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Biomass Production and Economic Value of *Phragmites australis* Reedbeds in the Southern Okavango Delta, Botswana

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ABSTRACT

Most work globally on *Phragmites* spp. has been done in temperate northern hemisphere localities, where winter low temperatures and short day lengths cause a seasonal decrease in growth. In this study, we report above-ground stem length-mass relationships, stem densities and daily growth rates in 3 *Phragmites australis* reedbeds in the flood-pulsed, subtropical Okavango Delta, with the aim of assessing the economic value of this plant, which is widely used throughout north-western Botswana for cladding house walls and fencing yards. Stem density averaged 77 m^{-2} in 32 plots. Length-mass relationships were best represented by a power function $y = 8.05x^{1.85}$, where y is the dry mass in grams, and x is the length in metres ($r^2 = 0.895$). The mean daily growth rate was 0.015 m and did not appear to vary systematically with season. The maximum standing crop calculated from stem length was 2.89 kg m^{-2}, and occurred in May 2005. Annual above-ground production was conservatively estimated at 20-30 t ha^{-1}. Assuming that harvesting takes place not more than once annually, reed beds in the Okavango Delta are worth ~US$ 45,000 ha^{-1} at market. This land use value is over 90 times that of flood recession agriculture in the same area.

Keywords: *Phragmites* reedbeds, standing stock, wetland resource value

INTRODUCTION

Phragmites is a genus of tall, perennial, emergent wetland grasses which can reach up to four metres in height. The perennial root structure is composed of an extensive underground network of rhizomes and stolons. From this root structure, aerial shoots can arise as frequently as at every node. It tolerates a range of water salinity – from freshwater to brackish – as well as a range of substrates and hydrologic conditions (Cronk and Fennessey 2001). Because of this versatility, *Phragmites australis* thrives as a native species on five continents (Haslam 2003).

Although *P. australis* is known to be sensitive to salinity (requiring levels of < 65 g/l Cl^-) (Hellings and Gallagher 1992; Adams and Bate 1999), this parameter is relatively constant in Okavango waters, with well-established gradients of salinity between channels, floodplains (surface water generally < 150 ppm) and island groundwater (> 150 ppm) (McCarthy *et al.* 1991, 1993; Cronberg *et al.* 1996; Bauer 2004; Wolski and Savenije 2006). Salinity is therefore unlikely to have a major influence on *P. australis* growth in the Delta. Nutrient levels are similarly generally low in Okavango surface waters: 0.072 mg/l total nitrogen, and 0.068 mg/l total phosphorus (Cronberg *et al.* 1996). Local nutrient status around reedbeds is not documented, but there is currently no evidence to suggest that reedbeds in the Delta differ significantly from the surrounding waters in terms of nutrient concentrations. It is likely, however, that the ability to maintain an aerobic rhizosphere, and to retain the bulk of senescent litter in a peaty substrate, are important competitive strategies in the nutrient-poor Delta waters (Ernst 1990; Armstrong *et al*. 1992).

P. australis is widely distributed in the Okavango Delta, and occurs both as a dispersed member of mixed communities of perennially flooded areas, and in dense, nearly mono-specific reed beds along the major distributaries. In such beds, channels may be flanked on one or both sides by reeds, which extend as the dominant species laterally away from the channel for up to 300 m. In northern Botswana, the reed is an important product used in the construction of houses (usually walls), for fencing the living area, and for weaving mats. To collect reeds, an individual would traditionally travel into the Delta in a dugout canoe and camp for a few days at a time. Because the reed beds are typically found on perennial, deeper channels, a minimum of one day's journey is needed to reach reed beds suitable for harvest. More recently, some people have access to motor boats, and when the water is deep enough, can carry more reeds than in a dugout canoe. The demand for and supply of reeds has increased over the last two decades, as the populations of settlements peripheral to the Delta have grown, raising questions about the sustainability of the resource. Sustainable management requires information on the production capacity of the resource as a necessary first step.

The aim of this study was to quantify the production and market value of *Phragmites australis* reedbeds in the distal Okavango Delta, to contribute to the development of sustainable management systems for wetland resources.

The specific objectives of this study were:

a) To obtain estimates for annual productivity of *Phragmites* in the distal Delta;
b) To obtain an economic value for *Phragmites* reedbeds in the distal Delta.

