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# Management procedures required to increase chironomid availability to waders feeding on artificial lagoons remain unclear

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## Summary

1. Rehfishch (1994) made various recommendations for how to increase chironomid biomass and its availability to waders in artificial lagoons. We argue that his studies form an insufficient basis for some of these recommendations.
2. He suggested protocols for depth manipulation based on a model predicting biomass in terms of depth and depth squared which was not a meaningful representation of his data. This model should therefore not be used as a guide for managing water levels.
3. He predicted that biomass would peak at a depth of about 117 cm, yet he only studied depths of up to 54 cm. We used data from a large, permanent, brackish lake to illustrate how biomass at shallow depths cannot be used to predict that found at greater depths.
4. His aim of a simple model allowing managers to predict chironomid biomass on the basis of depth in artificial lagoons was unrealistic, owing to wide variation in the biomass–depth relationship within and between sites.
5. The value of his ‘inverted sombrero’ design for a wader lagoon needs to be demonstrated empirically. He advocated regular drying-out of lagoons followed by immediate refilling, a flooding cycle that may not maximize chironomid biomass.

*Key-words:* Chironomidae, man-made lagoons, habitat management, water depth.

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Rehfishch (1994) provided a useful study of the biotic and abiotic factors influencing chironomid biomass in artificial, brackish pools managed specifically for waders at Blacktoft Sands in the Humber Estuary, England. However, we are concerned that he went too far when suggesting ‘easily applicable routines for increasing the biomass and productivity of a predominantly chironomid fauna’ (p. 383). We believe that some of his recommendations for improving reserve management in order to increase chironomid availability to waders are misleading, and may induce managers to adopt ineffective measures. We feel that the data set utilized and the analyses presented by Rehfishch (1994) are insufficient to justify all his conclusions.

Rehfishch (1994) presented an inappropriate analysis of the relationship between chironomid biomass and water depth. He used multiple regression to demonstrate conclusively that, in his study site, total chironomid biomass increases with increasing depth and

decreasing organic matter content of the substrate. He then went on to present ‘a simple model of more immediate use to a reserve manager for controlling the water depth in each lagoon’ (p. 383), which relied on water depth as the only independent variable. In Table 10, he presented a quadratic model relating total biomass  $b$  ( $\text{g m}^{-2}$ ) to water depth  $w$  (cm):

$$b = 0.32467 + 0.11239w - 0.00048w^2.$$

The above equation did not provide a useful fit to the available data, since the partial effect of  $w^2$  was nowhere near statistically significant ( $t = 0.43$ , 103 d.f.,  $P > 0.5$ ) and the partial effect of  $w$  was only weakly significant ( $P < 0.05$ ). Using the standard errors of Table 10, we calculated 95% confidence intervals for the regression coefficients, which indicated that the depth at which biomass peaked could lie anywhere from 1.6 cm to infinity. The above model therefore forms no sound basis for predicting real

values of  $b$  at Blacktoft Sands or anywhere else. A more satisfactory model for Rehfish's data was a simple regression between  $b$  and  $w$ , which he presented in Table 4 ( $r = 0.47$ ,  $P < 0.0001$ ).

According to the above quadratic equation,  $b$  peaked at  $w = 117$  cm, decreasing again at greater depths. As we have seen, neither the existence nor the position of this turning point is supported statistically, yet Rehfish (1994) gave it importance by recommending that 'reserve management should aim to keep the lagoons flooded to their maximal depths until used to attract feeding waders, as up to about 1.17 m, the greater the mean water depth over the year the greater the benthic invertebrate biomass' (pp. 394–395). Even if the above quadratic equation was statistically robust, it would still be imprudent to assume that there was a turning point at around 117 cm, since Rehfish (1994) was only able to collect samples over the depth range 0–54 cm. As he himself pointed out, 'predictions should only be made within the range of water depths found in the study area, as at greater depths overcrowding, reduced oxygen levels due to thermoclines, and the presence of new predator communities, such as fish which require water depths of over 1.7 m to establish themselves (Street 1989), would act as limiting factors' (p. 394).

To illustrate how analyses of data from shallow depths cannot be used to predict chironomid biomass at greater depths, we analysed data on chironomid biomass from Burdur Lake, a large, deep, permanent, brackish lake in Turkey (Green *et al.* 1996). From 10 February to 4 March 1993, benthic invertebrates were sampled twice at each 20-m interval along 200-m transects perpendicular to the shore at nine locations around the lake (Green *et al.* 1996). Samples were taken from a boat using an Eckmann Grab and washed in sieves of 1 mm and 0.25 mm square mesh. Dry mass of chironomid larvae in each sample was measured after storage in 70% methanol for 1–8 days.

