Theoretical Reservoir Ecology and its Applications, 67-83
Edited by J. G. Tundisi and M. Straškraba.

THE RELATIONSHIP BETWEEN FISH YIELD AND STOCKING DENSITY IN RESERVOIRS FROM TROPICAL AND TEMPERATE REGIONS

QUIRÓS, R.
AGRONOMY FACULTY, BUENOS AIRES UNIVERSITY, BUENOS AIRES, ARGENTINA

ABSTRACT

Direct empirical relationships between stocking density and fish yield have been documented for many sets of ponds, reservoirs, and lakes located worldwide. Exceptions, however, have often been observed. This study explores the empirical relation between stocking rate and yield in water bodies ranging from large lakes and reservoirs to ponds in both temperate and tropical regions. A variety of published data was used comprising measurements of yield, stocking density, mean size at stocking, presence of self-sustained fish populations, surface area, intensity of use, and latitude for more than 700 water bodies.

Yield was strongly related to stocking density for both the combined data, and for temperate and tropical subsets. Regressions differed significantly between temperate and tropical water bodies.

Furthermore, large water bodies with self-sustained fish populations and small systems under intensive aquaculture deviate positively from overall regression lines, in both data subsets. As expected, at low stocking densities yields are higher in tropical systems than in temperate ones. However, there were no significant differences in maximum yield between regions.

Yield varies nonlinearly with stocking density for both temperate and tropical systems. At very low stocking rates, increases in stocking correspond to little change in yield. At intermediate stockings, the rate of increase of yield accelerates with increasing stocking density; a concurrent increase in external energy inputs may be conjectured. At high stockings, yield-increasing rate decelerates, and even diminishes for very high stocking rates.

Key words: fish stocking, fish yield, tropical reservoirs, temperate reservoirs.

INTRODUCTION

In the continuum from capture to culture fisheries, stocking is the most widespread measure for reservoir fishery management in use today. For the former, as more conventional approaches to management by control of the fishery have proved incapable of limiting effort, compensation for shortfalls in recruitment caused by overfishing and environmental damage have been sought through the addition of young fish to the system (Welcomme & Bartley, 1998). Capture fisheries in inland waters, which are based on natural productivity, have generally reached levels at which the fish communities are fully exploited or are overexploited. Stocking for enhancement is the principal method used to maintain or improve stocks where production is actually (rational), or perceived to be (irrational and emotional), less than the water body could potentially sustain, but where reasons for the poor stocks cannot be identified (Cowx, 1998). Moving along the continuum from capture to culture fisheries, enhancements using fertilizers and external feeding are increasingly important to obtain higher yields (Kapetsky, 1998).

Heavy stockings usually result in higher fish yields, but stocking is only a necessary, and non-sufficient, condition to attain a successful fishery enhancement outcome. When the objective is to manage for maximize biomass, stocking should be adjusted according to reservoir natural productivity and inputs of fertilizer and feed (Quirós, 1998). For some countries, stocking has been used mainly to introduce fish for recreational fisheries and to introduce exotic for both commercial and recreational fisheries. Supplemental "precautionary" stocking for self-sustained fish populations, related to non-management schemes, is a common practice in many developing countries, as it was used in developed countries several decades ago (Cowx, 1998). For Chinese, Indian, Sri Lankan, Cuban, and northeast Brazilian reservoirs, stocking is a common practice to manage reservoirs for biomass production (Song, 1980; Sreenivasan, 1967; De Silva, 1987; Lu, 1992; De Silva *et al.*, 1992; Sugunan, 1995; Fonteles-Filho & Alves, 1995; Fonticiella *et al.*, 1995). Moreover, tilapias and cyprinids have been introduced and supplemented for reservoirs distributed worldwide, and supplemental stocking with native and introduced fish species is a usual practice to manage large water bodies and medium-sized and small reservoirs. Supplemental stocking is usually indicated when low production levels and low yields of favored fish species are seen to be due to insufficient recruitment to the fishable population. Moreover, more countries have usually reported stocking in reservoirs as a successful management measure for both recreational (managed for fish size) and commercial (usually managed for biomass) fisheries. However, numbers or weights of fish stocked are inadequate measures of management success. Stocking rate alone may be a poor indicator of survival of stocked material or of its contribution to the catch (Welcomme, 1995).

Moreover, the outcomes of stocking are determined by natural, institutional and socio-economic conditions (Lorenzen & Garaway, 1998).

Reservoir fisheries have been usually exploited on a trial-and-error basis and reservoirs have been stocked for many years but an assessment of stocking effectiveness was rarely conducted (Quirós, 1998).

Empirical relationships between fish stocking density and fish yield have been documented for some sets of reservoirs located worldwide (De Silva*et al.*, 1992; Fonticiella *et al.*, 1995; Quirós, 1994).

Exceptions, however, have often been observed (Quirós & Mari, 1999). For self-sustaining fish populations, stocking is not a good management measure when insufficient recruitment to the fishable population has not been observed (Quirós, 1998). Some water bodies stock excessive quantity of fish, which can not be supported by the naturally available food. It has been usually believed that high stocking rates would increase the survival rates (Cowx, 1998).

Statistical models for stocked fisheries and aquaculture may use explanatory variables that range from mainly environmental – trophic status indicators (e.g. morphoedaphic index, total phosphorus concentration, primary production), stocking density, fishing effort – to purely management variables – stocking density, fishing effort, fertilization and feeding type and rate – to predict fish yield (Lorenzen & Garaway, 1998).

Non-linear statistical stocking models have provided new insights into the technical basis of stocking, and allow a preliminary and simple evaluation of management outcomes (Quirós, 1998).

The main purpose of this study is to explore the empirical relation between total fish stocking density (FSD) and total fish yield (Y) in water bodies ranging from ponds to lakes in both temperate and tropical systems. A secondary purpose is to examine the hypothesis that nonlinear patterns in FSD – Y relationships are mainly associated with changes in external energy inputs for water bodies over a wide range of size. Is our intention here to show that the relationship between stocking density and fish yield might be a good indicator for stocking success when managing to maximize biomass is the objective.