METHODS

Study sites

Sites were selected in three reedbeds in the middle reaches of the Boro distributary. These reedbeds were selected on the basis of their long-term hydrology: they are upstream of the limit of the perennial flow of the distributary (**Fig. 1**). Sites were selected within each stand based on random coordinates within a grid of the bed extent. In 2003, NXR2 and NXR3 showed evidence of burning, and were used to assess the effects of fire on stem density and mass-length ratios by comparison with NXR1 and NXR4, the

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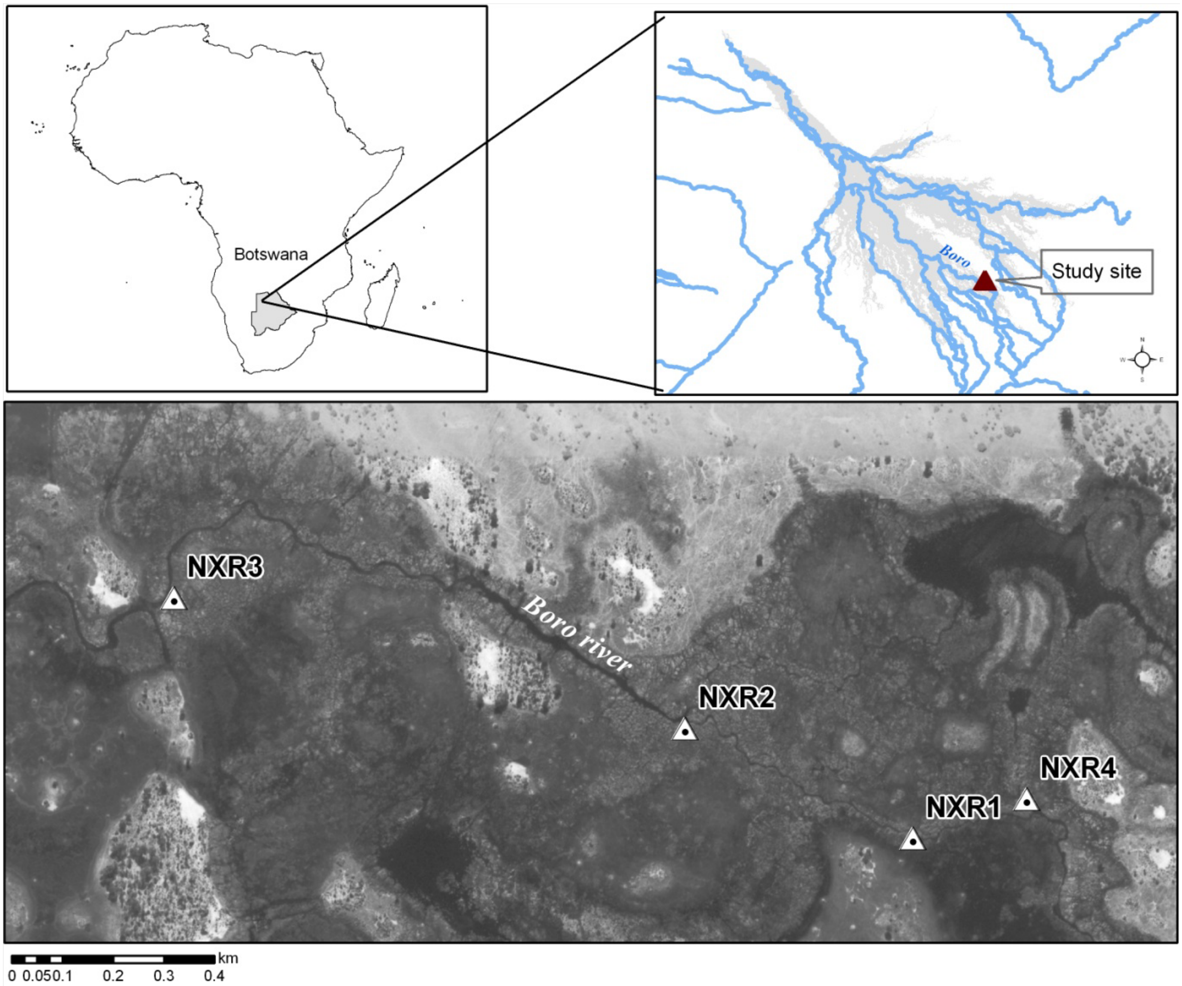

Fig. 1 Study site locations. The lower graphic is a mono-chromatic aerial photograph from 2001. Darker areas are floodplains, with channels and open water showing as black. Reedbeds are textured grey areas flanking the channels.

unburnt sites. In 2004-2005, monthly growth increments were recorded at NXR1, NXR2 and NXR4; the reedbed at NXR3 was severely damaged by elephant in early 2004, and was abandoned.