Samples were collected from depths of up to 21 m (Fig. 1), and fitting an equivalent quadratic model to the whole data set produced a satisfactory fit to the data, in which both  $w$  and  $w^2$  were highly significant (Table 1). According to this equation, biomass peaked at the turning point  $w = 11.2$  m, and then declined. Using the standard errors to calculate confidence intervals for the regression coefficients of Table 1, the true value at which biomass peaked was found within the range 7.3–17.7 m with a probability of 0.95.

However, fitting a similar model to a reduced data set of our samples taken at shallow depths of 0–2 m produced a completely different, U-shaped relationship in which neither  $w$  nor  $w^2$  had statistically significant partial effects, and biomass reached a minimum at the turning point  $w = 4.4$  m, with a higher biomass at lower and higher depths (Table 1). This illustrates how fitting a quadratic model at shallow depths does not help to predict the real relationship between  $w$  and  $b$  at greater depths. However, this is

precisely what Rehfish (1994) attempted, albeit for a very different wetland.

Even when sampling over a wider depth range, we believe that a model as simple as that presented by Rehfish (1994) relating  $b$  to  $w$  and  $w^2$  cannot provide reserve managers with an effective guide to manipulating water depth, even at the site where this model was developed. A more sophisticated approach is required to account for the considerable annual and seasonal fluctuations at a given site in the relationship between  $w$  and  $b$  (including the depth at which  $b$  peaks), which have been demonstrated in a wide range of wetland types (Forsyth 1986; Sephton & Paterson 1986; Kajak 1988; Carter & Murphy 1993). For example, Rehfish's model takes no account of the important influence of depth fluctuations (i.e. functions of past depth) on chironomid biomass. Rehfish (1994) rightly argued that the timing of lagoon flooding has a major influence on the speed with which chironomid biomass increases, owing to the seasonality of chironomid oviposition. However, his models relating  $b$  to  $w$  and  $w^2$  only included annual means of  $b$  and  $w$  (one for each of two study years) at each sampling point, ignoring the timing and extent of depth fluctuations and the importance of seasonal and annual variations.

At a given study site, the relationship between  $b$  and  $w$  can also change with fluctuations in the structure of the chironomid community. McLachlan (1970) found that fluctuations in water levels at Lake Kariba were accompanied by major changes in the species composition of benthic chironomid community, and in the relationship between  $w$  and  $b$ . Likewise, Rehfish (1994) recorded changes in the chironomid community at his study site, since *Chironomus annularius* 'was in the process of colonizing the lagoons and uncommon during the first study year' (p. 387), but much more abundant during the second and final study year. However, Rehfish (1994) did not say whether or not these observed changes affected the relationship between  $w$  and  $b$ .

Rehfish (1994) argued that his simple model developed at Blacktoft Sands could be used as a basis for lagoon management at other sites, at least in the UK (p. 396). However, even a sophisticated model developed at one site to predict chironomid biomass on the basis of depth would not be readily applicable to other wetlands. For a given community of chironomid species,  $b$  is in fact directly determined by oxygen supply, temperature and organic food supply (Brinkhurst 1974; Kajak 1988), as well as by salinity (Velasquez 1992), sediment stability and wave action (McLachlan & McLachlan 1969; Lindegaard & Jonasson 1979; Forsyth 1986; Sephton & Paterson 1986). It is the correlations between these variables and  $w$  which determine the relationship between  $w$  and  $b$ . As a result, this relationship is likely to vary greatly, even between different shallow lagoons in the UK. The variation across a range of wetland types is illustrated

