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Artificial structures as tools for fish habitat rehabilitation in a neotropical reservoir

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ABSTRACT

1. Since most of the natural habitats critical for freshwater fish survival have been adversely affected by human disturbance, the effectiveness of artificial structures in providing new and suitable habitats for fish has been increasingly investigated.

2. This paper evaluates the role of artificial structures as fish habitat in a structureless 30 km^2 Brazilian reservoir, through underwater surveys conducted monthly from April 1999 to March 2000.

3. In total, 5759 fish in nine species were recorded, but only three cichlid species — one native, *Geophagus brasiliensis* and two non-native, *Cichla kelberi* and *Tilapia rendalli* — showed consistent association with the artificial habitats, suggesting that this family reacts to submerged structures.

4. The absence of fish at control sites compared with high occurrences in sites provided with a physically complex structure suggests that artificial structures can play an important ecological role for cichlids smaller than 150 mm TL, probably related to shelter and/or feeding benefits.

5. The level of structural complexity and position in the water column influenced fish use of artificial structures. *C. kelberi* was associated with highly complex structures, whereas moderately complex bottom structures were more effective in harbouring *G. brasiliensis*. Bottom structures are apparently more important than midwater structures in harbouring *T. rendalli*, but structural complexity seemed to play a secondary role.

6. This study is the first in demonstrating that adding complex artificial structures can expand habitats for small fish (<150 mm TL), especially cichlids, in a neotropical impoundment. It seems reasonable to expect that deploying physically complex structures in other oligotrophic, structureless and cichlid-dominated impoundments in Brazil will lead to similar results to those found in this work.

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INTRODUCTION

Since the 1930s, the use of artificial structures in lentic freshwater systems has become widespread and numerous studies have been undertaken, mainly to elucidate the role of submerged habitats on attraction, concentration and catch of fishery resources (Wilbur, 1978; Walters *et al*., 1991; Johnson and Lynch, 1992; Ahmed and Hambrey, 1999; Rogers and Bergersen, 1999; Welcomme, 2002). Nowadays, there is growing concern over whether artificial structures could help in environmental rehabilitation, and the effectiveness of synthetic structures in providing suitable habitats for fish has been increasingly investigated (Nash *et al*., 1999; Knaepkens *et al*., 2004). This approach is important for practical conservation management, since many of the natural habitats critical for freshwater fish survival (e.g. macrophytes and flooded vegetation) have been adversely affected by human disturbance, such as river impoundment (Saunders *et al*., 2002).

Reservoirs have often been targeted for habitat manipulation studies, because they are generally structureless and homogeneous systems as a consequence of timber removal or decay, rapid siltation of hard substrate, or lack of aquatic vegetation caused by water level fluctuation (Wills *et al*., 2004). Some researchers have stated that artificial structures, in adequate amounts and appropriate complexity, should function in a similar way to natural aquatic plants in providing cover for small fish in temperate lakes and reservoirs (Winfield, 1986; Hayse and Wissing, 1996; Sandström and Karas, 2002). Conversely, there has been no similar work for South American systems, except a few studies in Brazil describing the general use of artificial structures by fish assemblages (Freitas and Petrere, 2001; Braga, 2002; Freitas *et al*., 2002, 2005). Brazilian reservoirs are attractive systems for investigating fish responses to habitat management, since they experience the general abiotic conditions of tropical regions (e.g. high temperatures, heavy rainfall and water deoxygenation). In addition, their fish assemblages are characteristically diverse, with very complex interrelationships compared with those in temperate reservoirs (Lowe-McConnell, 1987). Approaches that use artificial structures could be helpful in mitigating the adverse impacts on fish caused by river impoundments and dam operation routines in Brazil. According to Agostinho and Gomes (1997), most of the impacts of impoundments on fish assemblages could be reduced by creating, restoring or protecting habitats critical to species survival.

This paper describes the role of artificial structures as fish habitat in Lajes Reservoir, Brazil, an oligotrophic and structurally uniform impoundment. Since both the physical complexity of artificial structures and their location in the water column can influence fish use (Walters *et al*., 1991; Johnson and Lynch, 1992), the present study investigated whether fish reacted to shifts in those factors. The null hypothesis is that fish density, occurrence and diversity do not change with physical complexity and position of the structures in the water column. The potential use of artificial structures as tools for fish conservation is also discussed with regard to their general ability to harbour fish and their selective use by the prevalent species.

STUDY AREA

Lajes Reservoir (22° 42′–22° 50′ S; 43° 53′–44° 05′ W) is a 30 km^2 impoundment in Rio de Janeiro State (Figure 1), located 415 m above mean sea level in the upper slopes of the Serra do Mar (Sea Mountains) in south-eastern Brazil. This reservoir was filled between 1905 and 1908 mainly for hydroelectric purposes, damming streams and diverting small rivers of the East Hydrographic Basin (Araújo and Santos, 2001). Lajes Reservoir has low concentrations of nitrogen ($<10\,\mu g\,L^{-1}$), phosphate ($<120\,\mu g\,L^{-1}$) and chlorophyll α ($<2.5\,\mu g\,L^{-1}$) (Santos *et al*., 2004).

The reservoir is also used intensively for recreation, mainly for angling. Since the 1950s, many fish species have been introduced into the reservoir (Araújo and Santos, 2001). The non-native peacock bass *Cichla kelberi* (Kullander and Ferreira, 2006) (described as *Cichla monoculus* prior to this taxonomic revision) is the most prominent species because of its ecological and socioeconomic impacts. Santos *et al*. (2001) suggested that the predatory habits of *C. kelberi* over 50 years after its introduction resulted in adverse impacts on the indigenous fish species. Also, since the 1970s peacock bass has been the main species caught by the 2000 affiliates of a local angling club. Finally, a legal prohibition for harvesting *C. kelberi* <300 mm total length, for exceeding a bag limit of five trophy fish per day, and for catching any individual throughout its reproductive season exists in the reservoir to improve local angling.