Enhancements in standing fresh waters can include stocking, net and cage culture and fisheries in blocked-off arms (Kapetsky, 1998). All these stocking activities will be considered in our work. Global data sets will be employed herein to provide a worldwide perspective on stocking rate constraints on fish yield enhancements. The perspective described is global and continental rather than regional and national.

MATERIAL AND METHODS

A variety of published data was used comprising measurements of fish yield, fish stocking density, mean size at stocking, presence of self-sustained fish populations, intensity of use, lake surface area, and latitude for more than 700 water bodies from both temperate and tropical regions (Table I).

With the purpose of exploring fish stocking effects on fish yield a data base was constructed, depending on available information.

The data base includes published yield and stocking data for: a) reservoirs in Cuba (Mari, 1992; Fonticiella *et al.*, 1995), China (Song, 1980; De Silva *et al.*, 1992; Lu, 1992), India (Sreenivasan, 1967,1989; Sugunan, 1995), Mexico (Olmos *et al.*, 1992), and Sri Lanka (De Silva, 1987); b) Kentucky reservoirs (Kinman, 1995), Laurentian Great Lakes (Christie & Spangler, 1987), and European lakes (EIFAC, 1984; van Densen *et al.*, 1990); c) small and very small reservoirs in Cuba (Fonticiella *et al.*, 1995; Remedios & Cabezas, unpublished data), oxbow lakes in Bangladesh (Hazan & Middendorp, 1998), small water bodies in North America (Moehl & Davies, 1993; southern Africa (Marshall & Maes, 1994), and Latin America (Quirós, 1994) d) pond culture (Hepher & Pruginin, 1981; Middendorp, 1995; Milstein & Svirsky, 1996; PD/CRSP data base, 1998); and e) others small reservoirs and ponds distributed through temperate and tropical regions (Quirós files). Yield and stocking data were used as published, as estimated mean values for a complete year, and as estimated for a complete year secondly corrected for growing season length for temperate culture systems (Quirós files). All included water bodies were stagnant systems and had been used for culture-based fisheries or aquaculture (Table I).

Fish assemblage composition in species and altitude effects were not analyzed here.

However, both native and introduced species to reservoirs were included.

Fish stocking density (FSD) was expressed as number of fish stocked (FSD_N, number · ha^{-1} · yr^{-1}) or weight stocked (FSD_W, kg · ha^{-1} · yr^{-1}), and fish yield was expressed as gross weight (Y, kg · ha^{-1} · yr^{-1}) or net weight ($Y - FSD_W$, kg · ha^{-1} · yr^{-1}) of fish at landing, depending on data availability.

For estimations and predictions, yield and stocking data were used as published, considered as kg.ha^{-1} and number.ha^{-1} or kg.ha^{-1}, respectively.

Table I Fisheries and stocking characteristics for tropical and temperate data sets (as were published).

Variable	Tropical	Temperate
Surface area (AREA, km^2)	14.5 (0.00004 – 960)	518.5 (0.0001 – 82,414)
Fish yield (Y, kg/ha)	2512 (2 – 18,796)	2718 (0.38 – 23,717)
Latitude	14.2 (0 – 23.5)	31.3 (24 – 69)
Stocking density (FSD_N, fish · ha^{-1})	10020 (2 – 95,000)	10640 (0.4 – 437,500)
Stocking density (FSD_W, kg · ha^{-1})	451 (0.02 – 6,256)	607 (0.01 – 7,000)
Grade of intensification (#grade)	1.98 (1 – 3)	1.92 (1 – 3)

In order to take account of the condition of each system, a dummy variable (#region) was defined as 1 for water bodies situated in latitudes between 24 °N and 24 °S (tropical systems), and 2 for water bodies situated in latitudes higher than 24 °N or 24 °S (temperate systems).

Moreover, to take account of the grade of intensification for each reservoir, a second dummy variable (#grade) was defined as 1 and 2 for extensively and semi-intensively used reservoirs, respectively, and as 3 for intensive culture.

Grade of intensification was adjudicated to each water body as published. In order to stabilize the variance, all the variables except latitude, #grade, and #region, were log-transformed (Draper & Smith, 1981).

Data analysis was made by linear correlation, partial correlation, simple and multiple regression on the total data and on several data subsets (Weisberg, 1980). Stepwise multiple regression analysis was applied to the data using variables related to climate, morphometry, fisheries and stocking.

Regression analyses were performed on the entire data sets, on two data subsets grouped by latitude, and on three data subsets grouped by intensity of use.

Curvilinear trends in data and in simple regression residuals were studied using robust locally weighted regression and smoothing graphic techniques (LOWESS) (Cleveland, 1979).

The NCSS2000 statistical package (Hintze, 1997) was used.

RESULTS

Fish yield was highly and positively correlated with stocking density and grade of intensification, and was highly and inversely related to surface area (see Figure 1 and Table II).

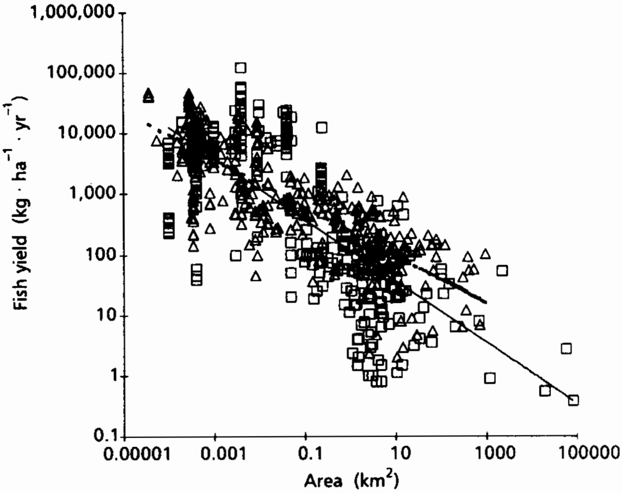


Figure 1 Relationship between fish yield (Y, kg · ha^{-1} · yr^{-1}) and water body surface area (AREA, km^2) for 709 water bodies distributed worldwide. (Δ), tropical; (□), temperate. Displayed data for yield represent mean annual averages.

