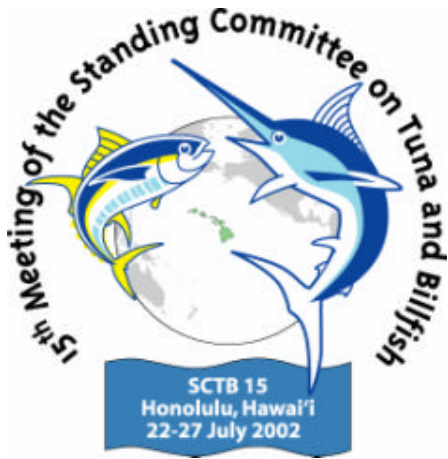
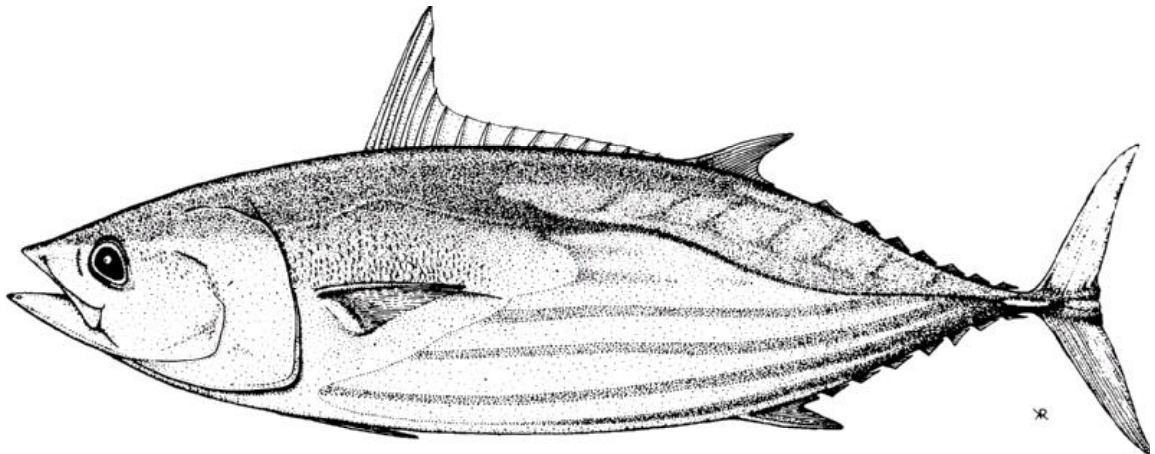


## MWG- 3



### Fundamental limitation of TAC as the goal of fishery management



**C.H. Wang**

Institute of Oceanography  
National Taiwan University  
Taipei, Taiwan, ROC

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C.H. Wang

Institute of Oceanography

National Taiwan University

## **ABSTRACT**

TAC, total allowable catch, is always setting to be the goal of fishery management. No matter what TAC is taken to be the goal of fishery management, some fundamental limitation of TAC is required. Generally, dome shape is used to express the relationships between the biomass and net production. There is unique point of biomass having the maximum net production (BMNP). This paper attempts to show that convergent area exists only as biomass larger than BMNP. In convergent area, it is possible to choose a TAC as the goal of fishery management. When biomass is lower than BMNP, they are divergent. In divergent area, any TAC setting to be the goal of fishery management might be failure. Based on Schaefer's surplus production model, this fundamental limitation of TAC can be proved theoretically.

**Keywords:** fundamental limitation of TAC, Schaefer's model, fishery management

## 1. Introduction

Due to compensation, the dome shape is commonly used to express the relationships between the net production and the biomass. As shown in Figure 1, it has a point with the maximum net production (MNP). On the right side of this point, it is of under fishing. Due to compensation, lower biomass always has larger net production. Contrary, on the left side of this point, larger biomass always has larger net production. One of the main purposes of fishery management is target on maintaining the biomass always having the maximum net production (BMNP). If catch is maintained equal to MNP, then this is the maximum sustainable yield (MSY) of fish stocks. In order to exploit the stock sufficiently and avoid the collapse of that fish stock, it needs to set a goal of fishery management. Generally, TAC (total allowable catch) is always taken to be the goal of fishery management. However, some fundamental limitation of TAC should be noticed in fishery management.