Lajes Reservoir exhibits a very low degree of physical habitat complexity, attributable to rain-forest removal prior to reservoir filling and to the wide water level fluctuations, which impaired growth of aquatic macrophytes and maintenance of other natural submerged structures (Araújo and Santos, 2001). Water level fluctuations are seasonal and dictated by dam operation, with differences among extremes of flood and drawdown events reaching up to 12 m (Duarte and Araújo, 2001). According to Santos *et al*. (2004), low water levels have overall negative impacts upon the habitat complexity and the fish fauna of the reservoir, but the most detrimental effects occur in years of severe and prolonged drawdown.

MATERIAL AND METHODS

Artificial structures

Each artificial structure had a circular frame of 19-mm-diameter polyvinylchloride (PVC) pipe of standardized

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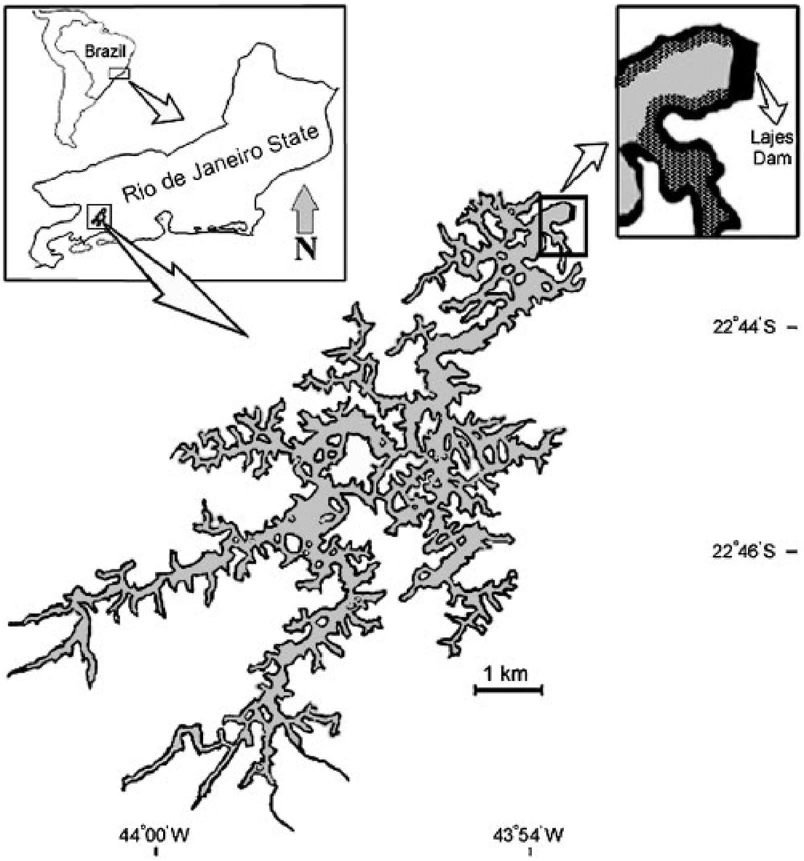

Figure 1. Illustration of Lajes Reservoir, Brazil, showing its geographic location and the area near the dam where artificial structures were deployed during this study.

dimensions (1.8 m in diameter and 2.5 m^2 surface area) (Figure 2). Polyethylene ropes were radially attached to the PVC pipe frame to improve physical integrity of the structure and to provide suitable substratum for tying bunches of buoyant green-brownish polypropylene ribbons (1 bunch = 20 ribbons) 40 cm long × 1 cm wide × 1 mm thick (Figure 3).

Three experimental levels of complexity (artificial vegetation density) were tested (based on the studies of Savino and Stein (1982) and Hayse and Wissing (1996)): *dense* (120 bunches or 2400 ribbons m^{-2}); *middle* (40 bunches or 800 ribbons m^{-2}); and *control* (lacking artificial vegetation) (Figure 3). Two locations in the water column were chosen for positioning the artificial structures: *bottom*—structures that were fixed directly onto the substrate of the reservoir using metallic clips; *midwater*—structures that were located in the water column, 1.5 m below the surface, by tying a float (polyethylene bottle) and a 25 kg concrete ballast (Figures 2 and 3). The distance of midwater structures from the surface was arbitrarily chosen to emulate floating macrophytes and to allow fish inspection by divers. Thus, six different types of artificial structures were assessed: bottom-dense (BD); bottom-middle (BM); bottom-control (BC); midwater-dense (MD); midwater-middle (MM); and midwater-control (MC).

Deployment of artificial structures

A protected area, close to the dam, was selected for deploying artificial structures (Figure 1). This area was easily inspected by hydroelectric company personnel, favouring monitoring and preventing interference by non-authorized people. The target area is deep with high transparency, steep margins, and few tributaries, while natural submerged structures and aquatic macrophytes are depleted. The environmental characteristics of this lacustrine zone accord with the general patterns of reservoir spatial differentiation proposed by Thornton *et al.* (1990).

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In total, 53 structures were put in place between 16 February and 20 March 1999: 11 BD; 11 BM; 12 BC; 6 MD; 6 MM and 7 MC. Artificial structures were deployed on protected and undisturbed sites, as hollows and bays, where the depth contour was 3.5 m and the substrate was composed mainly of soft mud and silt with a minor portion of sand. Sites were totally depleted of natural vegetation or other submerged structures. The position of each artificial structure was chosen non-randomly aiming to maintain a distance of 50–100 m between adjacent structures and to standardize depth, substrate type, and distance in relation to the margin among all artificial structures. This precaution was taken to minimize the risk of interaction and interference among treatments, assuming that fish, after colonizing a given structure, did not travel this distance across bare substrate to reach another structure because of the increased predation risk from large piscivorous fish (namely peacock bass (Santos *et al.*, 2001)). However, each artificial structure was randomly assigned to each location to avoid non-natural trends or sample bias.

