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A simple model for evaluating the costs and benefits of aquatic macrophytes

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Abstract

Dense beds of aquatic macrophytes often cause nuisance to boaters and swimmers, and may obstruct water flow. Management of aquatic vegetation is, therefore, often aimed at reducing the biomass of the plants. If the nuisance is caused by exotic invasive species, there usually is no controversy with nature conservation aims. In shallow lakes, however, the interests of recreational users may conflict with nature conservation because the promotion of indigenous submerged vegetation is considered an important tool for lake restoration. Aiming at intermediate vegetation biomass seems a good solution for this controversy at first sight. However, we argue that such a compromise is often not the best policy from a welfare economic point of view. We present preliminary results of a graphical model, showing that the overall benefit for all ecosystem users may be minimal at the intermediate vegetation biomass. Furthermore, even if there is an optimal benefit at an intermediate macrophyte biomass, we argue that it is may not always be feasible to force the vegetation biomass to the desired level. Due to ecological feedback mechanisms, the system can have two alternative stable states: one with high vegetation biomass and one with little or no vegetation. It is concluded that it will often be better to realise a management strategy aimed at keeping some lakes (or parts of lakes) free of aquatic plants, whereas allowing others to be densely vegetated.

Introduction

Dense beds of macrophytes can be a nuisance for boating, fishing, swimming in lakes and may obstruct the water flow in irrigation channels. Therefore, aquatic weed control is the topic of much research (e.g. Caffrey & Wade, 1996) and management of aquatic vegetation is often aimed at reducing the biomass of vegetation. If the nuisance is caused by exotic invasive species, there usually will be no controversy with nature conservation aims, as these species are a threat for native species (De Winton & Clayton, 1996).

In many shallow lakes, however, lake managers are trying to restore the vegetation that vanished as a result of eutrophication, which has led to turbid water and cyanobacterial blooms. Establishing a stable aquatic vegetation is considered a very important tool to restore eutrophic lakes (Crawford, 1979; Perrow et al., 1997a; Scheffer, 1998). The main benefit of an abundant vegetation is that vegetation reduces turbidity in shallow lakes (e.g. Hasler & Jones, 1949; Timms & Moss, 1984; Van den Berg et al., 1998). Also, bird abundance and biodiversity of many groups of animals is usually higher in vegetated lakes (Scheffer, 1998).

Aiming at an intermediate biomass of macrophytes seems the obvious solution to restore lakes without

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causing nuisance, as shown by the graphical model of Clayton (1999). In this paper, we present an extension of this model, which shows that such compromise is not always the optimal policy (i.e. the policy that maximises the mean benefit for all ecosystem users).

A graphical model of the costs and benefits of aquatic vegetation

Aquatic macrophytes are of importance to several different groups of ecosystem users, for example people interested in nature conservation, recreational users, farmers and boaters. The interests of these groups often conflict, but it is hard to compare the interests of these different groups. We use the approach of environmental economists to account for all interests in a common unit, namely ‘welfare’ or ‘benefit’ (Hanley & Spash, 1993; Varian, 1996; Perman et al., 1996). Environmental economists have ways to quantify the welfare of different groups including the value of environmental services (e.g. Carson & Mitchell, 1993; Dixon et al., 1994). Determining detailed quantitative welfare functions is beyond the scope of this paper; we will only discuss qualitatively different possibilities.

In our simple model we included the welfare functions of two groups of users:

1. Nature conservationists aiming at the restoration of eutrophic waters. In general, this group promotes indigenous macrophytes, possibly up to an optimum level, above which dense macrophyte beds could have a negative impact on biodiversity, water quality and conservation values. This group includes recreationists that are interested in nature: ‘eco-recreation’.
2. Recreational users that are hindered by dense vegetation. This group includes boaters, wind surfers and swimmers.

Of course there may be more groups of stake holders involved in many lakes. For simplicity, we ignore these groups in the current analysis, but our approach may be extended to include any group whose welfare depends in a known way on vegetation abundance in the lake. For simplicity, we also ignore in the welfare function of biomass harvesting costs and other costs to maintain biomass at a desired level.

