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Regional application of a fish yield estimation procedure to lakes in north-east Germany

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Abstract

Primary production and total phosphorus, respectively, have recently been used as the main variables to estimate the fish yield potential of lakes. In order to improve the accuracy of the estimation procedure for regional applications, two major adaptations were implemented. Both the relations between total phosphorus and primary production as well as primary production and corresponding fish yield potential were adjusted to specific regional conditions in north-east Germany and production patterns in shallow lakes, respectively. Applied to 786 lakes, the adapted procedure led to estimated fish yield potentials in the range of 8 … 67 kg/ha · a with shallow lakes showing significantly higher potentials than stratified ones. A comparison of estimated yield potentials with current yield statistics revealed an improved conformity of estimates attained by using the adapted procedure.

Key words: Fish yield estimation – nutrient dynamics – primary production – shallow lakes

Introduction

The assessment of fish stocks and their potential production in inland water bodies can be carried out by a variety of methods depending on the quality of available input data and the desired precision of the result (Cowx 2002). In cases, where a rough evaluation of fish biomass or fish yield for a number of water bodies is in question, a procedure applicable to all types of waters in the region of concern at a reasonable effort for data collection is needed. A typical target of such evaluations is the taxation of fishing rights in dependence to the specific fish yield potential of different water bodies. For a general calculation of fish biomass (FB) or fish yield potential (FYP) in lakes and reservoirs on a restricted level of precision, a variety of empirically derived relations between FYP or FB and either total phosphorus (TP), chlorophyll *a* or primary production of phytoplankton (PP) have been published and reviewed, respectively (Dillon & Rigler 1974; Oglesby 1977; Liang et al. 1981; Bulon & Vinberg 1981; Hanson & Leggett 1982; Peters 1986; Leach et al. 1987; Downing et al. 1990; Quiros 1990, 1991; Barthelmes 1992; Downing & Plante 1993; Nürnberg 1996; Knösche & Barthelmes 1998). Because TP is much easier and less expensive to measure than PP or chlorophyll *a*, and is sufficiently well correlated to PP the latter can be calculated from representative TP-values (Koschel et al. 1981; Barthelmes 1992).

The most recently developed fish yield estimation procedure of Knösche & Barthelmes (1998) is acknowledging this fact and is using PP calculated from TP-values as the main variable. For the estimation of the fish yield potential of 786 lakes in north-east Germany, this procedure has been chosen because of promising first results from a number of lakes (Knösche &

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BARTHELMES 1998). However, the original procedure incorporates severe drawbacks in terms of its applicability to shallow lakes as well as to specific regional conditions. Therefore, we implemented a number of adaptations which are presented in this paper besides the results obtained when the adapted procedure was applied to a wide range of lakes in north-east Germany.

Application of the general fish yield estimation procedure of KNÖSCHE & BARTHELMES (1998) to shallow lakes in north-east Germany

Calculating primary production from total phosphorus in shallow lakes

The fish yield estimation procedure of KNÖSCHE & BARTHELMES (1998) is basically founded on the extent of PP during the vegetation period. Although PP is influenced not only by TP but also by a number of site specific variables, BARTHELMES (1992) proposed for practical reasons to calculate PP from spring TP-values rather than to measure chlorophyll *a* or PP directly. The conversion of TP into PP relies on an equation published by KOSCHEL et al. (1981) as PP [g C/m^2 · a] = 148 · logTP [µg/l] – 39.6. This relation between PP and spring maximum TP was empirically derived from eight stratified German hardwater lakes. In the region of concern in north-east Germany, shallow lakes are prevailing. In such lakes, seasonal TP-concentration follows a different pattern compared to stratified lakes. Due to remobilisation effects in the sediment as well as frequent mixing of the whole water column, the TP pool of shallow lakes is experiencing multiple turn over within a vegetation period. It is therefore able to sustain a higher phytoplankton production as a comparable TP-value in stratified lakes. Consequently, the equation of KOSCHEL et al. (1981) leads to an underestimation of primary production in shallow lakes and is therefore not applicable to waters of this type (KRUMBECK et al. 2000).