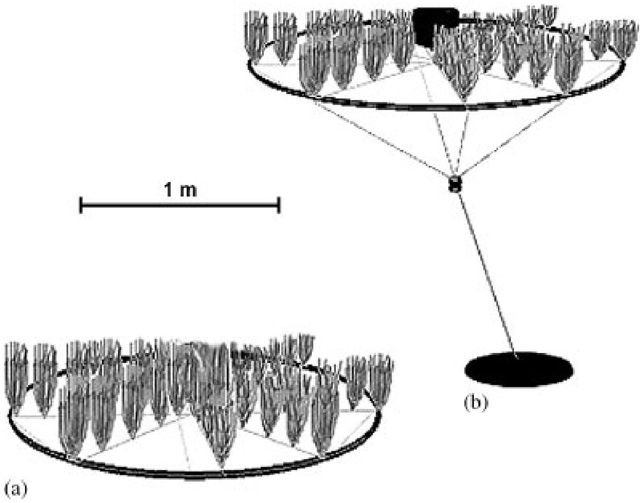

Figure 2. Two types of artificial structure deployed in Lajes Reservoir in February–March 1999, showing the final arrangement of bottom (a) and midwater (b) structures.

All artificial structures were adjusted to move with reservoir water levels that fluctuated up to 5.0 m throughout the study period (Figure 4). Adjustments were always made after fish inspections by moving structures to deepest or shallowest areas, in accordance with water level predictions provided by the hydroelectric company. Adjustments, which never exceeded 50 cm depth per month (Figure 4), maintained the physical integrity of the structures and ensured that the bottom treatments remained at about the 3.5 m depth contour, the midwater ones remained 1.0–1.5 m below the surface, and that both bottom and midwater treatments remained 4–6 m away from the margin.

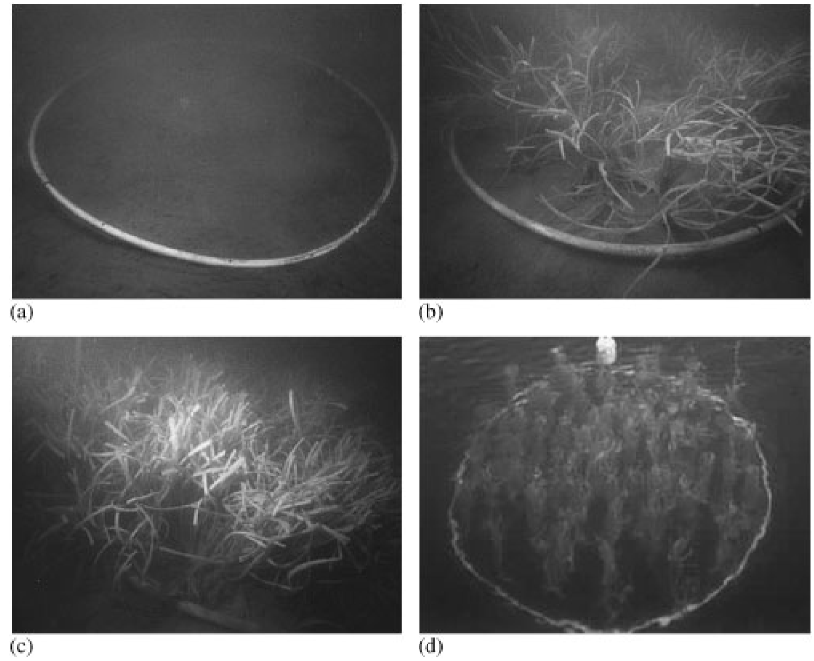

Figure 3. Artificial structures deployed in Lajes Reservoir, showing the similarity of artificial vegetation with natural flooded grasses and macrophytes: (a) bottom-control (BC); (b) bottom-middle (BM); (c) bottom-dense (BD); (d) midwater-middle.

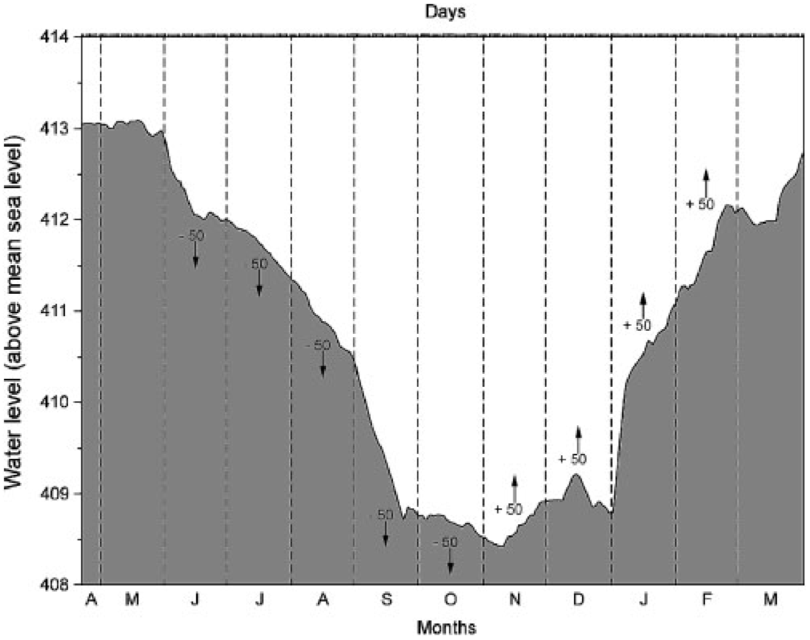

Figure 4. Time series of water level fluctuations (grey area; metres above mean sea level) in Lajes Reservoir, measured daily from 21 April 1999 to 28 March 2000. Values and arrows between dashed lines indicate depth and direction of structure relocations.