In our model, the welfare functions of both groups link the biomass of vegetation to the benefit or cost of these two ecosystem users. The welfare functions are defined as functions ranging from 0 (minimal benefit or maximal nuisance) to 1 (maximal benefit or minimal nuisance). The overall welfare of the society is composed of the contribution from welfare by users in each group, weighted by the number of individuals in that group.

The optimal strategy from a ‘rational social planner’s’ point of view is to aim at the biomass where the total welfare function is optimal.

For restoration of eutrophic lakes, the benefit of aquatic vegetation is strongly connected to the effect of macrophytes on turbidity and vice versa. Although the exact shape of especially the clearing effect of vegetation is yet unclear, the positive feedback of macrophytes on their own growth is known to cause alternative stable states (Scheffer, 1998). If a lake has alternative stable states, the benefit of vegetation is typically a threshold function. Below a certain biomass, the vegetation is not able to cause a shift from the turbid state to the clear water phase. The exact value of the critical biomass is not only dependent on the trophic state of the ecosystem, but also on the growth form of the macrophytes. Most beneficial are probably low growing species like charophytes (Crawford, 1979; Clayton & Tanner, 1988; Coops & Doef, 1996). Besides the clearing effect of macrophytes, there are also other benefits associated to macrophytes, such as an increase of habitats for invertebrates (e.g. Hargeby et al., 1994) and food sources for birds (e.g. Perrow et al., 1997b) and fish (e.g. Van Donk et al., 1994). These effects are probably more gradual. The total nature benefit of most types of indigenous macrophytes is probably most appropriately characterised by an increasing sigmoidal curve (Figure 1b, solid line).

The nuisance caused by aquatic plants for recreational users increases with macrophyte biomass. To our knowledge, the shape of this nuisance function has not yet been assessed. It seems reasonable, however, to assume a sigmoidal curve for this function also. Below a certain biomass level, boating and swimming is not hindered. If the vegetation stands exceed a certain density, and especially if the plants cover the water surface, vegetation becomes a nuisance (Figure 1 b, dotted line). The growth form of the macrophytes is important for this group too. The tolerance of recreational users for low growing species will be higher than for floating or canopy forming species.

Hill functions offer a convenient way to model such welfare functions. The Hill function has two parameters: the half saturation H which defines, in our case, the biomass (B) of plants where the welfare (w) is 0.5 and the exponent p which defines the steepness

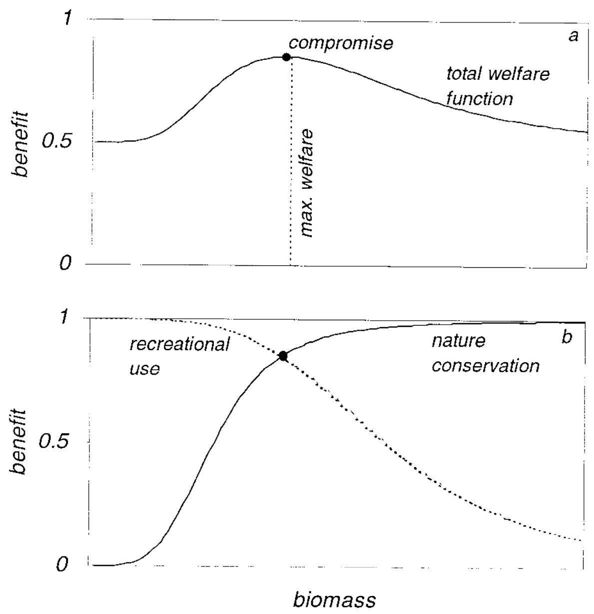

Figure 1. Vegetation with a low growth form. (a) the total welfare function (mean of functions in lower panel). The point with a compromise between both groups (closed circle) coincides with the maximum total welfare. (b) functions of benefit for recreational use and nature conservation.