The German States Association for Water (1998) published an empirically derived system to determine the trophic state of lakes from four basic parameters, amongst them TP-value during spring turnover. For each trophic index and correlated PP-value, a corresponding TP-value at spring turnover is presented separately for stratified and shallow lakes (Table 1). A comparison of TP-values in stratified and shallow lakes at a similar trophic index is leading to the following correlation:

$$TP_1 = 1.48198 \cdot TP_2^{1.2278}$$

where TP_1 = TP in stratified lakes leading to a certain trophic index and TP_2 = TP in shallow lakes leading to the same trophic index.

Table 1. Spring TP in stratified and shallow lakes and corresponding trophic index* (extracted from German States Association for Water 1998).

Trophic Index	Spring TP of stratified lakes (µg/l, n = 105)	Spring TP of shallow lakes (µg/l, n = 65)	Trophic class
0.5	2	–	oligotrophic
1.1	6	–	oligotrophic
1.6	14	–	mesotrophic
2.1	30	12	mesotrophic
2.6	69	23	eutrophic 1
3.1	153	44	eutrophic 2
3.6	348	86	polytrophic 1
4.1	>500	166	polytrophic 2
4.6	–	324	hypertrophic
5.0	–	>500	hypertrophic

* "Trophic index" is an integrated numerical parameter of lakes trophic level calculated from average summer chlorophyll *a*, Secchi depth, spring TP and summer TP.

Using this equation, we transformed measured spring TP-values of shallow lakes into corresponding values for stratified lakes with a similar trophic index and therefore a similar PP-value. According to the German States Association for Water (1998), at TP-values >500 µg/l in stratified lakes and >300 µg/l in shallow lakes PP is not limited by TP but other parameters like light availability (Table 1). Consequently, we restricted measured TP values of study lakes to a maximum of 500 µg/l and 300 µg/l for stratified and shallow lakes, respectively. Thereafter, transformed TP-values of shallow lakes were used for calculating PP according to the equation of KOSCHEL et al. (1981). In a first application of this adapted procedure, results for 114 shallow lakes in the German federal state of Brandenburg are demonstrating the higher accuracy of yield estimations in shallow lakes after transformation of measured TP-values (BRÄMICK 2002).

Before the proposed transformation of measured TP-values for shallow lakes is carried out it has to be decided, whether a lake is considered as lasting stratified or as none stratified during the vegetation period. This can be done by a theoretical calculation of the epilimnion layer (VENTZ 1974) or by recording vertical temperature profiles. But even if a lake has been classified as "stratified" in general, it still has shallow areas which in terms of nutrients and PP do act as a shallow lake. In the eight lakes studied by KOSCHEL et al. (1981) to establish the above mentioned correlation between TP and PP for stratified lakes, the average proportion of stratified area on the whole lake surface area turned out to be approximately 45%. Consequent-

Table 2. Regional adapted fish yield estimation procedure for lakes in north-east Germany.