Methods largely followed Dykyjova *et al.* (1973), except that no leaf area estimates or stem basal diameter measurements were made.

Stem density and length-mass relationships

Stem density was recorded in 32 0.25 m^2 quadrats 5 m apart along a transect oriented perpendicular to the access channel at each site NXR1 (n=3), NXR2 (n=10), NXR3 (n=10) and NXR4 (n=9). Transect starting points were located at a random proportion of the distance between upstream and downstream reedbed margins, and terminated at the last 5 m before intersecting reedbed margins. The first 16-17 stems encountered in the first quadrat of each transect were harvested for establishing length-mass relationships. Each stem was cut at substrate level, washed and measured from the cut end to the ligule of the top-most leaf. They were bagged and transported to the Okavango Research Institute laboratory where they were oven-dried at 80°C to constant weight.

Growth rates and production

Between May 2004 and July 2005, incremental growth was measured by marking stems and measuring stem length on a monthly basis. At NXR1, NXR2 and NXR4, a graduated staff was installed for measuring water level because substrate conditions were variably soft. Initially, the 10 stems closest to the boat bow were selected, and length to the ligule of the top-most leaf was measured relative to water level, and then corrected to absolute change by taking into account changes in water level between measurements. These first 10 stems from each site were also used to establish stem length distributions. There was a break in recording during the period November 2004 to January 2005, because the river levels were too low to permit boat access to the sites. Starting in August 2004 and continuing throughout the period of study, large flocks of red-billed quelea (*Quelea quelea*) used the study reedbeds as night roosts and nesting sites, resulting in very extensive damage to stems on a daily basis. van der Toorn and Mook (1982) also indicated that following the fate of individual stems in closed reed beds had effects on survival: repeated access by researchers decreased the total vegetative cover, and disturbed the substrate, among other effects. Consequently, stems which were dead, broken or not found were replaced with the next intact stems closest to the boat bow to maintain a constant sample of approximately 10 stems per site per month.

Market value

Reeds are sold in most towns and villages around the Delta, in bundles of 15-20 cm diameter. The February 2010 price for such a bundle with leaf sheaths intact was Botswana Pula (BWP) 10.00, equivalent to ~US$ 1.50, while for a cleaned bundle, BWP 15.00. The number of stems in 21 bundles at 2 different dealers was counted to estimate market value per stem; at the first locality this was a total count, while the uppermost 21 bundles from the stack at the second locality were counted. Approximately half the stems from the 10^{th} bundle at each site were measured to estimate length distribution.

RESULTS

Standing stock and length-mass relationship

The average stem density was 77 ± 6.8 m^{-2} (n = 32, mean ± standard error). There were no significant differences found in density between sites (F (3, 28) = 2.17, p = 0.115), or