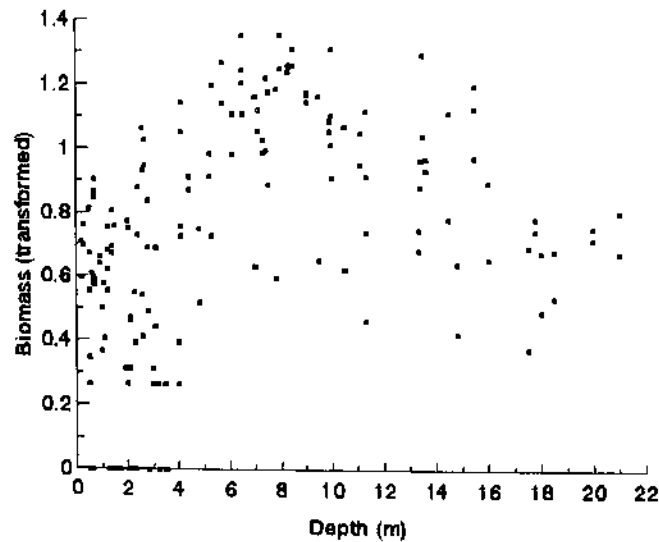


Fig. 1. Chironomid biomass [ $(\text{g m}^{-2})^{0.25}$ ] against depth (m) at Burdur Lake, Turkey, in February–March 1993.

Table 1. Multiple regression of total biomass of chironomid larvae  $b$  ( $\text{g m}^{-2}$ ) against water depth  $w$  (m) at Burdur Lake, presented for all data ( $w = 0\text{--}21$  m) and for shallow depths (0–2 m). The dependent variable is transformed ( $b^{0.25}$ ) to remove heteroscedasticity

	Intercept	$w$	$w^2$	$n$	$r^2$
All data	$0.2339 \pm 0.04537$	$0.1434 \pm 0.01436^{****}$	$-0.006383 \pm 0.0007878^{****}$	180	$0.4132^{****}$
$\leq 2$ m	$0.6542 \pm 0.1800$	$-0.3028 \pm 0.3638$	$0.03416 \pm 0.1582$	62	$0.1327^*$

The intercept and partial regression coefficients are given  $\pm$  SE.  $n$  and  $r^2$  refer to the overall model. Significance levels are given for the partial coefficients of  $w$  and  $w^2$ , and for  $r^2$ .  $^{****} P < 0.0001$ ;  $^* P < 0.05$ .

by the way that  $b$  has been found to peak at depths from 0.66 m (Vodopich & Cowell 1984) to 16 m (Graham & Burns 1983). Furthermore,  $b$  does not peak at intermediate depths in all wetlands. Iwakuma, Ueno & Nohara (1993) found no relationship between  $w$  and  $b$  over a depth range of 2–12 m, whereas Forsyth (1986) found  $b$  reached a trough at 5 m.

We also question Rehfisch's (1994) recommendation for an 'inverted sombrero' design for a wader lagoon, with a deep, permanent, central reservoir designed to boost chironomid biomass in shallows by promoting recolonization of newly flooded ground via larval migration from deep water. The value of such a reservoir needs to be demonstrated empirically, since adult oviposition may play a much more important role in the larval colonization of newly flooded areas than larval migration from deeper areas (McLachlan 1970; Sephton & Paterson 1986). Rehfisch (1994) found differences in the depth distribution of six different species of detritivorous chironomids. The value of a reservoir is therefore partly dependent on the extent to which deeper water species colonize shallow waters, an important issue not addressed in his paper. Such a reservoir could conceivably lower larval biomass in the shallows because of its unknown impact on predators or competitors of chironomids.

Rehfisch (1994) also recommended that dried lagoons should 'be refilled as quickly as possible' (p. 396) after drying out, thus reflooding dry mud. He did not fully consider the 'pros and cons' of reflooding temporary lagoons with or without allowing time for the dry basin to be colonised by terrestrial plants. Allowing sufficient time for the development of terrestrial vegetation may increase  $b$  upon reflooding, owing to the increased nutrient supply from the rotting vegetation (Kajak 1988). Such an effect led to a peak in  $b$  in reflooded shallows at Lake Kariba, Zimbabwe (McLachlan 1970). The potential for increasing chironomid biomass by allowing time for dry water lagoons to be colonized by terrestrial vegetation before reflooding should be investigated, although many wader species prefer to feed in bare mud than amongst rotting vegetation.

Furthermore, Rehfisch's (1994) stated view that 'drying out periods are essential as they [maintain] a chironomid-dominated early colonizer community' (pp. 395–396) is not applicable to all wetlands. Paterson & Fernando (1969) found that, in a drawdown reservoir,  $b$  was always lower in reflooded areas than in permanently flooded areas. Chironomids are dominant in the benthos of Burdur Lake despite its permanent nature (Green *et al.* 1996). High salinities can

be sufficient to stimulate chironomid-dominated benthic communities in shallow lagoons in the absence of drying out periods (Velasquez 1992).

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