Step	Parameter	Estimation procedure	Literature/ Comments
1	TP	Measurement in surface water outside the littoral zone during spring turnover (µg/l)	KNÖSCHE & BARTHELMES (1998)
2	Stratification	Recording vertical temperature profiles or calculation of the epilimnion thickness as $4.91 \cdot D^{0.4}$ with D being the maximum length plus width of wind fetch (km) divided by 2	VENTZ (1974)
3	TP	Stratified lakes: Maximum TP = 500 µg/l Shallow lakes: Maximum TP = 300 µg/l	Limitation of measured TP-values (German Association of Water 1998)
4	$TP_{transformed}$	$TP_{transformed}$ (µg/l) = $1.48198 \cdot TP_2^{1.2278}$ (TP_2 = TP measured in shallow lakes)	Transformation of TP for shallow lakes (new)
5	Hypolimnic area	Estimation of the percentage of the hypolimnic area from bathymetric maps (%)	KNÖSCHE & BARTHELMES (1998)
6	Hypolimnic difference (Hd)	Hypolimnic difference (Hd) = 45% – Hypolimnic area percentage (step 5)	Differentiation of shallow and stratified parts within one lake (new)
7a	PP in regular stratified lakes (Hd = 0)	PP (g C/m² · a) = 148 · logTP – 39.6	KOSCHEL et al. (1981)
7b	PP in partially or entirely shallow lakes (Hd > 0)	PP (g C/m² · a) = (Hd/100 · {148 · log $TP_{transformed}$ – 39.6}) + ({1 – [Hd/100]} · {148 · logTP – 39.6})	Separate calculation for stratified and shallow parts within one lake and entirely shallow lakes (new)
7c	PP in lakes with extreme stratification (Hd < 0)	PP (g C/m² · a) = ({1 + [Hd/100]} · {148 · logTP – 39.6})	Reduced calculation for stratified lakes with more than 45% hypolimnic area (new)
8a	FYP (for lakes with PP ≤380)	FYP (kg/ha · a) = $6.315 \cdot e^{0.0062 \cdot PP}$	Regional adaptation for lakes in north-east Germany (new)
8b	FYP (for lakes with PP > 380)	FYP (kg/ha · a) = 57.937 · lnPP – 278.09	Regional adaptation for lakes in north-east Germany (new)
9	FYP_{corrA}	FYP_{corrA} (kg/ha · a) = (1 – 0.6 · {1 – $1/e^{[A/700\ ha]}$} · FYP	Correction of FYP for lake area (new)
10	FYP predatory species	$FYP_{Predator}$ (kg/ha · a) = $FYP_{corrA} \cdot 0.3$	KNÖSCHE & BARTHELMES (1998), modified

ly, the equation of KOSCHEL et al. (1981) can be used for lakes with a stratified proportion of 45% only ("regular stratified"). In lakes with less than 45% hypolimnic area we suggest to carry out a separate calculation for surplus shallow parts in addition to calculation for the "regular stratified" proportion. If on the other hand the hypolimnic area is exceeding 45%, calculation of PP is reduced to the "regular stratified" proportion of the lake (Table 2).

Regional application of the correlation between primary production and fish yield potential to lakes in north-east Germany

After calculation of PP the yield estimation procedure of KNÖSCHE & BARTHELMES (1998) goes on with estimating the potential fish yield on the basis of PP according to an equation published by BULON & VINBERG (1981). For this equation latter authors collected PP and corresponding fish yield data from 42 lakes, reservoirs and seas in Asia and Europe. Despite the inclusion of different climatic zones and both fresh and seawaters, a significant correlation between PP and FYP could be found, namely

$$FYP = (1.8 \pm 0.9) \cdot 10^{-3} \cdot PP.$$

Although the findings of BULON & VINBERG (1981) demonstrate a fundamental correlation between PP and FYP in stagnant waters irrespective of its type, the precision of the equation is necessarily low due to the inhomogeneous data base. Also NÜRNBERG (1996) reviewed relationships between TP and fish biomass or harvest worldwide and found the latter to be a general indicator for the trophic state of lakes. Due to a ten-fold difference of predicted fish yields for lakes with comparable TP-values, NÜRNBERG (1996) concluded that although the regression is generally significant, the parameters differ in geographically different areas.

In order to enhance the precision of the result for neighbouring lakes in north-east Germany and therefore within a restricted area we concluded to search for a regional relation between PP and FYP rather than to adopt general terms from water bodies of different types or areas as it was done in the original procedure of KNÖSCHE & BARTHELMES (1998). For the region of concern in north-east Germany, we collected figures of PP and corresponding sustainable fish yield of professional fishermen for 28 lakes between 1970-1990. This time interval was chosen because under the economic frame conditions of former East Germany an intense fishery on all species was carried out largely uninfluenced from market preferences or prices. The resulting dataset is proving a statistically significant correlation between PP and fish yield (Spearman rank, $p \leq 0.001$) which can be described best by an exponential function (Fig. 1).

According to LIANG et al. (1981) the principle relation between PP and obtainable fish yield is turning from an exponential to a logarithmic function with increasing-PP values and is approaching an upper asymptote. In north-east Germany, corresponding fish yield was available only for lakes with a PP not higher than 400 g $C/m^2 \cdot a$. At the same time, the relation between PP and FYP of the entire dataset could be described with a logarithmic function, too ($r^2 = 0.34$). The intersection of the exponential and logarithmic function in our dataset can be found in the area of PP = 380 g $C/m^2 \cdot a$ (Fig. 1).