## 2. Fundamental limitation of TAC

Due to dome shape of the curve shown in Figure 1, there are two points corresponding to the same net production except the point of biomass having MNP (BMNP). No matter what TAC is taken, if any fixed TAC is taken to be the goal of fishery management, then one of the following cases could be faced to.

If  $TAC > MNP$ , then population will collapse due to continuous decreasing of the biomass. The larger of TAC implies more rapid of the collapse of the fish stocks. Therefore,  $TAC \leq MNP$  is necessary.

1. If  $TAC < MNP$ , then theoretically there are two equivalent catch points can be found, say  $TAC = P_1$  at biomass  $B_1 < BMNP$  and  $TAC = P_2$  at biomass  $B_2 > BMNP$ . Unless we can meticulously and continuously manage the biomass just at equilibrium, three following cases might be happen.
  - 2-1: If  $TAC = P_2$  with  $BMNP < B_2 < K$ , then it is a convergent point. Any discrepancy of biomass decreasing to  $B < B_2$ , biomass will increase continuously and converge to  $B_2$  due to the net production  $P > TAC$ . Contrary, any discrepancy of biomass increasing to  $B > B_2$ , biomass will decrease continuously and converge to  $B_2$  due to the net production  $P < TAC$ . Hence,  $B_2$  is a convergent point.  $BMNP < B_2 < K$  is convergent area. Any TAC setting at this area could be a successful goal of fishery management.
  - 2-2: If  $TAC = P_1$  with  $BMNP > B_1 > 0$ , then it is a divergent point. Any discrepancy of biomass decreasing to  $B < B_1$ , biomass will decrease continuously and converge to zero due to the net production  $P < TAC$ . This is the collapse of fish stock. Contrary, any discrepancy of biomass increasing to  $B > B_1$ , biomass will increase continuously and converge to  $B_2$  due to the net

production  $P > TAC$ . Hence,  $B_1$  is a divergent point,  $BMNP > B_1 > 0$  is divergent area. Any TAC setting in this area will be a failure goal of fishery management.

2-3: BMNP is a critical point. If  $TAC = MNP$  then any discrepancy of the biomass increasing to  $B > BMNP$  implies that biomass will decrease continuously and converge to BMNP due to the net production  $P < TAC$ . On the other hand, any discrepancy of the biomass decreasing to  $B < BMNP$ , biomass will decrease continuously and approach zero due to the net production  $P < TAC$ . Hence, BMNP is a critical point. It is divergent if  $B < BMNP$ , and convergent if  $B > BMNP$ .

As stated above, Taken some TAC as the goal of fishery management should be carefully. If the biomass corresponding to TAC is unfortunately lower than BMNP, then it might be a failure decision making of fishery management. Evenly, it might be one of the main reasons of the collapse of fish stocks. On the other hand, if fortunately it is setting TAC at  $B > BMNP$ , then it could be a successful decision making of fishery management.

Since BMNP is a critical point, it is not a good choice of the goal of fishery management. In this case, any discrepancy of the biomass with  $B < BMNP$  might cause the collapse of the fish stocks due to the net production  $P < TAC$ .

Conclusively, the biomass with  $K \geq B \geq BMNP$  is the fundamental limitation of the choice of TAC as the goal of fishery management.

### 3. Theoretical proof

Schaefer's surplus production model (Schaefer 1954) was extensively used in assessing fish stocks and fishery management. Under fishing, it can be given as follows.

$$f = \frac{dB}{dt} = rB\left(1 - \frac{B}{K}\right) - FB = (r - F)B - \frac{r}{K}B^2 \quad (1)$$

Equation (1) can be rewritten as follows.

$$f = -\frac{r}{K}\left[B - \frac{K}{2}\left(1 - \frac{F}{r}\right)\right]^2 + \frac{rK}{4}\left(1 - \frac{F}{r}\right)^2 \quad (2)$$

This implies that maximum net production  $MNP = f_{\max} = \frac{rK}{4}\left(1 - \frac{F}{r}\right)^2$  can be

obtained as biomass at  $B = \frac{K}{2}\left(1 - \frac{F}{r}\right)$ . If  $F = 0$ , then  $MNP = rK/4$  is obtained

at  $B = K/2$ . If catch is maintained just equal to MNP, i.e.,  $Y = rK/4$ , then this is the basic concept of the maximum sustainable yield (MSY).

