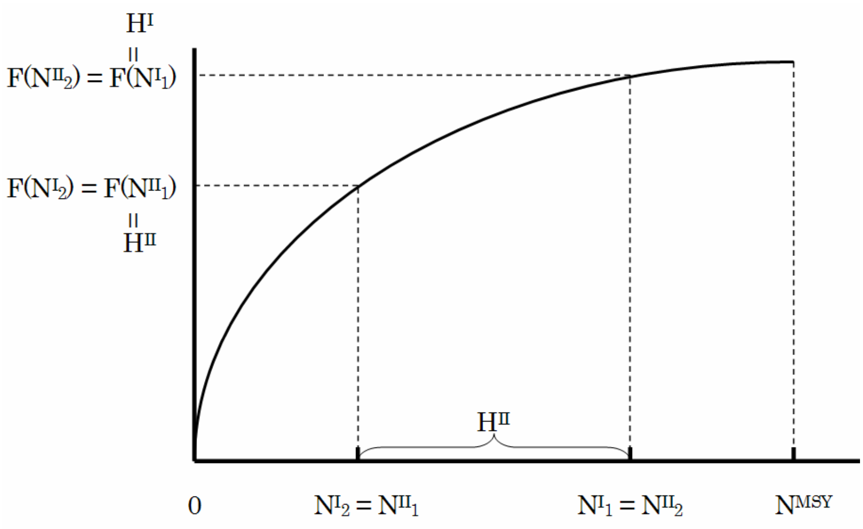

Fig. 2 Diagonal explanation of proposition 2

Proof

It is sufficient to hold $H^{II} < F(N^{I}_{2})$ for condition I (that is, it is sufficient for condition III). $H^{II} = F(N^{II}_{1})$, which is the amount of growth when the resource level is N^{II}_{1}. Conversely, $F(N^{I}_{2})$ is the amount of growth when the resource level is $N^{I}_{2} = N^{I}_{1} - H^{II}$. Note that we postulate a situation in which the resource level is below N_{MSY}. Therefore, as the resource level decreases, the amount of growth also decreases. Then it follows that $H^{II} < F(N^{I}_{2})$ holds when $N^{II}_{1} < N^{I}_{1} - H^{II}$ holds. The last equation is reduced to $H^{II} < N^{I}_{1} - N^{II}_{1}$.

It is sufficient to hold $H^{I} < F(N^{II}_{2})$ for condition II to hold. $H^{I} = F(N^{I}_{1})$, which is the amount of growth when the resource level is N^{I}_{1}. $F(N^{II}_{2})$ is the amount of growth when the resource level is $N^{II}_{2} = N^{II}_{1} + H^{II}$. Then it follows that $H^{I} < F(N^{II}_{2})$ holds when $N^{I}_{1} < N^{II}_{1} + H^{II}$ holds. The last equation is reduced to $H^{II} > N^{II}_{1} - N^{I}_{1}$.

Finally it is obvious that conditions I and II will not hold simultaneously.

In Fig. 2, a specific case is described for an easier explanation for when $N^{I}_{2} = N^{II}_{1}$ and $N^{I}_{1} = N^{II}_{2}$. Condition I will be satisfied, $H^{II} < F(N^{I}_{2})$. This means that N^{I}_{2} is located to the right of N^{II}_{1}. But in this case, condition II will not be satisfied as is easily seen in Fig. 2. The same discussion is applicable for cases where condition II is satisfied. In Fig. 2, we suggest the following corollary of proposition 2.

<u>Corollary 1</u>

Fish I will become extinct if $H^{II} > N^{I}_{1} - N^{II}_{1}$.

Fish II will become extinct if $H^{II} < N^{I}_{1} - N^{II}_{1}$.

Resource levels of fishes I and II will not change if $H^{II} = N^{I}_{1} - N^{II}_{1}$.

The implications of propositions 1 and 2 are as follows. Under assumptions 1 and 2, it is optimal to harvest fishes I and II separately, and second, if we apply our method, it is impossible to recover fishes I and II unless the amount of the total harvest ($H^{I} + H^{II}$) is reduced at least one year and third, when the values of the growth curve parameters are similar, resource recovery seems difficult in our proposed method. In what follows, we examine the cases where we lose assumptions I and II.

3.3. When Two Species Are Not Homogeneous - Removing Assumption 1

In reality, the biological parameters of two fishes would not have the same values. In this section, we remove assumption 1, while keeping assumption 2. Under this more realistic situation, we examine if it is possible to recover fishes I and II without reducing the amount of the harvest, where fishes are harvested alternately annually. Because we assume that the biological parameters are different, the values of carrying capacities and growth rates are different. This suggests that the growth functions are different: one growth function can be located above the other. Hereafter, it will suffice to examine the case where $N^{I}_{1} \geq N^{II}_{1}$. First, we analyse the case in which the growth curve of fish I is above that of fish II. We offer the following propositions.