From our data and the principle relation between PP and FYP described by LIANG et al. (1981) we concluded, that FYP estimation needs to be carried out in dependence on PP-values. At a PP of up to 380 g $C/m^2 \cdot a$ an exponential formula is adequate, while at higher PP values FYP is preferably calculated according to a logarithmic equation (Table 2). Because this split approach as well as the parameters of the relation between PP and FYP resemble the specific situation in lakes of north-east Germany, we used both the exponential and logarithmic function to substitute the equation of BULON & VINBERG (1981) in the FYP estimation procedure of KNÖSCHE & BARTHELMES (1998; Table 2).

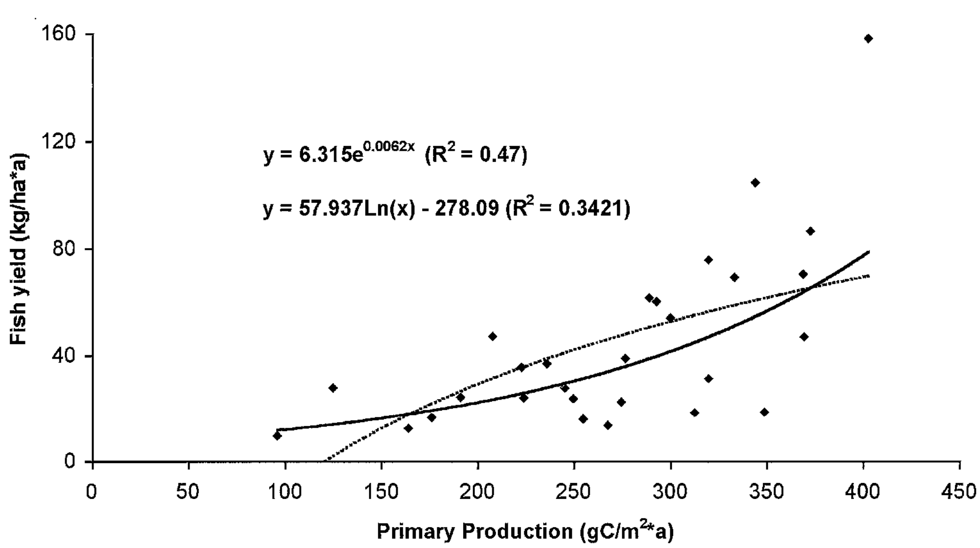

Fig. 1. Primary production and correlated actual fish yield in 28 lakes in north-east Germany. The solid graph is based on an exponential function, the dotted graph on a logarithmic one.

The influence of lake size on fish yield

The original fish yield estimation procedure of KNÖSCHE & BARTHELMES (1998) does not consider lake size as a parameter. When analysing fish yield statistics from 333 north-east German lakes we found a negative correlation between lake size and fish yield for lakes with a comparable trophic class. In this dataset, the average fish yield decreases with increasing lake surface. This phenomenon is not biologically reasoned but is the result of a lower effectiveness of pelagic fishing methods in open waters compared to fisheries near the shoreline in small lakes. In order to take this methodically caused lower yield potential of larger lakes into account, an empirically derived correction of the calculated FYP for lake size has been introduced into the estimation procedure (Table 2).

Results with the newly adapted procedure in lakes in north-east Germany

Between the years 1995 and 2001, FYP for a total of 786 lakes in north-east Germany was estimated on the basis of their trophic state. The FYP estimation procedure of KNÖSCHE & BARTHELMES (1998) was therefore adapted for shallow lakes as well as for regional conditions in the area of concern as described above (Table 2).

Lakes investigated cover a wide range in terms of morphological and limnological parameters and are dominated by cyprinids (Table 3). The calculated FYP varied between 8 and 67 kg/ha · a with shallow lakes showing significantly higher values in comparison to stratified counterparts (t-test; $p \leq 0.001$). In particular FYP classes with more than 35 kg/ha · a were dominated or exclusively filled by shallow lakes while stratified ones prevailed in low FYP classes (Fig. 2).

Table 3. Morphological and limnological characteristics of study lakes.