Table II Correlation matrix for total data. AREA (surface area km^2); Y, gross fish yield (kg · ha^{-1} · yr^{-1}); FSD_N, stocking density in number (fish · ha^{-1} · yr^{-1}); FSD_W, stocking density in weight (kg · ha^{-1}); Y- FSD_W, net fish yield (kg · ha^{-1} · yr^{-1}); #grade (grade of intensification).

	Y	FSD_N	FSD_W	Y- FSD_W	Latitude	#grade
AREA	–0.77	–0.79	–0.78	–0.69	0.26	–0.70
	(n = 709)	(n = 691)	(n = 490)	(n = 490)	(n = 709)	(n = 709)
Y	1	0.80	0.88	0.89	–0.17	0.83
		(n = 691)	(n = 490)	(n = 490)	(n = 709)	(n = 709)
FSD_N		1	0.90	–0.72	–0.25	0.70
			(n = 476)	(n = 476)	(n = 691)	(n = 691)
FSD_W			1	0.69	–0.23	0.76
				(n = 490)	(n = 490)	(n = 490)
Y- FSD_W				1	–0.16	0.74
					(n = 490)	(n = 490)
Latitude					1	–0.12
						(n = 709)

The direct relationships between yield and stocking density or grade of intensification were also significant when surface area was held constant in partial correlation analyses ($r = 0.69$ and $r = 0.63$, respectively, $P < 0.0001$).

However, the inverse relationship between yield and reservoir area was no longer significant when stocking density and grade of intensification were held constant ($r = -0.23$, $P < 0.001$). Fish yield was strongly related to fish stocking density in number and in weight for the combined data [equations (1) and (2), $P < 0.0001$], and for tropical [equations (3) and (4), $P < 0.0001$] and temperate [equations (5) and (6), $P < 0.0001$] subsets.

The regression equations for the relationship between stocking rates and fish yields were as follows.

Tropical and temperate reservoirs

$$\log_e Y = -0.454\ (0.215) + 0.856\ (0.025) \log_e FSD_N$$

$$(n = 691, R^2 = 0.634) \tag{1}$$

$$\log_e Y = 3.755\ (0.095) + 0.703\ (0.017) \log_e FSD_W$$

$$(n = 490, R^2 = 0.769) \tag{2}$$

Tropical reservoirs

$$\log_e Y = 0.430\ (0.240) + 0.774\ (0.027) \log_e FSD_N$$

$$(n = 389, R^2 = 0.676) \tag{3}$$

$$\log_e Y = 4.553\ (0.108) + 0.594\ (0.020) \log_e FSD_W$$

$$(n = 274, R^2 = 0.770) \tag{4}$$

Temperate reservoirs

$$\log_e Y = -1.215\ (0.359) + 0.920\ (0.042) \log_e FSD_N$$

$$(n = 302, R^2 = 0.611) \tag{5}$$

$$\log_e Y = 2.903\ (0.141) + 0.812\ (0.026) \log_e FSD_W$$

$$(n = 216, R^2 = 0.820) \tag{6}$$

Fish yield was highly related to stocking in semi-intensively and intensively used reservoirs ($R^2 = 0.66$, $n = 157$; $R^2 = 0.64$, $n = 157$, both with $P < 0.001$, for #grade 2 and 3, respectively). Furthermore, for extensively used reservoirs, total fish yield was significantly but lightly related to total fish stocking density ($R^2 = 0.27$, $n = 176$, $P < 0.001$).

Regressions differed significantly between temperate and tropical water bodies ($F = 46.6$, $P < 0.0001$) and among the three values of fishery grade of intensification ($F = 62.4$, $P < 0.0001$).

Moreover, regression models were significantly different for the six combinations of #region and #grade dummy variables ($F = 58.8$, $P < 0.0001$). Therefore, a six lines regression model will be better that one line total model to predict stocking output (Quiros, unpublished data).

Our results indicate that reservoir area or latitude are not the best statistical variables to explain total fish yield variability in reservoirs managed for biomass. Moreover, regional regression models including fish stocking density and grade of intensification as independent variables will explain fish yield variability better for this type of reservoir fisheries.

For water bodies ranging from large reservoirs to small reservoirs and ponds, total fish yield varies non-linearly with fish stocking density (see Figure 2).

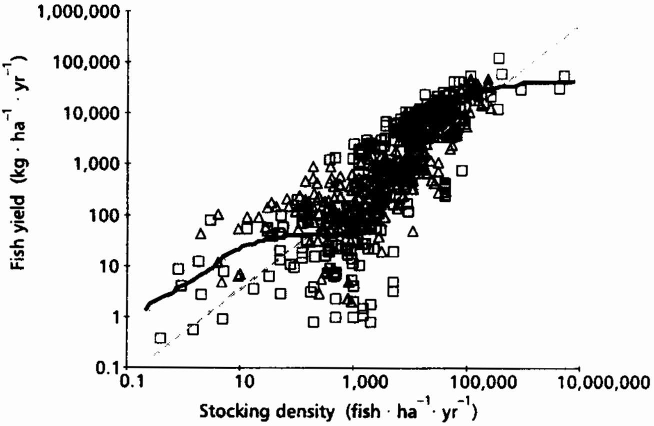


Figure 2 Relationship between fish yield (Y, kg · ha · yr) and fish stocking density in number (FSDN, fish · ha^{-1} · yr^{-1}) for 691 water bodies distributed worldwide. (Δ), tropical; (□), temperate. Displayed data represent mean annual averages.

The LOWESS analysis showed a sigmoidal relation between fish stocking density and fish yield.

At very low stocking rates, increases in stocking density correspond to little change in fish yield, in coincidence with the presence of self-sustaining fish populations. Some systems deviate negatively, mainly for reservoirs depleted of fish or with fish recruitment problems.

At intermediate stocking rates (5-150 kg · ha^{-1}), the rate of increase of fish yield accelerates with increasing stocking density; a concurrent increase in external energy inputs may be hypothesized.

The rate of increase of fish yield decreases markedly once stocking rate surpasses 250-500 kg · ha^{-1}.