Attempts were made to standardize and to rigorously control the depth, substrate features, and distance from the margin at which artificial structures were deployed, since these variables may confound fish use analysis (Walters *et al.*, 1991). Each artificial structure was analysed with respect to its position in the water column (bottom or midwater) and complexity (dense, middle or control).

Fish monitoring

Preliminary inspections were conducted by divers every week during the first month after the artificial structures were deployed. Structures showed no physical damage with experimental underwater translocations (50 to 150 cm per week), and these preliminary inspections indicated that an undisturbed period of 15 days was enough to allow structures to be colonized by periphyton and fish. The formal survey programme was conducted monthly from April 1999 to March 2000 and the fish associated with artificial structures were identified and counted by underwater observations by two snorkelling divers. Three replicates of each treatment ($N = 18$) were monitored monthly, totalling 216 standardized underwater surveys. Artificial structures were inspected between 10:00 and 15:30 to optimize visibility and fish identification, and the order in which treatments were surveyed on each sampling occasion was determined at random. Water temperature ranged from 15.3 to 30.6°C, dissolved oxygen remained higher than $4.7\,\mathrm{mg\,L^{-1}}$ and Secchi disk measurements averaged 2.30 m ± 0.05 S.E. during the entire study period.

Divers remained 1 m from the structures attempting to record fish that were moving away and leaving the divers' field of view. After that, they swam about 1 m over the top of the structures to record the fish present. Finally, they inspected the entire structure within the artificial vegetation, looking for fish that sought refuge among the interstices of polypropylene ribbons. Each underwater survey took 5–6 min per structure and fish were considered to be associated with artificial habitats if they were up to 1 m from the structures. All fish associated with the structures were visually identified and counted, and data were recorded separately by each diver on an underwater writing tablet. The total length of fish (TL) was estimated visually, comparing fish size with adjacent objects of known distance, and by measuring to the nearest 5 mm a subsample of individuals that were captured by experimental seines (10×2.5 m; 8.0 mm mesh) immediately after underwater surveys.

It was possible to identify all fish to species level under field conditions, since the majority of species using the artificial structures were distinctive. Exceptions occurred only for small individuals (<20 mm TL) of two cichlids — *Geophagus brasiliensis* (Quoy and Gaimard, 1824) and *Tilapia rendalli* (Boulenger, 1897); but these species rarely occupied a given structure at the same time. The identification of a subsample of individuals captured by the seines provided the supplementary data for successfully solving this problem. The two divers' counts were averaged for each structure unit by month and species, and each observation of a structure was considered independent of the observation from the month before. Voucher specimens were preserved in 10% formalin and deposited in the Ichthyological Collection of Laboratory of Fish Ecology, Federal Rural University of Rio de Janeiro, Brazil.

Data treatment and statistical analysis

Artificial structures with no adhering plastic filaments (both bottom and midwater controls) were levelled to naturally unstructured areas of the reservoir. Although controls were slightly more complex than the structureless areas of the reservoir, it was considered in the present study that the PVC pipe + ropes + floater + concrete ballast, with no stems of artificial vegetation, had no or negligible effects on fish use. Fish density (number m^{-2}) and percentage frequency of occurrence (i.e. the occurrence of fish in a given structure as a percentage of all observations) were used for comparing the effectiveness of each type of artificial structure as fish habitat. The entire fish assemblage associated with each structure was assessed, with a focus on the structure use by the prevalent species (e. g. total percentage abundance and frequency of occurrence greater than 1% and 10%, respectively).

Since the abundance data did not conform to the main assumptions of traditional parametric statistics (not normally distributed and/or heterogeneous variance), a permutational multivariate analysis of variance (PERMANOVA) was applied for univariate comparisons of fish density among different types of artificial structures. PERMANOVA is a computer program for testing the simultaneous response of one or more variables to one or more factors in an ANOVA experimental design on the basis of any distance measure, using permutation methods (Anderson, 2001; McArdle and Anderson, 2001). The Euclidean distance was chosen as the basis of all PERMANOVA analysis and data were permutated 4999 times per analysis, according to recommendations of Manly (1997) for tests at an α-level of 0.01. Where significant differences were found, pair-wise *a posteriori* comparisons were performed under 4999 permutations (see Anderson (2005) for further details).

RESULTS

In total, 5759 fish in nine species were recorded in the artificial structures. Among these, 1177 individuals (20.4%) and six species (66.7%) are indigenous while 4582 individuals (79.6%) and three species (33.3%) are non-native (Table 1). Only juvenile or forage fish used artificial structures, with size ranging from 15 mm to 140 mm TL.

Cichla kelberi, *G. brasiliensis* and *T. rendalli* accounted for 99.0% of total abundance and between 16.2% and 34.3% of individual occurrence in the artificial structures. *C. kelberi* was the most abundant and frequent species, while *G. brasiliensis*

Table 1. Fish species recorded through underwater surveys (snorkelling) at artificial structures in Lajes Reservoir, from April 1999 to March 2000, showing numbers, percentage abundance and occurrence, size range (mm), origin status and adult length classes

Scientific name	Number of fish	Percentage abundance	Percentage occurrence	Total length min–max	Status	Length class
Perciformes						
Cichlidae						
Cichla kelberi	4312	74.9	34.3	35–110	NN^{E}	L
Geophagus brasiliensis	1148	19.9	21.8	15–100	I	M
Tilapia rendalli	242	4.2	16.2	15–120	NN^{B}	M
Characiformes						
Characidae						
Metynnis maculatus	28	0.5	3.2	50–100	NN^{E}	M
Astyanax cf *bimaculatus*	20	0.3	1.4	30–175	I	S
Oligosarcus hepsetus	2	<0.1	0.5	40–180	I	M
Brycon opalinus	1	<0.1	0.5	80	I	M
Erythrinidae						
Hoplias malabaricus	3	<0.1	1.4	90–140	I	L
Siluriformes						
Auchenipteridae						
Trachelyopterus striatulus	3	<0.1	0.5	30–110	I	S
Total	5759					

I, indigenous from small rivers of the East Hydrographic Basin.
NN^{E}, non-native to the East Hydrographic basin but indigenous in other regions of Brazil (*C. kelberi*: Araguaia and Tocantins River basins; *M. maculatus*: Amazon and Paraguay River basins).
NN^{B}, non-native to Brazil, indigenous to Africa. S, <200 mm TL; M, 200–400 mm TL; L, $\geqslant 500$ mm TL.