Parameter	Volume/ value/ range
Water surface area	0.01 ... 112 km^2
Maximum depth	0.5 ... 72 m
Share of hypolimnic area	0 ... 90.1%
TP concentration at spring turnover	5 ... 7 105 µg/l
Primary production (calculated)	45 ... 402 g $C/m^2 \cdot a$
Fish yield potential (calculated)	8.0 ... 67.6 kg/ha · a

Assessment of FYP estimation precision

In order to proof the quality and accuracy of the adapted fish yield estimation procedure, recent yield statistics for 333 out of the 786 lakes studied could be made available. Because of the preference of predatory freshwater fish species by German consumers, only stocks of those species are exploited by commercial fishermen according to the productivity of the lakes. Therefore current yield statistics were broken down to predatory species and compared to the calculated FYP for predatory fish (according to KNÖSCHE & BARTHELMES (1998) generally assumed as FYP · 0.3, see Table 2) for calibration purposes. As a result, both the adapted as well as the original estimation procedure lead to FYP with partially remarkable deviations from yield statistics and show a tendency to overestimate yields for poor lakes in particular (Fig. 3, Fig. 4). This tendency is more pronounced in FYP estimated with the original procedure while the adapted one results in FYP closer to yield statistics. The mean square of residuals of FYP compared to the 1:1 line in Fig. 3 amounts to 34.1 for the adapted against 92.1 for the original procedure.

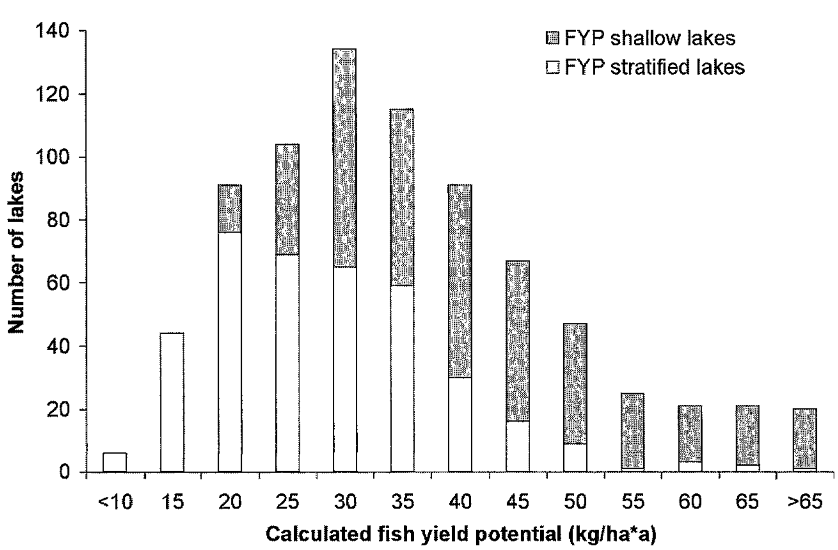

Fig. 2. Frequency distribution of calculated fish yield potential in shallow lakes (grey columns) and stratified lakes (white columns).

Table 4. Number of lakes with predicted FYP deviating less than 50% from actual yield statistics when using the original and the adapted estimation procedure, respectively.

Lake stratification regime	Lake number	Number of lakes with predicted FYP deviating less than 50% from actual yield statistics	
		Original procedure	Adapted procedure
Shallow	136	34	77
Stratified	197	77	83
Stratified with poor hypolimnion (up to 45% of total lake area)	104	38	48
Stratified with large hypolimnion (> 45% of total lake area)	93	41	35
All lakes	333	103	150