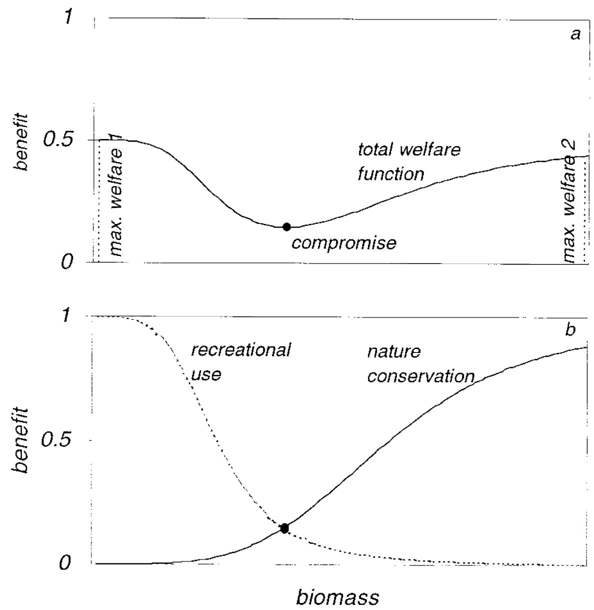

Figure 2. Canopy forming or floating vegetation. (a) the total welfare function (mean of functions in lower panel). The point with a compromise between both groups (closed circle) coincides with the maximum total welfare. (b) functions of benefit for recreational use and nature conservation.

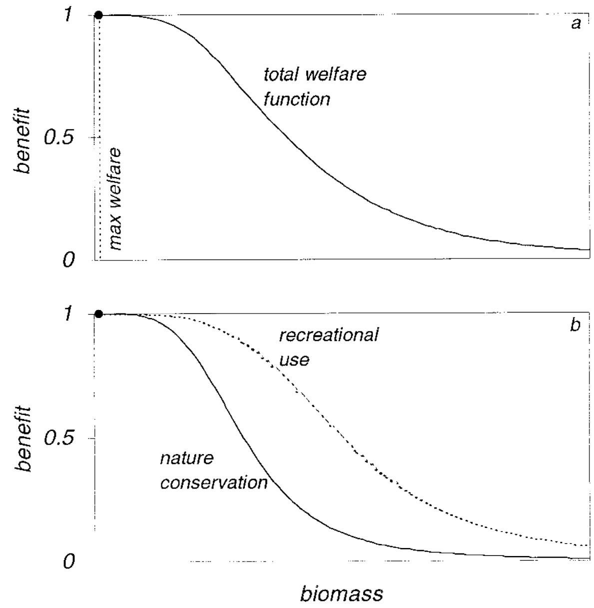

Figure 3. Exotic invasive species. (a) the total welfare function (mean of functions in lower panel). The point with a compromise between both groups (closed circle) coincides with the maximum total welfare. (b) functions of benefit for recreational use and nature conservation. Both groups have the same interests, the target of the management should be control (or eradication) of the plants.

of the function:

$$w = \frac{B^p}{H^p + B^p}.$$

This increasing function can be mirrored to become a decreasing function by changing it the following way:

$$w = \frac{H^p}{H^p + B^p}.$$

We explored the effect of different combinations of welfare functions on the resulting total welfare. For simplicity, we give both user groups an equal weight. Several different situations may arise, of which we highlight three examples in our analysis: 1. Vegetation with a low growth form (Figure 1). The benefit of low growing plants for water quality is relatively large, whereas the nuisance is relatively low. Therefore, the half saturation of nature benefit is assumed to be lower than the half saturation of recreational nuisance. This large overlap in welfare functions causes an optimum in total welfare at intermediate vegetation densities. Thus, the compromise between both types of ecosystem users coincides with an optimum overall welfare and aiming at intermediate biomass seems the optimal policy in such a case. 2. Canopy forming or floating vegetation (Figure 2). This type of vegetation causes more nuisance for boating and swimming and is less beneficial for lake restoration. As a result, a moderate amount of such plants may be too much from a recreational point of view and insufficient from a nature conservation point of view. In the model, we represent this by setting the half saturation of nature benefit higher than the half saturation of recreational nuisance. This causes the total welfare to be at minimum at an intermediate biomass. Compromising between both groups is obviously a bad policy in this case, provided that the same strategy is applied to the entire water body. Designing separate areas for recreation and nature conservation can a better policy in such situations, if free-floating species are not dominant. 3. Vegetation dominated by exotic invasive species (Figure 3). As mentioned before, usually the interests of nature conservationists and recreationists do not conflict in this case. We have mirrored the Hill function of nature conservation to represent this. The exact shape of the curves and the value of the half saturation coefficients is not essential in such situation. The optimum policy is always to eradicate the species.