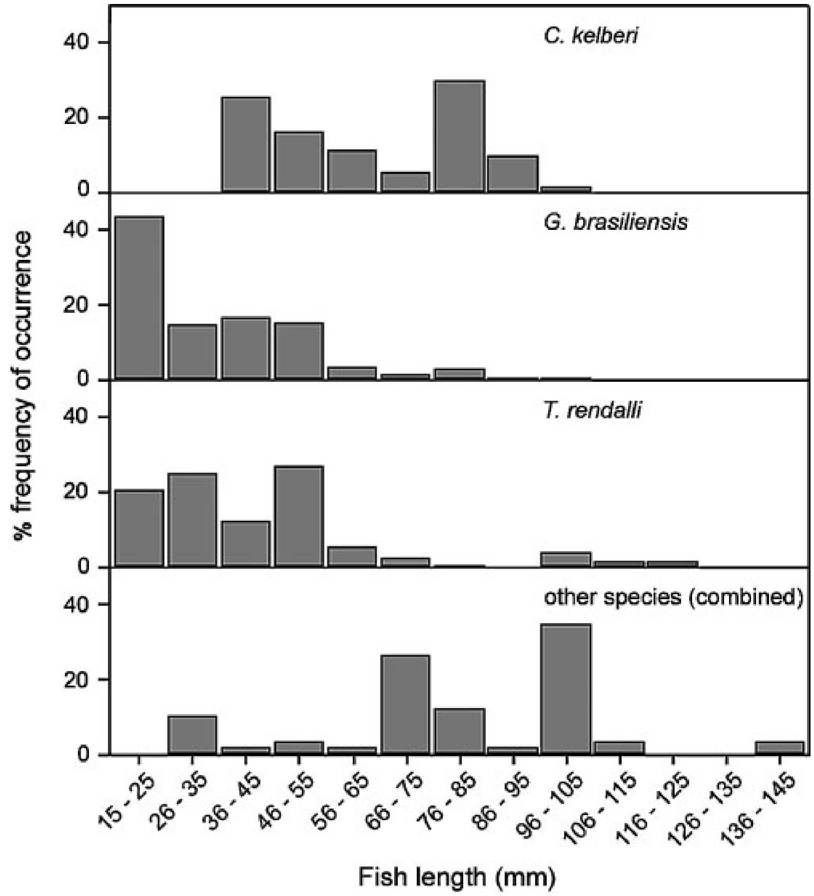

Figure 5. Length–frequency distribution of the three cichlid species — *C. kelberi* ($n = 4312$), *G. brasiliensis* ($n = 1148$) and *T. rendalli* ($n = 242$) — and six other fish species (combined data; $n = 57$) recorded by snorkelling divers at artificial structures in Lajes Reservoir.

and *T. rendalli* were less common. Three species of Characiformes — *Metynnis maculatus* (Kner, 1858), *Astyanax* cf *bimaculatus* (Linnaeus, 1758) and *Hoplias malabaricus* (Bloch, 1794) — occurred at more than 1.0% in the structures, but their relative abundances were lower than 1.0% of the total number of fish. The relative abundances and occurrences of the other species were lower than 1.0%.

Small individuals (<55 mm TL) of *G. brasiliensis* and *T. rendalli* occurred consistently in the artificial structures (Figure 5), but *G. brasiliensis* exhibited a unimodal size distribution, whereas few changes in abundance were observed for *T. rendalli* within the 15–55 mm TL size range. Less than 5% of *G. brasiliensis* and *T. rendalli* populations fell within the size range in which *C. kelberi* was the most abundant (76–85 mm), whereas no *C. kelberi* were recorded in the 15–25 mm class in which *G. brasiliensis* was abundant.

The number of fish and species differed between the types of artificial structures ($F = 22.7$ and 27.3 respectively; df $= 5, 210$ and $P = 0.0002$ for both). Although mean number of fish and species did not differ statistically (Figure 6; PERMANOVA's pair-wise *a posteriori* test; $P > 0.05$) among physically complex bottom and midwater structures (i.e. BD, BM, MD and MM), they were significantly greater for those treatments than for the controls (PERMANOVA's pair-wise *a posteriori* test; $P < 0.01$), since there was not even a single fish recorded at bottom and midwater structures with no plastic filaments (i.e. BC and MC).

Overall, high complexity midwater structures (MD) harboured more than 20 individuals m^{-2}, but data variability around the mean was high (Figure 6). Bottom-dense (BD) and bottom-middle (BM) structures harboured nearly 15 individuals m^{-2} whereas midwater-middle (MM) sheltered 11.4 ± 0.42 individuals m^{-2}. Fish occurrence was