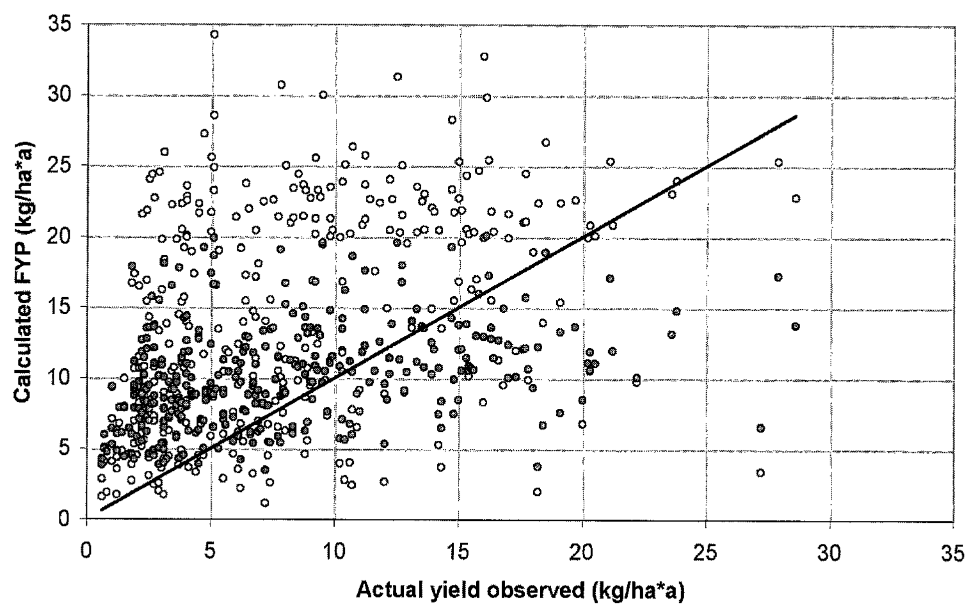

Fig. 3. FYP estimated with the original procedure (empty dots) and the adapted procedure (filled dots) compared to observed yields from yield statistics for 333 study lakes. The 1:1 line marks the area, where calculated FYP for a lake matches the corresponding actual yield observed.

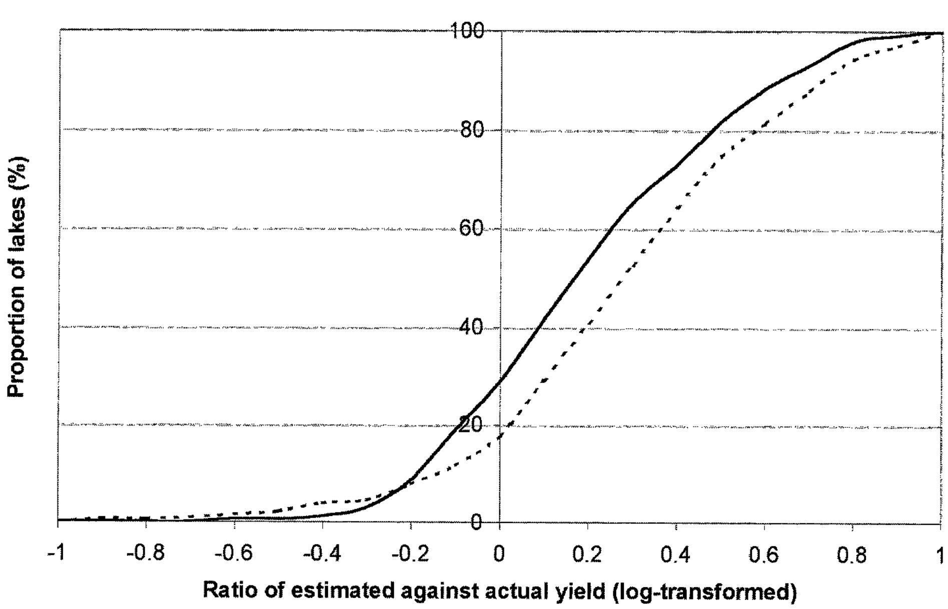

Fig. 4. Cummulative frequency of the ratio between calculated and actual yield of predatory fish species estimated with the original procedure of Knösche & Barthelmes (1998, dotted line) and the newly adapted procedure (solid line) for 333 lakes. A log-transformed ratio value of "0" results for all lakes, where calculated FYP exactly matches yield statistics.

Using the adapted estimation procedure, for 45% of study lakes (150 lakes) FYP was predicted with less than 50% deviation from corresponding yield statistics, while the original procedure predicted FYP just for 31% of the lakes within this range (Table 4). For shallow lakes, this figure amounts to 57% for the adapted procedure compared to 25% for the original one. For stratified lakes, both estimation procedures show a lower precision (Table 4).