<u>Proposition 3</u>

Let $N^{I}_{1} \geq N^{II}_{1}$ and suppose that the growth curve of fish I is above that of fish II. It follows that conditions I and II will not be satisfied simultaneously.

Proof:

The proof of this proposition is almost the same that of proposition II. First, $H^{II} < F(N^{I}_{2})$ is required for condition I to be satisfied. Moreover, $H^{II} < N^{I}_{1} - N^{II}_{1}$ is required, so that $H^{II} < F(N^{I}_{2})$ is attained. Also, $H^{I} < F(N^{II}_{2})$ is required for condition II to be satisfied. Moreover, $H^{II} > N^{I}_{1} - N^{II}_{1}$ is required, so that $H^{II} < F(N^{I}_{2})$ is attained. Therefore, conditions I and II cannot be satisfied simultaneously.

<u>Proposition 4</u>

Let $N^{I}_{1} \geq N^{II}_{1}$ and suppose that the growth curve of fish II is above that of fish I. If $F(N^{II}_{2}) > H^{I}$ is attained, fishes I and II could recover simultaneously.

In the above model, we assumed concave growth functions. However, we may obtain the same results if some part of these growth functions has a non-concave shape. For example, when the growth functions of fishes I and II have a non-concave shape or when the growth function of fish I is concave and some part of the growth function of fish II is non-concave, propositions 3 and 4 may still hold.

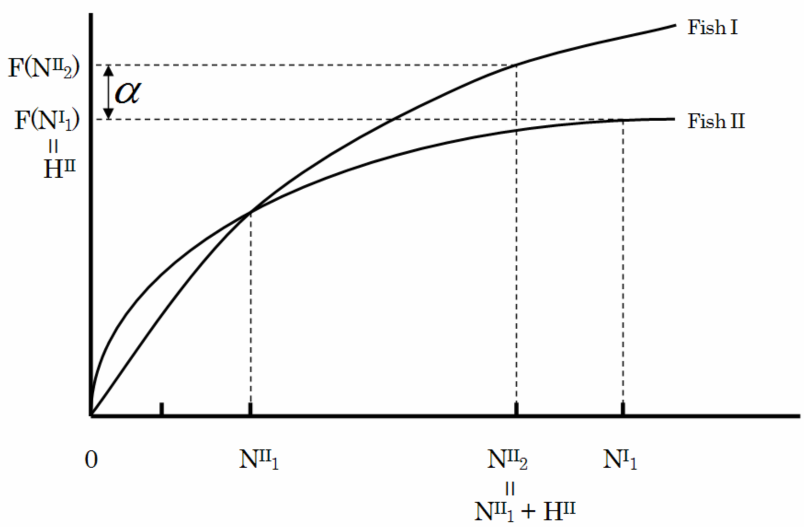

Fig. 3 Diagonal explanation of proposition 4

Proof

For simplification, let us examine the situation where N^{II}_1 coincides with the resource level at which growth curves I and II intersect (see Fig. 3). Suppose condition I is satisfied. It will suffice to show that condition II is also satisfied. Since the initial resource level of fish II is N^{II}_1 and the amount of harvest at t = 1 is 0, the resource level at the beginning of t = 2 is $N^{II}_2 = N^{II}_1 + H^{II}$, while the amount of growth during t = 2 is $F(N^{II}_2)$. Note that the growth curve of fish II is above that of fish I. Therefore, we obtain the following equation: $F(N^{II}_2) = H^I + \alpha$ (Fig. 1). If $\alpha > 0$, condition II is satisfied.

3.4. When the Daily Amount of Fishing Is Not Limited—Removing Assumption 2

In this section, we examine the situation where we remove assumption 2 while keeping assumption 1. We should separate the two cases. In a case when resource recovery is possible, the time required will be shortened. In a case when resource recovery is unlikely, the resource recovery might still be possible. In the latter case, it is an empirical issue in which resource recovery becomes possible, and it should be examined numerically.

As we have stated, Kawata and Kitano (2007) empirically exhibited a method to recover fish without reducing the amount of the harvest. As examined, when two bastard species exist, the time required to recover the fishes' population could be shorten by combining the method in this paper and that presented in Kawata and Kitano (2007).

4. Concluding Remarks

If it is possible to recover over-exploited fishery resources without reducing landings levels, then fishery resource management incentives may be improved and made more effective. We have demonstrated that given two types of fish that have different habitats and growth functions, but are similar in other aspects such as price, consumer perceptions and fishing methods, the desired resource level might possibly be recovered without reducing the number of landings. This will be accomplished by alternating the harvesting of the two fishes, such that only one fish will be harvested each year.

In the real world, many uncertainties exist that make it difficult to apply our method or the desired result of the application cannot be realized. We must take into account the fact that many fishermen cannot afford to reduce their landings, even for a few years, or are strongly opposed to reducing their landings for other reasons. That said, our method could make resource recovery projects more attractive and encourage more fishermen to participate.

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