In conclusion, aiming at an intermediate vegetation biomass is only a good strategy for maximising overall welfare in a limited class of cases (Figure 1).

Discussion

Whether or not aiming at an intermediate vegetation biomass is a good policy from an environmental economist's point of view, depends on the way in which welfare of different groups of lake users varies with vegetation biomass and the cost of harvesting biomass or other management costs. For a thorough analysis, one would need to assess the actual shape of these curves to analyse any field situation in practice and the management characteristics. However, our analysis shows that, at least, the qualitative point can be made that a compromise with intermediate vegetation biomass will only lead to a high average welfare for all users of the lake in a limited subset of cases.

Obviously, the benefit curves will not always have the shape as presented in our model. The Hill curves that we used in our model are not appropriate to describe all complex relations that exist in reality. We disregarded the fact that very high biomass levels of canopy forming and floating vegetation can have a detrimentally impact on water quality, biodiversity and conservation values. The benefit curve of nature conservation will have an optimum then. Furthermore, the nature value of a water body that is dominated with exotic species can still have a substantial value for nature conservation. Again, there will be situations where an optimum curve would be a better description. For clarity, and because we lack detailed information on the real shape of the benefit curves, we presented these simplified relationships.

Another aspect that we did not consider in the current benefit analysis is that loss of vegetation usually invokes algal blooms in shallow eutrophic lakes. For swimmers and other recreational users that often complain about high vegetation biomass, such algal blooms would also cause a nuisance (Herath, 1997; Boggess et al., 1997). This implies that recreational users may wish for a situation (a clear lake with little vegetation) that is ecologically impossible under the high nutrient conditions. With our model, it would mean that recreational users really have a more complex welfare function: aiming at the lowest biomass that is sufficient for preventing algal blooms that would yield the highest welfare for recreational users in this case. Also, in reality, recreational users are a diverse group with often conflicting interests. For instance, power boating is incompatible with many other recreational activities (Nuttall & Richardson, 1989).

An interesting feedback could result from damage to aquatic vegetation by recreational users, which is observed frequently (Murphy & Eaton, 1983; Best, 1987; Mumma et al., 1996). Murphy & Eaton (1983) showed that heavy pleasure-boat traffic can even be a principal factor in suppressing macrophyte abundance in British canals. In such cases, it is likely that recreational users have a positive effect on the suitability of the water for recreation, implying a potential positive feedback in recreational use, which could lead to alternative stable states. Moreover, Murphy & Eaton (1983) found a critical level of boat traffic above which the macrophyte community was affected. This is a further indication that there could be alternative stable states (Scheffer, 1998). This phenomenon would be a much like the maintenance of 'grazing lawns' in which invasion by large unpalatable (hindering) plants is prevented by intense use by terrestrial and aquatic grazers (McNaughton, 1984).

From the environmental economic analyses, we concluded that, in certain situations (with low growing macrophyte species), the optimal management strategy could be to aim at intermediate biomass. However, if the system has alternative stable states (Scheffer, 1990; Scheffer, 1998), it will be impossible to set vegetation to any desired level. The vegetation biomass could suddenly drop to zero after a certain critical biomass is exceeded. One should, therefore, keep in mind that the best policy economically may not be feasible due to ecological constraints.

In conclusion, environmental economic aspects suggest that aiming at intermediate vegetation biomass is only a good policy for maximising overall welfare of different types of lake users in a limited number of situations. An example of such a situation is for vegetation with a low growth form, as illustrated in Figure 1. In situations where recreation and nature conservation are competing, a compromise can be better achieved by assigning lakes or parts of lakes to recreational use and other areas for nature conservation. Alternatively, a selective control of submerged macrophytes aimed at a shift in the species composition towards low growing species could be a good solution for the controversy.

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