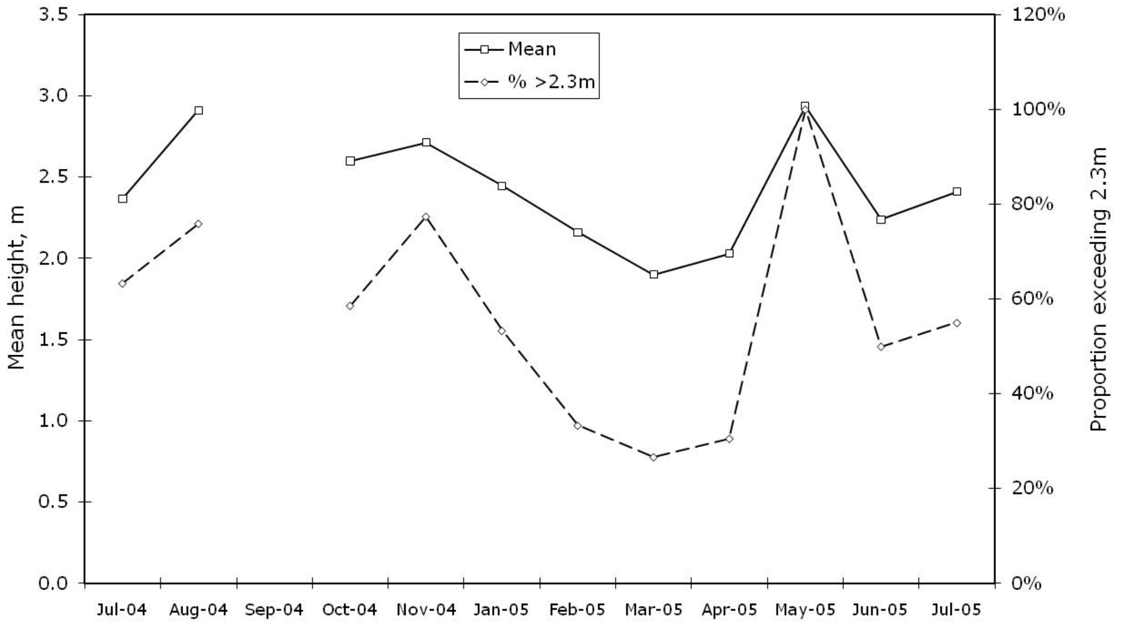

Fig. 2 Mean stem lengths in monitored sites, and the proportion of stems exceeding the minimum harvested length. Solid line - mean length; dashed line – proportion of stems longer than 2.3 m.

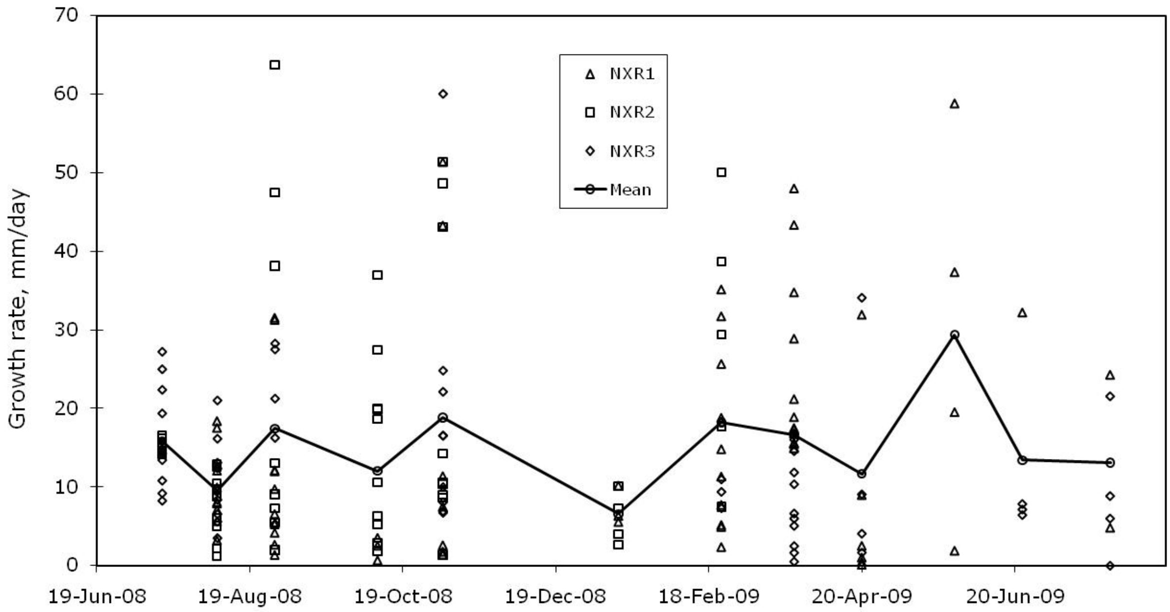

Fig. 3 Daily growth rates for all sites. Rates were calculated for each interval plotted.

between burnt and unburnt quadrats (F (1, 30) = 2.64, p = 0.113). The length-mass relationship is best fit by the power function $y = 8.0471x^{1.8489}$ ($r^2 = 0.89$), where y is the dry mass in grams, and x is the length in metres.

Stem length in harvested quadrats was highly variable and positively skewed, with a mode of 2.34 and a range of 3.2 m (n=30).