For the general case, biomass under fishing could be expressed as follows

$$B = aK(1 - \frac{F}{r}) \quad (3)$$

Here,  $a$  is the index of relative biomass and  $0 < a \leq 1$ . Correspondingly, the net production and catch under fishing can be given as follows.

$$f = rB(1 - \frac{B}{K}) - FB = arK(1 - \frac{F}{r})^2(1 - a) \quad (4)$$

$$Y = FB = FaK(1 - \frac{F}{r}) \quad (5)$$

At equilibrium,  $Y = f$ , it implies that

$$FaK(1 - \frac{F}{r}) = arK(1 - \frac{F}{r})^2(1 - a) \quad (6)$$

$F=r$  or  $a=0$  is the extinction status, both are meaningless in fishery management. Therefore, equation (6) can be rewritten as follows.

$$F = r(1 - \frac{F}{r})(1 - a) \quad (7)$$

Solved equation (7) for  $F$ , it implies that

$$F_{eq} = \frac{r(1 - a)}{2 - a} \quad (8)$$

This is the fishing mortality rate of catch at equilibrium. It is depending on the index of relative biomass and the intrinsic growth rate. Since  $0 < a \leq 1$  by definition, it implies  $0 < F_{eq} \leq r/2$ . For example, if  $a=1/2$ , the case of MSY, then  $F_{eq} = r/3$

(Wang 1996). For the extreme case,  $F_{eq} = 0$  for  $a=1$ ,  $F_{eq} = r/2$  for  $a=0$ .

Equation (8) implies a serious warning about the decision making of fishery management. The equivalent catch point can be obtained only if the fishing mortality rate is still lower than the half of the intrinsic growth rate. If the fishing mortality rate has been larger than the half of the intrinsic growth rate, then no equivalent catch could be obtained. Therefore, any decision making of taken a goal of fishery management with  $r > F_{eq} > r/2$  is very dangerous in conservation of fish stocks, because of no equivalent catch point could be found.

As stated above, if Schaefer's model is acceptable in fishery science, then theoretically the equivalent catch point could be obtained only if  $r/2 \geq F_{eq} \geq 0$ .

Generally,  $r/2 \geq F_{eq} \geq 0$  means that the stock is still of under fishing. This is consistent with the case of the biomass at  $K/2 \leq B \leq K$ . It proved that the convergent point could be obtained only if biomass at  $K/2 \leq B \leq K$ .

## Discussion

As stated above, this is a puzzle to fishery science. Generally,  $r > F_{eq} > r/2$ , means the over fishing of the fish stocks. Fishery management is necessary, but no equivalent catch point could be found. In this case, how to chose a sustainable yield as the goal of fishery management? It seems an interesting problem about decision making of fishery management. On the other hand, although equivalent catch point can be found in  $r/2 \geq F_{eq} \geq 0$ , however it implies that the stock is still under fishing. In this case, fishery management is generally unnecessary or at least it is not so urgent.

When  $r > F_{eq} > r/2$  and if fishery management is required, then there are two another suggestions could be considered. One might be maintaining the biomass always having the maximum net production. It is mainly basing on the biological consideration. The biomass having the maximum net production could be considered as the best density of the stock. Maybe it is one of the important purposes of fishery management. In this case, unique equivalent catch point could be obtained (Wang 1996). It could be one of the choices of the goal of fishery management. However, it is still based on the assumption of the constant environmental conditions.

Hilborn and Walters (1992) showed that total allowable catch would be adjusted from year-to-year, due to the fluctuation of the environmental conditions. The problem is how to adjust it. Wang (2001) suggested a useful method for maintaining  $d_t = m_t - F_t$ , the difference between the net production rate  $m_t$  and fishing mortality rate  $F_t$ , always in positive and as small as possible. The positive difference means that net production rate is always larger than the fishing mortality, i.e., biomass always in increasing status. It is useful and helpful for the conservation of the populations under the uncertainty and instability of the environmental conditions. The smaller difference means to exploit the fish stocks as more sufficient as possible.