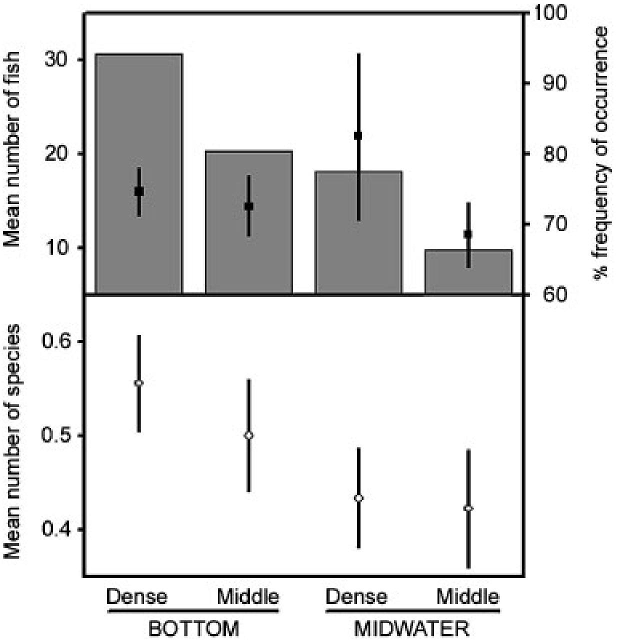

Figure 6. Mean number of fish m^{-2} (closed squares), percentage frequency of occurrence (grey bars) and mean number of fish species m^{-2} (open circles) recorded by snorkelling divers in physically complex artificial structures placed in Lajes Reservoir. Vertical lines indicate the standard error.

greater than 90% at BD structures and lower than 70% at MM structures, while intermediate values were recorded for BM and MD structures; only BD structures attracted more than 0.5 species m^{-2} (Figure 6).

Cichla kelberi, *G. brasiliensis* and *T. rendalli* were the only species recorded in all kinds of structures (except in the controls), but their abundances and occurrences shifted according to each treatment (Figure 7). Significant differences in mean density of *C. kelberi* among types of structures were detected ($F = 7.7$; df = 5, 210; $P = 0.0002$) with higher values in the treatments than in the controls; no difference was found between bottom and midwater structures with high or intermediate density of plastic filaments (PERMANOVA's pair-wise *a posteriori* test; $P < 0.01$). Density and occurrence of *C. kelberi* were greater than 20 individuals m^{-2} and 60% at MD structures, but they did not exceed 5 individuals m^{-2} and 41% at BM. Intermediate values of about 10 fish m^{-2} and 50% occurrence were recorded for the BD and MM structures (Figure 7).

Mean densities of *G. brasiliensis* and *T. rendalli* also differed statistically among types of artificial structure ($F = 16.0$ and 4.5 respectively; df = 5, 210 for both; $P = 0.0002$ and 0.0012, respectively). Mean density of *G. brasiliensis* was greater in bottom structures than the other structures (Figure 7; PERMANOVA's pair-wise *a posteriori* test; $P < 0.01$), but no significant differences occurred between BD and BM treatments (Figure 7; PERMANOVA's pair-wise a posteriori test; $P > 0.05$). Bottom structures harboured 3–9 individuals m^{-2} for BD and BM treatments, respectively, but less than 1.0 individual m^{-2} at MD and MM treatments. Similarly, occurrence of *G. brasiliensis* was equal to or higher than 50% at bottom structures but lower than 20% in midwater structures. Mean density of *T. rendalli* was statistically lower in BC, MC and MD than in the other treatments (Figure 7; PERMANOVA's pair-wise *a posteriori* test; $P < 0.01$). The BM treatment sheltered 1.30 ± 0.59 S.E. individuals m^{-2} on average, which did not significantly differ from those values recorded for BD (0.8 individuals m^{-2}) and MM (0.5 individuals m^{-2}) treatments. Occurrence of *T. rendalli* was similar among the BM, BD and MM treatments (about 30%), but it was comparatively greater than the 11.1% recorded for the MD treatments (Figure 7).

The use of artificial structures by fish species other than the cichlids decreased remarkably, with densities and occurrences never exceeding 0.5 individuals m^{-2} and 12% respectively (Figure 7). Among the secondary species, only *A*. cf *bimaculatus*, which was recorded exclusively at MD structures, was statistically more abundant in this treatment than the others ($F = 2.9$; df = 5, 210; $P = 0.0372$; PERMANOVA's pair-wise *a posteriori* test; $P < 0.01$).

DISCUSSION

Selective use of artificial structures

Artificial structures were used selectively as habitat by fish, since only nine species were observed during visual surveys — one-third of the total species number recorded for Lajes Reservoir (27 species; L. N. Santos, unpubl. data). Among those, only three species of cichlids were consistently found in the structures, comprising all of the Perciformes taxa recorded for Lajes Reservoir during the study period. According to Bolding *et al.* (2004), the use of artificial structures by fish is dependent on the species composition of the fish community and their general abundance. Cichlids overall are characterized as non-migratory diurnal fish with high affinity to submerged structures (Lowe-McConnell, 1987). The majority of Characiformes and Siluriformes that were not observed in artificial structures are also not usually caught in Lajes Reservoir by experimental fisheries (Araújo and Santos, 2001; Santos *et al.*, 2001). Thus, the typical behaviour of *C. kelberi*, *G. brasiliensis* and *T. rendalli* and their high abundances in Lajes Reservoir (Araújo and Santos, 2001) probably led to the prevalence of these species in artificial structures.