For temperate and tropical regions, a mean maximum fish yield of 11,000 and 13,000 kg · ha^{-1}, respectively, may be predicted for stagnant small water bodies. For data as were published, a sharp increase in yield is noticeable for stocking densities between 500 and 800 fish · ha or between 5 and 150 kg · ha^{-1}. When the data subsets were analyzed separately, there were no significant differences in maximum fish yield between temperate and tropical systems.

Large water bodies with self-sustained fish populations and small water bodies under intensive aquaculture deviate positively from overall regression lines, for both temperate and tropical data subsets (see Figure 3).

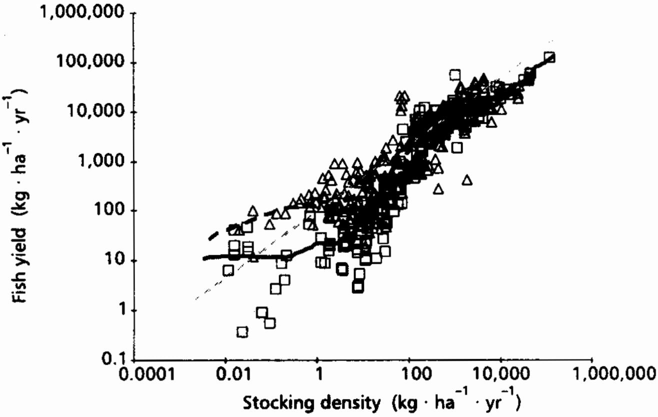


Figure 3 Relationships between fish yield (Y, kg · ha^{-1} · yr) and fish stocking density in weight (FSDW, kg · ha^{-1} · yr^{-1}) for tropical (-----, n = 274) and temperate (——, n = 216) water bodies. (Δ), tropical; (☐), temperate. Displayed data represent mean annual averages.

This result also suggests that fish yield varies nonlinearly with fish stocking density in both tropical and temperate regions. At low stocking densities, fish yields are higher in tropical systems than in temperate ones.

From data as were used in this paper, there is a sharp increase in fish yields with fish stocking densities between 10-15 and 250-300 kg · ha^{-1} · yr^{-1}. For the combined data, a maximum fish yield of 15,000-30,000 kg · ha^{-1} · yr^{-1} is reached for fish stocking densities above 1000-1200 kg · ha^{-1} · yr^{-1}. However, at comparable stocking rates some sites showed higher fish yields.

Multiple linear regression models among total data sets have shown lightly differences, but LOWESS fitting models displayed large differences, mainly for intensive culture (#grade = 3). These latter results are related to consider different time scales for data analyses. In a yearly basis, tropical systems will have higher yield than temperate ones. The most significant changes in slope were concurrent to the changes in the grade of intensification, regardless the type of data we had used.

The non-linear relation between fish yield and stocking rate was better displayed when residuals to stocking density – fish yield regressions had been plotted against stocking density (see Figures 4 and 5). Mexican, Sri Lankan, and half of Kentucky reservoirs and large and some medium-sized Cuban reservoirs deviate positively at the lower stocking densities. At intermediate stocking rates, reservoirs deviate both sides from the log-log linear regression equation, although most reservoirs deviate negatively from the regression line. This group encompasses most of Chinese and Indian reservoirs, a half of medium-sized and small Cuban reservoirs and one third of other ponds and very small reservoirs through tropical and temperate regions. Furthermore, at high stocking densities most small reservoirs and ponds have fish yields higher than predicted from the linear regression model.

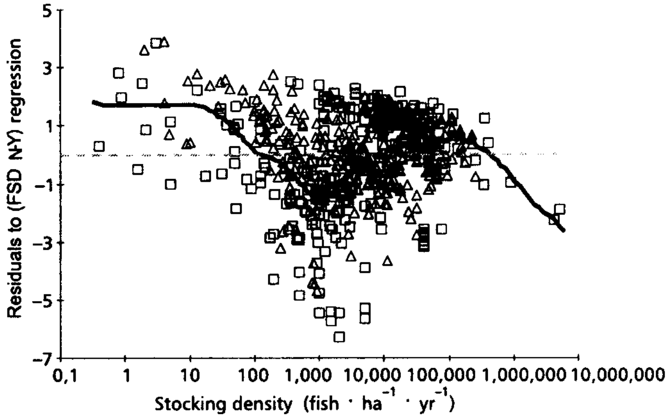


Figure 4 Relationship between residuals to stocking density in number (FSDN) – fish yield (Y) regression and stocking density in numbers (FSD_N, fish · ha^{-1} · yr^{-1}) for 691 water bodies distributed worldwide. (Δ), tropical; (□), temperate. Displayed data represent mean annual averages.

Grade of intensification (#grade) and region (#region) were important variables explaining total fish yield variability, in spite of reservoir area, after stocking density effects have been accounted for.

In multiple regression analyses for the total data, incorporation of #region and #grade improved the explained variation in yield from 77% to 86% and from 63% to 79% for stocking density in weight (FSD_W, n = 490) and in number (FSD_N, n = 691), respectively. Moreover, the distribution of residuals has not changed qualitatively when compared with residuals to the FSD-Y regression model (see Figure 4). This latter result indicates that nonlinear patterns in FSD-Y residual distributions are related more to overstocking or environmental constrains than to regional characteristics, although underestimate of yield or fish poaching effects can not be disregarded (Wolf D. Hartmann, pers. comm.).