After log-transformation of the ratio between calculated FYP and yield statistics, the frequency distribution between both estimation procedures is significantly different (Fig. 4; U-test, $p < 0.001$), with a median value of ratios of 0.28 for the original and 0.17 for the adapted procedure. The closer the median approaches a value of 0, the higher the average precision of estimates. If lakes are considered separately according to their stratification regime for shallow lakes the difference between the two estimation procedures is increasing ($n = 136$; median values of 0.34 for the original procedure compared to 0.10 for the adapted procedure) while in stratified lakes ($n = 197$) it remains statistically insignificant (median values of 0.22 and 0.23, respectively). The higher precision of the adapted procedure for shallow lakes is also demonstrated by the frequency distribution of the ratio between estimated FYP and the corresponding actual yield (Fig. 5).

Discussion

The fish yield potential of lakes can be estimated roughly using the general procedure published by Knösche & Barthelmes (1998). However, as demonstrated by our results from lakes in north-east Germany, this procedure gives room for specific regional adaptations. PP as the main variable governing the fish yield potential of lakes

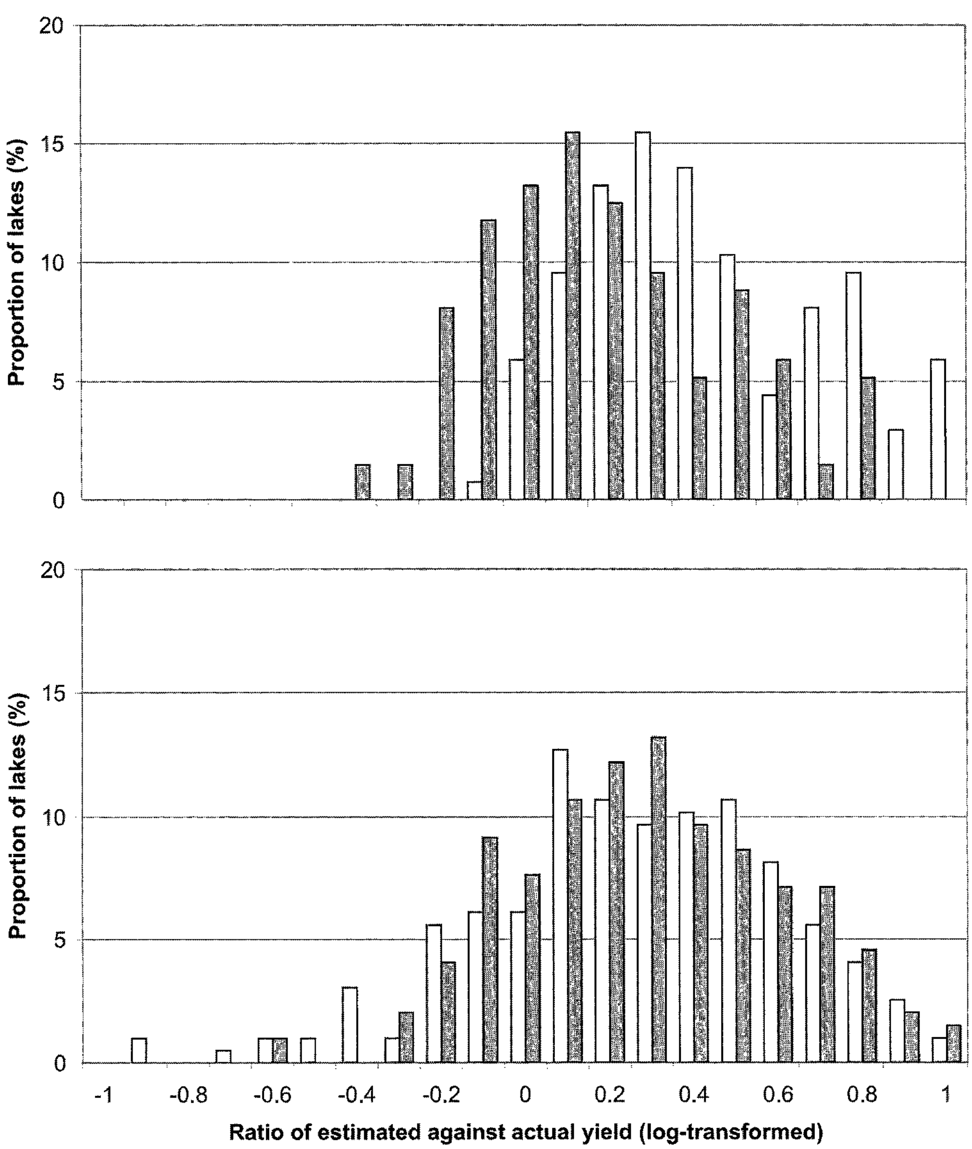

Fig. 5. Frequency distribution of the ratio between calculated and actual yield of predatory fish species estimated with the original procedure of Knösche & Barthelmes (1998, white columns) and the newly adapted procedure (grey columns) for shallow lakes (upper figure, n = 136) and stratified lakes (lower figure, n = 197) in north-east Germany. A log-transformed ratio value of "0" results for all lakes, where calculated FYP exactly matches yield statistics.

(Downing et al. 1990; Oglesby 1977; Nürnberg 1996, and others) needs to be calculated in consideration of the lake stratification regime and the extent of the hypolimnic area. Combined with a regional based correlation between PP and FYP and a correction with respect to lake size, the precision of the yield estimate can be improved. Our results demonstrate, that calculated yields for predatory fish on the basis of the adapted estimation procedure are matching current yield statistics at a better rate than FYP calculated by using the original procedure of Knösche & Barthelmes (1998). In particular for shallow lakes and stratified lakes with a poorly developed hypolimnion the adapted procedure leads to a higher precision of estimates. Nevertheless, also when using the adapted procedure there are still a number of cases with a 3 to 10 fold overestimation of FYP remaining. The reason for this discrepancy is likely to be found in the available yield statistics of commercial fishermen, because differences in fishing pressure and fishing gear used may have caused different yields independent from lake morphology or productivity. In addition, a number of lake specific parameters well known to severely influence lake productivity like water residence time or external nutrient loads were not considered in the estimation procedure due to a lack of available data.