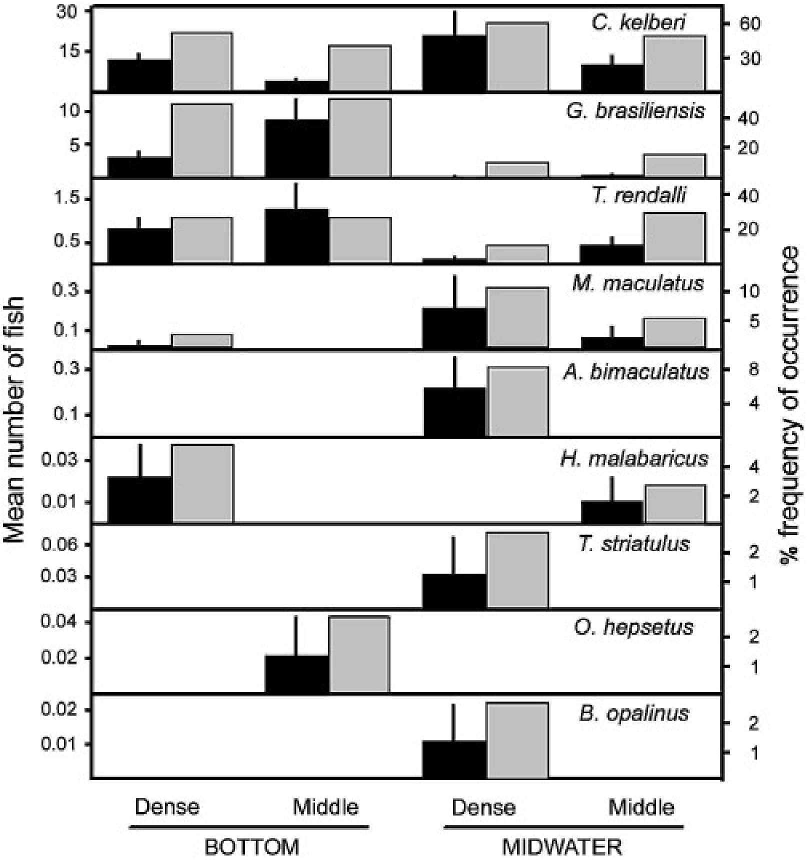

Figure 7. Mean number of fish (black bars) and total percentage frequency of occurrence (grey bars) recorded by snorkelling divers for the nine species associated with physically complex artificial structures placed in Lajes Reservoir. Vertical lines indicate the standard error.

In temperate systems, artificial structures have been used consistently by bottom and structure-oriented species, such as the centrarchids, but are virtually useless for open water species (Johnson *et al*., 1988; Walters *et al*., 1991; Bassett, 1994). Rold *et al*. (1996) observed that only three species of Centrarchidae—*Lepomis macrochirus*, *Lepomis auritus* and *Micropterus salmoides*—exhibited consistent associations with structures installed at Goose Lake, USA, accounting for 93% of total fish abundance. Graham (1992) reported that the centrarchids *L. macrochirus*, *M. salmoides* and *Pomoxis nigromaculatus* were the major fish species observed at artificial structures deployed in Lake Anna, USA, but only *L. macrochirus*, because of its prevalence in samples, was used as a target species for evaluating fish use of structures. Thus, the findings in the present study suggest that the cichlids, as the centrarchids in temperate systems, could be used as target species for evaluating the effectiveness of artificial structures as fish habitat in neotropical ecosystems.

A combination of the size of artificial structure units and the method used for fish surveys could have accounted for the exclusive occurrence of small fish (<150 mm TL) in the present study. For example, it is possible that the 2.5 m^2 artificial structure unit used is too small to yield large fish (>150 mm TL) or that, since no underwater observation was performed at night by the divers, some large fish only used the artificial structures after sunset. In addition, large fish that might have used the structures could have been disturbed by the divers' approach. Hayse and Wissing (1996) and Graham (1992) reported that fish larger than 150 mm TL often moved further way from artificial structures as divers came closer (i.e. a fright response). However, additional work is needed to clarify the influence of those factors on the use of submerged habitats by neotropical fish species.

Effects of position and complexity of artificial structures

Fish use of artificial structures changed with their location in the water column, but no significant difference in mean numbers of fish and species among physically complex

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treatments was detected. *C. kelberi* is a benthopelagic species (Kullander and Ferreira, 2006) and used both bottom and midwater structures indiscriminately because there may have been no feeding or anti-predator advantages in choosing between a benthic and a pelagic habitat. *T. rendalli* is also benthopelagic (Lowe-McConnell, 1987), but its slight preference for bottom structures suggests that it obtained more benefit using these types of habitat than midwater ones. Savino and Stein (1982) reported that *L. macrochirus* reduced their vulnerability against *M. salmoides* predation by congregating near to the bottom edges of the experimental pools. While staying in these sediment–water interfaces, bluegills were ventrally and laterally protected from attacks. Likewise, *T. rendalli* may have preferred bottom structures by using sediment–water interfaces to attain additional protection from predators. Behaviour was probably also the main reason why the benthic *G. brasiliensis* and the pelagic *A.* cf. *bimaculatus* preferred bottom and midwater structures, respectively, but these species certainly obtained additional feeding and/or anti-predator benefits by using these treatments.

Structural complexity also influenced fish use of artificial structures, but its effect became more evident for the prevalent species. Dense and middle-complexity structures undoubtedly sheltered more fish than the controls, since not even a single individual was observed at treatments lacking artificial vegetation. Physical complexity can influence fish use of habitats by providing substrata for spawning, reducing vulnerability to predation or by enhancing feeding (Crowder and Cooper, 1982; Savino and Stein, 1982; Winfield, 1986). Although spawning requirements were not addressed in the present work, there is some evidence that vulnerability to predation and food availability led to fish use of artificial structures in Lajes Reservoir. Almost all species used dense treatments, but *C. kelberi* and *A.* cf. *bimaculatus* appeared to prefer highly complex structures, despite no significant differences among these treatments (BD, BM, MD and MM) for the former species. Also, small *C. kelberi* ($\leqslant$80 mm TL) and *A.* cf. *bimaculatus* are strongly preyed on by large *C. kelberi* ($>$200 mm TL), the prevailing diurnal-visual predator in the reservoir (Santos *et al.*, 2001). Complex structures may create prey refuges by reducing visual encounters with predators (Crowder and Cooper, 1982) or by excluding predators from the structure (Lynch and Johnson, 1989), so prey vulnerability decreases as structural complexity increases (Savino and Stein, 1982). However, the rate at which fish associated with highly complex structures capture their prey also decreases owing to greater availability of prey refuges (Gotceitas, 1990; Hayse and Wissing, 1996). According to Werner *et al.* (1983) and Johnson and Lynch (1992), predation by largemouth bass *Micropterus salmoides* could have restricted small bluegills *Lepomis macrochirus* to complex structures even though such habitats were not energetically the most profitable. Thus, it was expected that in the clear and structureless waters of Lajes Reservoir, small *C. kelberi* and *A.* cf. *bimaculatus* were probably constrained to use highly complex structures especially to avoid predation by large *C. kelberi* rather than to obtain feeding benefits.