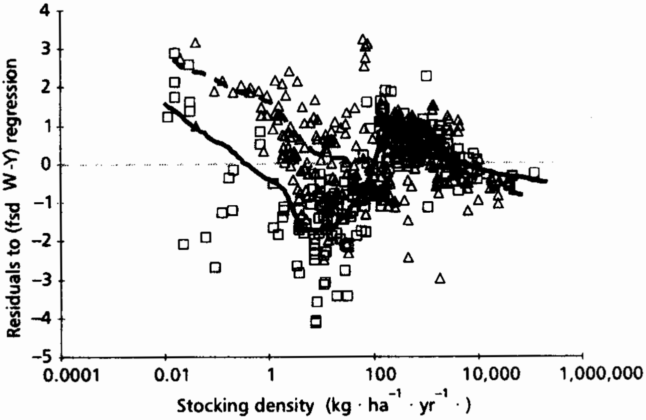
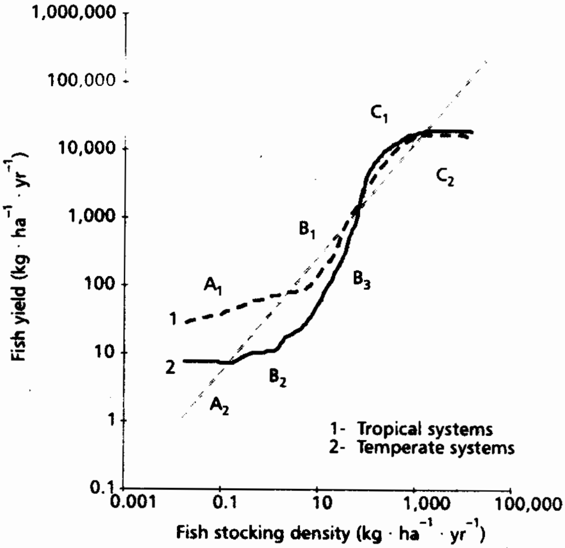


Figure 5 Relationships between residuals to stocking density in weight (FSDW) – fish yield (Y) regression and stocking density in weight (FSD_W, kg · ha^{-1} · yr^{-1}) for tropical (------, n = 274) and temperate (——, n = 216) water bodies. (Δ), tropical; (□), temperate. Displayed data represent mean annual averages.

Stocking effectiveness for individual reservoirs could be evaluated using the obtained relationships between fish yield and stocking density. For both tropical and temperate regions, three main groups of systems can be distinguish from the general distribution pattern for stocked reservoirs (see Figures 6 and 7):

- **A** This first group encompasses large reservoirs where self-sustaining fish populations are present. The water bodies included in this group have relatively low fish yields and low stocking densities matched to the presence of self-sustaining fish populations. Stocking may be enhancing fish populations (both self-sustaining and non-reproducing) increasing recruitment to the fishable stocks. For this group, total fish yield is usually higher than predicted by the lineal relation between yield and stocking (A1). Mexican and Sri Lankan reservoirs, and large and some medium-sized Cuban and Indian reservoirs are included in this subgroup. However, for some systems yield is lower than predicted from linear regression models. For this latter group (A2) some environmental constrains may be suspected (e.g. the Laurentian Great Lakes).
- **B** This group includes medium-sized and small reservoirs used for semi-intensive fish production. They have been stocked from medium to large stocking densities. For this group as a whole, there is a clear increasing relation between stocking density and fish yield, a concurrent increase in fertilization and supplemental feeding may be hypothesized. However, three chief subgroups can be characterized:
  - **B_1** Medium-sized and small reservoirs that deviate positively from the general log-log regression model relating fish yield to fish stocking density. For this group, stocking linked to external energy inputs, like fertilizers, and/or to the presence of self-sustaining fish populations may be beneficial. Almost one third of the analyzed Cuban reservoirs belong to this subgroup.

- **B_2** Medium-sized reservoirs used for extensive culture-based fisheries. Very often self-sustaining fish populations are present, stocking is not adjusted to carrying capacity, or competitors and predators have not been eliminated. These reservoirs deviate negatively from the general log-log regression model. Almost half of medium-sized Cuban reservoirs and most of studied Indian and Chinese reservoirs belong to this subgroup.
- **B_3** Small and very small reservoirs used for semi-intensive culture. Very often stocking is incompatible with fertilization and/or feeding levels and, therefore, fish yield is lower than predicted from the general log-log regression model. More than half of small and very small Cuban reservoirs and one fourth of other ponds and very small reservoirs situated in tropical and temperate regions belong to this subset.



Trophic state indicators and management variables		
→	fish production	→
←	water quality	←
←	biodiversity	←
→	morphoedaphic index	→
→	material inputs	→
←	surface area	←
→	fishing effort density	←
→	fish stocking density	→

Figure 6 Relationships between fish yield and fish stocking density. General distribution patterns for tropical and temperate stocked reservoirs. The axis values are for data as were published.

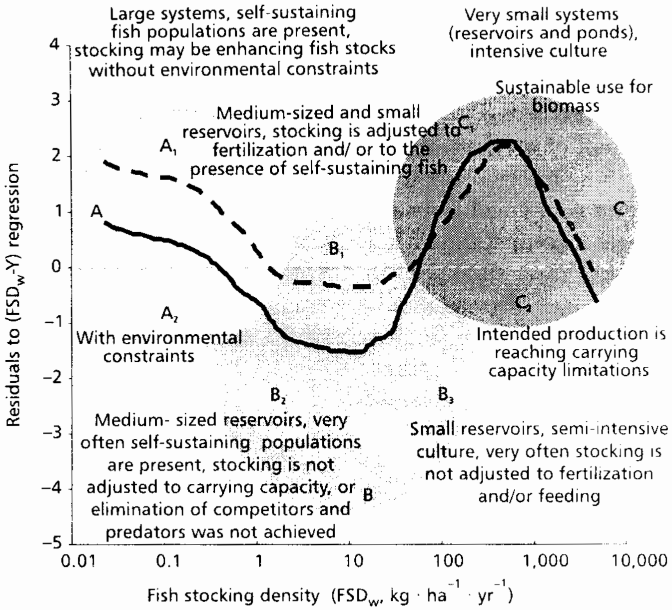


Figure 7 Relationships between residuals to stocking density – fish yield (Y) regression and stocking density. General distribution patterns for tropical and temperate stocked reservoirs. The axis values are for data as were published.

C This group encompasses very small reservoirs and ponds used for intensive fish production where stocking density is linked to fertilization and feeding levels may be beneficial (C_1). At the highest levels of fish stocking density, fish yield may be far over carrying capacity for stagnant water bodies (C_2). It can generally be assumed that the degree of exploitation of water bodies of this subgroup is close to the sustainable maximum, despite omnivorous fish species in culture.