Imprecision was pointed out by Peters (1986) as a general problem of predictive limnology. Therefore, models may be helpful in formulating management strategies for numbers of lakes. If they are applied to single lakes, special attention has to be given to specific conditions (Peters 1986). In this context it has to be stressed again, that the results of the adapted procedure still remain a rough estimate for average conditions. They are neither suitable to be used as a precise figure for detailed management decision making nor to point out the expected fish yield in lakes with specific morphological or limnological conditions. But due to the low costs and its potential for regional adaptations, the procedure can be favourably applied when a larger number of lakes need to be scanned for their yield potential.

The results obtained when estimating FYP need to be interpreted as an average yield expectation of commercial fisheries at a common level of fishing effort as it was observed in north-east Germany between 1970–1990. During this period, fish stocks of lakes were constantly exploited on a regular basis without market constraints nor signs of overfishing. Consequently, the estimation procedure does not calculate a maximum sustainable yield. If actual yields for a lake exceed estimated FYP this can not necessarily be interpreted as an indication of overfishing of stocks. On the other hand, if economic or other specific frame conditions cause a declining fishing effort, the procedure needs to be corrected in order to gain reliable results.

Nutrient turnover and the volume of primary production in dependence on TP availability in shallow lakes are the main obstacles for further improvement of fish yield estimation procedures. The currently used transformation of measured TP in shallow lakes according to the system of the German States Association for Water (1998) remains a substitute for the absence of a specific correlation between TP and PP in shallow lakes as presented for stratified ones by Koschel et al. (1981). A direct measurement of PP can not fill in this gap because of the incomparably higher effort associated with PP measurements over an entire vegetation period.

A second major drawback is arising from the scarcity of well defined yield statistic data from intensely and constantly exploited fresh water fish populations on a regional basis. In particular for lakes at a higher trophic state ($PP > 350$ g C/m^2 · a) only very few data were available in our case. Consequently, the relation between PP and FYP could not be assured for nutrient rich waters. Following Liang et al. (1981), the curve should saturate as a logistic one. To assess the turning point from the exponential to the logarithmic part, yield statistics of professional fishermen from time periods with an intense fishery on all species are essential.

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