Stem length and the proportion of harvestable stems both reached their maxima in May 2005 (**Fig. 2**). Average standing crop at this period was 2.89 kg m^{-2}, calculated from the length-mass relationship and stem density, and represents the maximum attained during the study period.

Mean growth rate for all sites for the duration of the study was 15 mm per day (std. dev. 13.1) (**Fig. 3**). There was an apparent large increase in rate during the period April-June, corresponding with the onset of the rising flood, but falling off before the flood peaked. Variance in measured increments was large in all months, except in the initial two campaigns.

Breakage and stem mortality was high in all 3 reed-beds studied, primarily as a result of quelea roosting at night. An average of 6.8% of marked stems were broken during the 13 months of study; this reached a maximum of 46% of marked stems in October 2004, while stem mortality reached 28.6% of marked stems in September 2004 and 26% in April 2005, with an average of 11.6%.

Characteristics of marketed stems

The average number of stems per bundle in two separate stalls in Maun in February 2010 was 59 ± 7 and 46 ± 5, respectively (n = 21 in both cases). The difference between bundle size at these two outlets was significant (t (36) = 7.789, $p < 0.001$). Mean stem length did not differ significantly (t (60) = 0.665, p = 0.508) between the outlets, being 2.78 ± 0.32 (n = 34) and 2.85 ± 0.3 m (n = 29), respectively. The minimum stem length recorded in these bundles was 2.32 m, while the maximum was 3.29 m. Both respondents reported harvesting reeds in the Boro or Xudum/Matsebi distributaries.

Economic production

At a growth rate of 0.015 m/day, a new shoot will reach the minimum harvested length in 153 days, and the maximum harvested length in 220 days; in both cases, less than a full year's growth. Assuming damage and mortality of 18.4% (corresponding to the sum of the means of those recorded in this study), an "average" square metre of reedbed will produce 63 such shoots every 220 days, or 104 harvestable stems per year. Taking the average of bundle size from the two dealers sampled as 53 stems, at the price of a cleaned bundle, a single stem is worth approximately BWP 0.28 at market. Taking the maximum harvested length and its growth period to represent a year's production, one square metre of reedbed will produce stems worth approximately BWP 29.00 (approx. US\$ 4.50/m^2) at market each year, equivalent to BWP 290,000 ha^{-1} (US\$ 45,000 ha^{-1}). Clearly this does not include the cost of harvesting or cleaning.

DISCUSSION

Productivity

Stem density in the study sites is comparable with values from other parts of the world. Haslam (1972) notes a range from "low-nutrient" sites with 2-16 shoots m^{-2} to "high-nutrient" sites with 70-110 shoots m^{-2} in Britain. Okavango reedbeds fall in the latter category, although the nutrient status of Okavango water is oligo-mesotrophic (Cronberg *et al.* 1996). This may be the effect of the extended growing season resulting from the greater insolation and elevated temperatures of the Delta. Modal stem height similarly was slightly higher than the modal heights presented in Haslam (1972) – 2.3 m in the Delta compared with 0.85-2.05 m for breck fens in England. Mook and van der Toorn (1982) found that maximum standing crop gives a "fairly close approximation of total above-ground production, deviations remaining below about 10%". In this study, the maximum standing crop (2.89 kg dry mass m^{-2}) occurred in April-May 2005 (when growth rates were largest). This occurred coincident with the rising flood, and may be a response to the increased availability of dissolved nutrients due to higher channel discharges; it did not take place in the longer warmer days of mid-summer. This value is higher than those for above-ground *Phragmites* biomass reported from temperate reedbeds in the northern hemisphere (Haslam 1972; Westlake *et al.* 1998), but similar to high values of standing stock (3 ± 0.04 kg m^{-2}) reported by Tarr *et al.* (2004) for a South African sub-tropical wetland. It is also higher than those reported for other large emergents in temperate wetlands. Brinson *et al.* (1981) report values for above-ground biomass of between 0.996 and 1.68 kg dry mass m^{-2} for *Typha latifolia* marshes in wetlands characterized by high water level fluctuations in North America and England. In Uganda and Kenya, both tropical settings, Saunders *et al.* (2007) report emergent biomass in *Cyperus papyrus* stands of 2.26 kg dry mass m^{-2}, a comparable figure to that found in this study. Much higher (9.89 kg m^{-2}) above-ground biomass of *Phragmites* as peak standing crop was reported by Hocking (1989) from a nutrient-enriched swamp in Australia. Interestingly, this peak standing crop occurred in May, a similar seasonal maximum to that found in our study, perhaps indicating that for *Phragmites* in southern hemisphere wetlands, autumn is a period of higher growth.