No matter what policy of fishery management we want, there are two basic purposes we need keeping in mind. First is the demand of human's food. Second is the conservation of fish stocks. Due to human's demand, the fishing could be kept

going on. If the biomass is still in better condition, then the goal of fishery management should be mainly target on the sufficient exploitation of the fish stocks. Zero of the difference means the catch at equilibrium. Contrary, if the biomass has been in worse condition, then the fishery management should be mainly target on the conservation of the fish stocks. The larger difference implies the increasing of stock more quickly. Extremely, all of fishing behavior should be ceased completely.

## Conclusions

Only convergent point could be considered as the goal of fishery management. However, convergent point could be found only if the biomass is larger than the half of the carrying capacity. Hence, any TAC taken to be the goal of fishery management should be lower than the maximum net production and with the biomass larger than the half of the carrying capacity. This is the fundamental limitation of the decision making of TAC.

Theoretically, it can be proved that equivalent catch point could be found only if the fishing mortality rate varied in the ranges of  $r/2 \geq F_{eq} \geq 0$ . Based on Schaefer's model, this is consistent with the case of biomass  $K/2 \leq B \leq K$ . This is a puzzle to fishery science. If  $r > F_{eq} > r/2$ , it is over fishing, fishery management is necessary, but no equivalent catch point could be found. If  $r/2 \geq F_{eq} \geq 0$ , equivalent catch point can be found. However, it is still of under fishing, fishery management is unnecessary or at least it is not so urgent.

If fishery management is required for the case of  $r > F_{eq} > r/2$ , then two another methods could be considered. For the stable environmental conditions, fishery management should be target on maintaining the biomass always having the maximum net production. In this case, there is unique equivalent catch point could be found. This is naturally one of the best choices of the goal of fishery management. Another one is keeping the difference between the net production rate and fishing mortality rate always in positive and as small as possible. The size of the difference is depending on the current status of the biomass.

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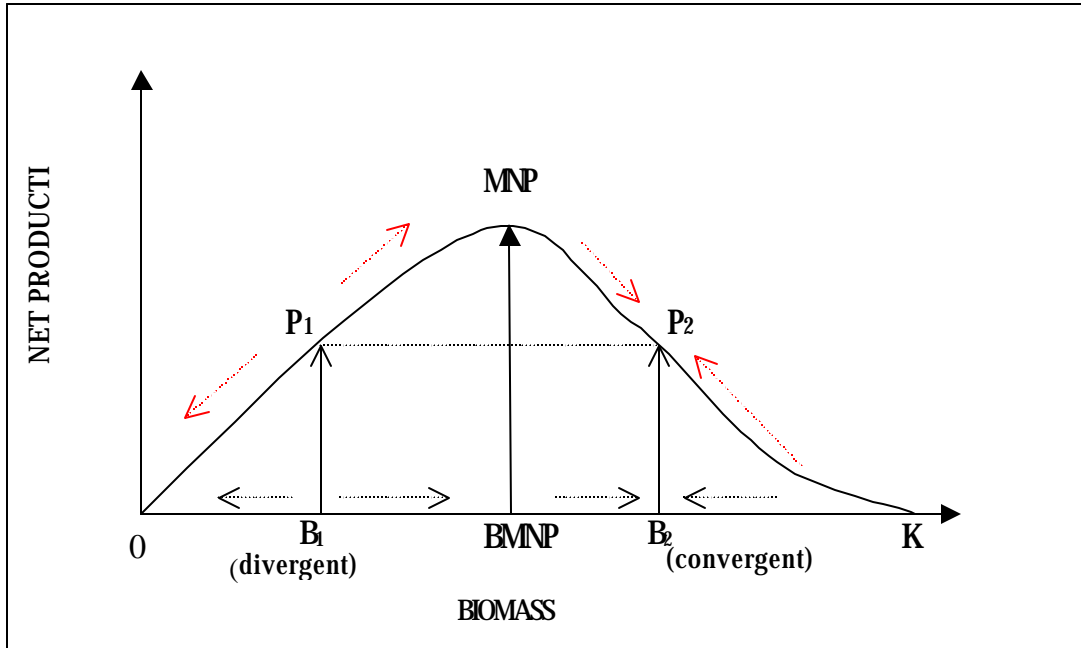


Figure 1. The relationship between biomass and net production.