Unlike *C. kelberi* and *A.* cf. *bimaculatus*, *G. brasiliensis* appeared to prefer middle complexity structures, which probably offered more advantages to this species than the other treatments. Intermediate structural complexity may optimize predator–prey interactions by providing neither prey nor predator with an overwhelming advantage (Walters *et al.*, 1991). *G. brasiliensis* is a benthic and omnivorous-opportunist species, eating preferentially benthic invertebrates in Lajes Reservoir (Santos *et al.*, 2004). Studies have reported that structurally complex habitats concentrate significantly more periphyton and invertebrates than naturally unstructured areas (McLachlan, 1970; Moring *et al.*, 1986). Although no quantitative approach had been made, many freshwater shrimps *Macrobrachium* spp. and nymphs of Odonata were caught using experimental seines in the complex structures in Lajes Reservoir. Nevertheless, *G. brasiliensis* was never found in the stomachs of large *C. kelberi* ($>$200 TL) in Lajes Reservoir (Santos *et al.*, 2001). Since *G. brasiliensis* is unlikely to be vulnerable to predation by large *C. kelberi*, and complex structures appeared to concentrate a large amount of invertebrate prey, middle complexity habitats could have effectively provided both refuge against predators as well as profitable prey for *G. brasiliensis* in Lajes Reservoir.

Middle complexity structures were slightly more attractive to *T. rendalli* than the other treatments, but this species, despite ranking among the preferred prey of large *C. kelberi* ($>$200 mm TL) in Lajes Reservoir, was never sought among ribbons of artificial vegetation. Most activities were observed in open water, near to structures, whereas the cover edges were used only occasionally. These results were very similar to those found by Bickerstaff *et al.* (1984), reporting that *Tilapia zilli* fry never retreated into bundles of artificial plants to avoid predation by juveniles of *L. macrochirus*. Similarly to *T. zilli*, *T. rendalli* may depend on tight schooling or visual barriers to escape from predators; thus middle complexity structures appeared to be effective in providing visual barriers against predators for this species. According to Walters *et al.* (1991), the presence of attached food should benefit fish using artificial structures, particularly in waters where there is little naturally available substrate. Since *T. rendalli* feeds heavily on submerged plants and periphytic algae in Lajes Reservoir (L. N. Santos, unpubl. data), and because natural substrate is usually scarce in the reservoir and a large amount of periphyton was observed covering ribbons and bunches of artificial vegetation, *T. rendalli* may use middle complexity structures as profitable feeding areas.

Implications for fish conservation and management

This study is the first to demonstrate that the deployment of complex artificial structures may expand habitats for small fish (<150 mm TL), especially cichlids, in an oligotrophic and structureless neotropical impoundment. Several studies have reported that control or non-structured habitats were less used by fish than physically complex habitats (Wilbur, 1978; Hayse and Wissing, 1996; Rold *et al.*, 1996; Freitas and Petrere, 2001; Braga, 2002). However, we have been unable to locate other reports of no fish recorded in non-structured habitats. It could be that in naturally unstructured areas of Lajes Reservoir, which prevail during most of the year, vulnerability to predation and scarcity of food resources leads to severe mortality of small fish (<150 mm TL). This may partly explain why Araújo and Santos (2001), who performed standardized fish surveys during every month of 1994, found an unexpected absence or very low abundance of small-sized species in the reservoir. If that hypothesis is true, submerged habitats play an important ecological role for small fish (<150 mm) in Lajes Reservoir, and it would be expected that deploying complex structures would lead to an increase in cichlid abundance. Since the effectiveness of artificial structures is dependent not only upon the species composition of the fish community and their general abundance but also on the availability of natural submerged habitats (Bolding *et al.*, 2004; Wills *et al.*, 2004), it seems reasonable to expect that adding artificial structures in other oligotrophic, structureless and cichlid-dominated impoundments in Brazil will lead to similar results to those found in this work. However, the issue of whether artificial structures bring about increases in population size, as opposed simply to attracting or concentrating fish, will not be conclusively solved without additional studies. These would need to target survival and growth rates of the species associated with artificial structures and natural areas of the reservoir.

There are some other issues arising from this work that must be taken into account by habitat rehabilitation programmes based on using artificial structures. First, managers should attempt to understand existing fish populations and their behavioural patterns in order to improve the effectiveness of artificial structures; in this study complex bottom treatments appeared to be the most effective in harbouring the three species of cichlids. Second, the potential of artificial structures for benefiting either indigenous species or non-native species must be addressed prior to any ecosystem intervention. In this sense, middle complexity bottom structures seem to be more suitable for conservation purposes, since they were used consistently by the indigenous *G. brasiliensis*, whereas high complexity midwater structures appear to be more profitable for fishing or species control purposes, owing to their effectiveness in sheltering the invasive *C. kelbery*. Finally, the implementation of large-scale artificial structure programmes in neotropical reservoirs should take into account the previous results obtained from small-scale projects (e.g. they will provide valuable information to define the management goals and optimize the effectiveness of artificial structures (Frissell and Nawa, 1992; Bolding *et al.*, 2004)). Knowing the results of small-scale pilot projects, managers are better able to improve the positive ecological effects (e.g. habitat rehabilitation or enhancement for native species) and to minimize the risks of detrimental impacts on fishery resources and ecosystems (e.g. favouring undesirable species or decreasing water quality) with the development of a large-scale artificial structure programme.

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