Given the potential for damage and consequent mortality to aerial shoots in the Delta from quelea and other sources, such as herbivory by elephant, which extensively damaged one of the study reedbed sites, it is considered that the calculated maximum standing stock value of 2.89 kg/m^2 represents the upper limit of actual long-term net annual production based on Mook and van der Toorn's (1982) approximation. Taking into account potential damage and mortality at ~18%, it is suggested that the use of a range for net above-ground annual production in Okavango reedbeds of 2-3 kg m^{-2} yr^{-1} or 20-30 tonnes ha^{-1} yr^{-1} is appropriate.

Reedbed economic values

Phragmites beds in the Okavango Delta are important ecological resources for humans through direct (consumptive) use, and through their habitat value for a diverse biota, including some rare and endangered species. Here we have presented monetary values for these reedbeds on an area basis for harvesting, as a first step towards deriving an ecosystem service value. Without further research on cost-distance relationships, it is not possible to derive a net value for the resource landed at market, although in a study of river reed utilisation in the northern Okavango, Mmopelwa (2006) estimated the annual net cash income from reed sales per household to be in the range BWP 182-550. It is also not possible to derive a value for conservation or the provision of habitat (and their associated tourism value). Scudder *et al.* (1993) estimated a value for reedbeds in the Delta and Boteti areas of about BWP 1.00 m^{-2}, from harvest and sale of reeds. Their estimate was based on a bundle size of 36 stems at a price of BWP 1.00 per bundle, March 1992 prices. Clearly prices have risen since then, and the value of the currency has declined. However, escalating prices for inflation by 10% per annum produces a 2010 value of BWP 5.55 m^{-2}; it would appear that Scudder's study undervalued the resource. The value of BWP 29.00 m^{-2} found in this study was based on production rather than standing stock, as in the Scudder study. In addition they were deliberately conservative, and assumed that one bundle of 36 represented the production of 1 m^2 of reedbed, while their counts produced an average of 85 stems m^{-2}, slightly higher than this study found. Clearly the net value of the resource will be less than the estimate presented here, but it is equally clear that reedbeds represent a major store of natural value which can be used to generate income for people in the Delta. The production value of BWP 290,000 ha^{-1} year^{-1} can also be assessed in relation to other means of wetland-based livelihoods in northern Botswana, such as flood-recession agriculture, valued at BWP 3,300 ha^{-1} year^{-1} for sorghum under optimal flooding conditions (2000 kg ha^{-1}) (Botswana Agricultural Marketing Board 2009). Agricultural production in this case represents approximately 11% of the value of reedbeds ha^{-1} (in both cases, the value is based on price at market).

CONCLUSIONS

Phragmites australis in the Okavango Delta, as in many wetlands worldwide, occurs as a component of mixed communities of emergent plants, but also in extensive almost mono-specific stands. These stands, called reedbeds, are highly productive and resilient systems. In the seasonally pulsed distal distributaries of the Delta, the annual production of *Phragmites* reedbeds of 2-3 kg dry mass m^{-2} is high for wetland emergent macrophytes globally, and compares favourably with the giant sedge, *Cyperus papyrus*, in tropical wetlands. In the case of *P. australis*, a widely used building material, this high annual production translates directly inot high economic value. We estimate that these reedbeds have an at-market value of US\$ 45,000 ha^{-1}. This value, exceeding that of subsistence agriculture by nearly 90 times, provides strong incentives to conserve reedbeds and ensure the sustained delivery of the resource and its associated ecosystem services. Although fires are frequent in the Okavango Delta (Heinl *et al.* 2008), it appears that the production of reedbeds is not adversely affected by above-water burning. Thus a primary target for conservation of reedbeds would appear to be to secure the hydrology.

Clearly, reedbeds represent a resource of significant monetary value to the people of this wetland. Future estimations of cost-distance functions for harvesting, and also of the conservation value of reedbeds, will add depth to this rather crude valuation. Further work on the assessment of the effects of harvesting on production will also improve our ability to manage reedbeds sustainably.

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