Management measures to improve culture-based fisheries and to correct mismanagement are, in some way, implicit in the description of each reservoir subgroup. A similar general pattern has been observed for a data set for reservoirs situated in tropical Latin America (Quirós, 1998).

DISCUSSION AND CONCLUSIONS

Heavy stockings resulted in higher fish yields, but stocking was only a necessary, and non-sufficient, condition to attain a successful enhancement outcome. Other conditions, like presence of self-sustained and/or non-reproducing fish populations, exploitation of stocked fish, external inputs (fertilizers and/or food) adapted to stocking rates, and, obviously, stocking rates adjusted to water body natural carrying capacity and/or external inputs, also must be attended. The relationship between fish yield and stocking density is usually a good indicator for stocking success when managing to maximize biomass is the objective. Analysis of existing data sets demonstrates that strong correlation exist between stocking densities and yield, and between yield and area of water body stocked. These relationships indicate that stocking is a biologically viable practice for species that do not have strongly self-reproducing populations or where the carrying capacity of the water have not been reached.

There were no significant differences between tropical and temperate highly stocked systems, but small and very small tropical reservoirs may provide the equivalent, in fish farming terms, of two harvest per year, but these kind of reservoirs located in temperate regions are discontinuous growth systems that can produce the equivalent of about one harvest per year, or less (Kapetsky, 1998). Most of data we have used for small and very small reservoirs and ponds come from short time culture experiences and should not be assigned to entire year harvests. Anyway, the general curvilinear pattern we obtained remains unchanged despite of the period we had taken for integrating yield and stocking data. The low-significant relationship between total fish yield and stocking density for reservoirs under extensive exploitation is to be expected. Most of the reservoirs included in that subgroup have self-sustaining fish populations, and in more than half of those reservoirs self-sustaining populations might not have recruitment failures. It is to be expected that morphoedaphic factors (Ryder, 1965) and hydrology (water residence time) will have a great influence on fish production of both tropical (Quirós, 1998) and temperate reservoirs.

There is not any doubt that most reservoir fisheries are based on stocking. However, if we accept categorized fish stocking simply as introductory (introducing a species or genetic variety that is not native to the recipient water body but that is expected to establish a self-sustaining population there), as maintenance (repeated annual stocking to create a population of fish that could not reproduce in the water body), or as supplemental (augmenting a self-reproducing population by stocking fish of the same species) (White *et al.*, 1995), we can conclude that some reservoir fisheries are well managed capture fisheries based mainly on introductory stocking, and most reservoir fisheries are cyprinid fisheries based on maintenance stocking. However, in some cases stocking has not always been suited to self-sustaining fish populations and to non-reproducing fish species in the same reservoirs (Quirós & Mari, 1999). It should be noted that the activities carried out in most of the successful cases are not strictly stocking as the managers further enhance production through fertilization and eventually through external feeding, so it is more akin to extensive and semi-intensive aquaculture (Cowx 1998). Therefore, a continuum from capture fisheries to culture fisheries and aquaculture was expected.

Fisheries managed for biomass have problems with the supplementation concept, similar to, fisheries managed for biodiversity. The supplementation concept seems out of keeping with ecological and rational management (White *et al.*, 1995). In some sense Chinese, Indian, and Cuban reservoir fisheries have been well-managed reservoir fisheries. However, indiscriminate supplemental overstocking is not a good way to enhance freshwater fisheries. Moreover, supplemental stocking programs for self-sustaining fish populations in reservoirs will need to be studied and analyzed in a case by case basis.

Surface area effects on fish yield were not displayed for tropical and temperate reservoirs after stocking rate and intensification grade effects had been accounted for. The supposition that competition and predation would be greater in larger reservoirs and therefore survival rates will be reduced was not apparent for both tropical and temperate reservoirs. The efficiency of stocking in terms yield per unit stocked (Y/ FSD) roughly increased with the size of the stocked water bodies. For highly heterogeneous wide data sets, a hidden direct effect of self-sustaining fish populations on efficiency of stocking may be suspected. Those facts could be explained because a management tendency to stock fish at lower densities into larger water bodies (Welcomme & Bartley, 1998).

Some other reservoir data sets have been studied worldwide for the relation between fish yield and stocking rate (De Silva *et al.*, 1992; Quirós, 1998). However, this study is one of the firsts where reservoirs with very different situation, size, and fishery enhancement level have been compared. Regardless of the wide-scale results we have obtained, we believe these general patterns may be useful to manage a group of reservoirs for culture-based fisheries. However, generalized statistical models vary in their accuracy and should be viewed with caution when applied to the management of individual sites. FSD-Y linear regression models for total data are a poor tool to predict stocking outputs. The results obtained from reservoir comparisons are "mean effect results" and many exceptions for individual reservoirs can be expected. The regression models we have presented were not derived from empirical experience on comparable data sets. Therefore, to be effective and useable for management models for data subsets have to be obtained (Quirós, unpublished data). Our intention was to study non-linear trends in stocking-yield data for reservoirs rather than to develop predictive regression models. LOWESS fitting gave conceptual models to understand stocking process in reservoirs. We have analyzed data by focusing more on trends than on absolute slopes. Discontinuities may be caused by scale-limited strategies of fisheries management and social- styles that develop in response to physical boundaries and economic forces. I conclude, therefore, that discontinuities in stocking rate-fish yield relationship are general in wide aquatic system comparisons and associated with changes in external man driving forces as stocking, fertilization and external feeding. The discontinuities shown earlier at a continental level (Quirós, 1998) will also occur for water bodies distributed worldwide.

MANAGEMENT IMPLICATIONS

Stocking is a much used, but all too often abused, tool in fisheries management. This is partly because of the misconception that stocking will always improve yield from fisheries (Cowx, 1998). For self-sustaining fish populations, stocking is not a good management measure when insufficient recruitment to the fishable population has not been observed. Supplemental stocking programs may be justified in some other cases (White *et al.*, 1995), but generally are undesirable from economic standpoint when managing for biomass is the main objective. Supplemental stocking is one step in the process attempted to increase yields from natural capture and recreational fisheries to intensive aquaculture (Welcomme, 1995). It is clear that where there is adequate natural reproduction stocking may well be superfluous, as in the case of tilapias in Cuban reservoirs (Quirós & Mari, 1999). For introduced species that need continuous addition of young fish to develop fishable stocks, stocking must be adjusted to reservoir's natural carrying capacity (climate and morphoedaphic factors) (Quirós, 1994; Fonteles-Filho &

Alves, 1995), to diffuse external organic matter inputs, and to external inputs of fertilizers and food (Song, 1980; Lu, 1992; Quirós, 1994, among many others).

Stocking is a hot issue for fisheries managers worldwide. Welcomme (1995) mentioned cost and survival as the two main factors that influence the size chosen for stocking material. However, in Latin America, socio-economic constraints like public impulses and political pressures among other non-rational factors, also constrain both stocking number and mean fish weight at stocking.

The obtained general pattern for stocked reservoirs can be used as a general, not detailed, tool for rationalizing stocking, to assess stocking programs, or to correct mismanagement measures and obtain successful outcomes.

Stocking is not a magic management measure for resolving almost any problem in freshwater fisheries. For some countries, despite considerable differences, current stocking practices (Olmos *et al.*, 1992; Fonticiella *et al.*, 1995; Fonteles-Filho & Alves, 1995, among many others) have to change from random stocking to decisions based on the productive capacities of reservoirs, sound fisheries enhancement measures, and fish community compatibility, rather than trying to exceed natural or actual capacity just with stocking. Random supplemental overstocking is not the best way to enhance freshwater fisheries. Stocking should be adjusted to the presence of self-sustaining fish populations and should be assessed for each reservoir.

When the objective is to maximize the biomass, stocking should be matched with inputs of fertilizers and food, as exemplified by some semi-intensively managed small and very small reservoirs. Supplemental stocking programs for self-sustaining fish populations need to be studied and analyzed on a case-by-case basis. To stock fish continuously in extensively and semi-intensively used reservoirs expecting total fish yield increases, supported or not by an hypothetical "filling of vacant niches", has not a clear answer from the results obtained for analyzed reservoirs. To what extent the more productive reservoirs have been heavily stocked is a question, we can not answer here. For medium-sized reservoirs, our results indicate that heavily stocked reservoirs were not often the most productive. Cuban and Indian results suggest that for extensively used reservoirs, they were intensively fished and stocked heavily in the same years (Sugunan, 1995; Quirós & Mari, 1999).

A number of measures are available for enhancing of fish production of reservoirs ranging from simple stocking to full control of the fish assemblage and the productivity of the water. The greater the control needed, the greater the human and ecological impacts are likely to be (see Figure 6).

REFERENCES

CHRISTIE, W. J. & SPANGLER, G. R. (eds.), 1987, International Symposium on Stock Assessment and Yield Prediction. *Can. J. Fish. Aquat. Sci.*, 44 (Suppl. 2) (several papers).

CLEVELAND, W. S., 1979, Robust locally weighted regression and smoothing scatterplots. *J. Amer. Stat. Assoc., 74*: 829-836.

COWX, I. G., 1998, An appraisal of stocking strategies in the light of developing country constraints. pp. 119-132. *In*: T. Petr (ed.), ***Inland fishery enhancement***. Papers presented at the FAO/DFID Expert Consultation on Inland Fishery Enhancements. Dhaka, Bangladesh, 7-11 April, 1997. *FAO Fisheries Technical Paper,* 374. Rome, FAO. 463p.

DE SILVA, S. S., 1987, Stocking practices in Sri Lanka. pp. 224-232. *In*: T. Petr (ed.), Reports and Papers presented at the Indo-Pacific Fishery Commission Expert Consultation on the larger Indo-Pacific islands. Bangkok, Thailand, 4-9 August, 1986. *FAO Fisheries Report,* 371 (Suppl. 1).

DE SILVA, S. S., LIN, Y. & TANG, G., 1992, Possible yield-predictive models based on morphometric characteristics and stocking rates for three groups of Chinese reservoirs. *Fish. Res.*, *13*: 369-380.

DRAPER, N. R. & SMITH, H., 1981, *Applied regression analysis*. John Wiley & Sons, Inc., New York, USA. 709p.

EIFAC, 1984, Documents presented at the symposium on stock enhancement in the management of freshwater fish. Vol. 2. Introductions and transplantations. Budapest, Hungary, 31 May-2 June, 1982. European Inland Fisheries Advisory Commission. *EIFAC Technical Paper*, 42 Suppl. Vol. 2: 283-554. Rome, FAO (several papers).

FONTELES-FILHO, A. A. & ALVES, A. L., 1995, Produção pesqueira e produtividade em açudes públicos do Nordeste do Brasil. *B. Inst. Pesca*, *22*: 1-14.

FONTICIELLA, D. W., ARBOLEYA, Z. & DIAZ PEREZ, G., 1995, La repoblación como forma de manejo de pesquerias en la acuicultura de Cuba. *COPESCAL Documento Ocasional*., 10. Roma, FAO. 45p.

HAZAN, M. R. & MIDDENDORP, H. A. J., 1998, Optimizing stocking density of carp fingerlings through modelling of the carp yield in relation to average water transparency in enhanced fisheries in semi-closed water bodies in western Bangladesh. pp. 159-168. *In*: T. Petr (ed.), *Inland fishery enhancement*. Papers presented at the FAO/DFID Expert Consultation on Inland Fishery Enhancements. Dhaka, Bangladesh, 7-11 April, 1997. *FAO Fisheries Technical Paper*, 374. Rome, FAO.

HEPHER, B. & PRUGININ, Y., 1981, *Commercial fish farming*. Wiley-Interscience, NY, 261p.

HINTZE, J. L., 1997, *Number cruncher statistical system*. NCSS 97. User's guide I. Dr. Jerry L. Hintze. Kaysville, Utah, USA, 570p.

KAPETSKY, J. M., 1998, Geography and constrains on inland fishery enhancements. pp. 37-63. *In*: T. Petr (ed.), *Inland fishery enhancement*. Papers presented at the FAO/DFID Expert Consultation on Inland Fishery Enhancements. Dhaka, Bangladesh, 7-11 April, 1997. *FAO Fisheries Technical Paper*, 374. Rome, FAO.

KINMAN, B., 1995, Use of cultured fish put-grow-and-take fisheries in Kentucky impoundments. *American Fisheries Society Symposium*, *15*: 518-526.

LORENZEN, K. & GARAWAY, C. J., 1998, How predictable is the outcome of stocking? pp. 133-152). *In*: T. Petr (ed.), *Inland fishery enhancement*. Papers presented at the FAO/DFID Expert Consultation on Inland Fishery Enhancements. Dhaka, Bangladesh, 7-11 April, 1997. *FAO Fisheries Technical Paper*, 374. Rome, FAO.

LU, X. (comp.), 1992, Fishery management approaches in small reservoirs in China. *FAO Fisheries Circular*, *854*. Rome, FAO. 69p.

MARI, A., 1992, Pesquerias derivadas de la acuicultura en aguas interiores de Cuba. pp. 72- 105. *In*: *Manejo y explotacion acuicola de embalses de agua dulce en America Latina*. Proyecto GCP/RLA/075/ITA. Documento de Campo Nº 1.

MARSHALL, B. & MAES, M., 1994, Small water bodies and their fisheries in southern Africa. *CIFA Technical Paper* 29. Rome, FAO. 68p.

MIDDENDORP, A. J., 1995, Pond farming of Nile tilapia, *Oreochromis niloticus* (L), in northern Cameroon. Feeding combinations of cottonseed cake and brewery waste in fingerling culture, hand-sexed male monosex culture, and mixed culture with police-fish, *Clarias gariepinus* (Burchell). *Aquaculture Research 26*: 715-722.

MILSTEIN, A. & SVIRSKY, F., 1996, Effects of fish species combinations on water chemistry and plankton composition in earthen fish ponds. *Aquaculture Research*, *27*: 79-90.

MOEHL Jr., J. F. & DAVIS, W. D., 1993, Fisheries intensification in small water bodies. A review for North America. *FAO Fisheries Technical Paper*, 333. Rome, FAO. 44p.

OLMOS, M. E., QUINTANA, A., BANDA, A., VELOZ, Y. A., ALVARADO, J. D., ISLAS, J. A., PEREZ-GALÍCIA, M. & VALDIVIESO, J., 1992, Situación actual y perspectivas de las pesquerias derivadas de la acuicultura en Mexico. pp. 106-162. *In*: *Manejo y explotación acuicola de embalses de agua dulce en America Latina*. Proyecto GCP/RLA/075/ITA. Documento de Campo Nº 1.

PD/CRSP, 1998, *Pond Dynamics/Aquaculture Collaborative Research Support Program*. Data Base. Oregon State University, Office of International Research and Development, Corvallis, Oregon, USA. `http://www.orst.edu/dept/crsp/pubs/publications`

QUIRÓS, R., 1994, Intensificación de la pesca en los pequeños cuerpos de agua en America Latina y el Caribe. *COPESCAL Documento Ocasional* Nº 8, Rome, FAO. 41p.

QUIRÓS, R., 1998, Reservoir stocking in Latin America, an evaluation. pp. 91-117. *In*: T. Petr (ed.), *Inland fishery enhancement*. Papers presented at the FAO/DFID Expert Consultation on Inland Fishery Enhancements. Dhaka, Bangladesh, 7-11 April, 1997. *FAO Fisheries Technical Paper,* 374. Rome, FAO. 463p.

QUIRÓS, R. & MARI, A., 1999, Factors contributing to the outcome of stocking programmes in Cuban reservoirs. *Fisheries Management and Ecology*, *6*(*3*): 241-254.

RYDER, R. A., 1965, A method for estimating the potential fish production of north-temperate lakes. *Trans. Amer. Fish. Soc.*, *94*: 214-218.

SREENIVASAN, A., 1967, Fish production in some rural demostration ponds in Madras (India) with an account of the chemistry of water and soil. pp. 179-197. *In*: T. V. R. Pillay Proceedings of the FAO world symposium on warm-water pond fish culture, Rome, Italy, 18-25 May 1966. Vol. 3. Review and experience papers of meetings 2 and 3. *FAO Fisheries Report,* 44 (Vol. 3), 423p.

SREENIVASAN, A., 1989, Fish stock enhancement in larger Indo-Pacific inland water bodies using carps and tilapias. pp. 6-33. *In*: T. Petr (ed.), The use of cyprinids in the fisheries management of larger inland water bodies of the Indo-Pacific. *FAO Fisheries Report,* 405 (Suppl.). Rome, FAO.

SONG, Z., 1980, Manual of small-scale reservoir fish culture. *FAO Fisheries Circular* 727. Rome, FAO, 18p.

SUGUNAN, V. V., 1995, Reservoir fisheries of India. *FAO Fisheries Technical Paper* 345. Rome, FAO, 423p.

VAN DENSEN, W. L. T., STEINMETZ, B. & HUGHES, R. H., (eds.), 1990, Management of freshwater fisheries: proceedings of a symposium organized by the European Inland Fisheries Advisory Commission. Goteborg, Sweden, 31 May-3 June, 1988. Wageningen, PUDOC, 649p. (several papers).

WEISBERG, S., 1980, *Applied linear regression*. John Wiley & Sons, Inc., New York, USA. 283p.

WELCOMME, R. L., 1995, Evaluation of stocking and introductions as management tools. pp. 397-413. *In*: I. G. Cowx (ed.), *Stocking and Introductions of Fish*. Fishing News Books, Blackwell Science Ltd. Oxford, UK.

WELCOMME, R. & BARTLEY, D. M., 1998, An evaluation of present techniques for the enhancement of fisheries. pp. 1-35. *In*: T. Petr (ed.), *Inland fishery enhancement*. Papers presented at the FAO/DFID Expert Consultation on Inland Fishery Enhancements. Dhaka, Bangladesh, 7-11 April, 1997. *FAO Fisheries Technical Paper* 374. Rome, FAO.

WHITE, R. J., KARR, J. R. & NEHLSEN, W., 1995, Better roles for fish stocking in aquatic resource management. *Amer. Fish. Soc. Symp.*, *15*: 527-547.