

Analysing the Potential for Genetic Change in Pike Populations Exploited by Recreational Fisheries

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Goal

To analyze the possibility for recreational fishing to induce genetic changes in exploited fish populations, and thereby to increase awareness of such potential among stakeholders and stimulate increased research effort and long-term monitoring of fish populations exploited by angling fisheries.

Background and motivation

As a result of selective (i.e. non-random) mortality, exploitation of wild living resources can directly or indirectly act as an (often overlooked) evolutionary force (Stokes et al. 1993; Law 2000; Palumbi 2001; Ratner and Lande 2001; Heino and Godø 2002; Coltman et al. 2003; Ernande et al. 2003). Fishing-induced selection has been identified as having the potential to alter the genetic architecture of fish populations, leading to changes in stock properties such as long-term yield and demographic traits such as size and age at maturation or growth rate (Ricker 1981; Law & Grey 1989; Heino 1998; Conover & Munch 2002). Although much of the available evidence of a potential evolutionary effect is still inconclusive, it seems necessary to include its implications in sustainable fisheries management strategies (Law 2000; Heino & Godø 2002). This, *inter alia*, results from the precautionary approach to fisheries management and the internationally binding Convention on Biodiversity that demand that fishing effects should be reversible, and not irreversibly alter biodiversity of evolving natural resources, neither at the level of species nor communities.

Until now, empirical and theoretical research on potential adaptive change induced by fishing has mostly focused on commercial exploitation in the marine environment or in anadromous fish (see Borisov 1979; Ricker 1981; Policansky 1993; Law 2000; Heino and Godø 2002 and references therein). In industrialized countries of the temperate regions, recreational fisheries (angling) systems constitute important socio-ecological systems that involve millions of people exploiting thousands of different freshwater fish stocks (Arlinghaus et al. 2002). As a result, substantial social and economic benefits are generated (Arlinghaus 2004a, 2004b). But the ecological and evolutionary impacts of angling fisheries are less well understood. Furthermore, the systems' behavior and management has not been studied thoroughly, and most research on recreational fisheries appears parochial, with a strong national orientation and relatively small frames of reference in terms of theory, concepts, models, and empirical bases (Aas 2002).

As ecological processes and anthropogenic impacts of fisheries can only be understood at a more regional or local level, recreational fisheries systems provide an alternative to analyze fishing-induced genetic changes and natural resource-people interactions. As such, the development of predictable models in recreational fisheries

would increase our understanding of the interplay between social and ecological systems and expand the awareness of potential fishing-induced genetic change to the angling environment, particularly in freshwater ecosystems. Some features of angling practices such as the release of caught fish are unique in recreational fisheries, which limit the transfer of management systems and research results from commercial to recreational fisheries (Arlinghaus et al. 2002). In addition to direct angling mortality and despite high rates of catch-and-release angling in many recreational fisheries (Policansky 2002), substantial hooking mortality (Munoeke & Childress 1994) or sublethal physiological and fitness alterations (Cooke et al. 2002) may occur in recreational fisheries, leading to opportunities for angling selection to operate even without physical harvest. Therefore, as regards recreational fisheries specific models have to be developed or established ones tuned and predictions have to be tested empirically.

One might be tempted to assume that angling impacts are less severe than commercial impacts. However, this assumption is flawed under conditions of high angling effort, hence impact, which is particularly strong near metropolitan centers or in areas with limited angling waters available (Post et al. 2002; McPhee et al. 2003). Angling mortality as fishing mortality in general is strongly size-dependent, which is the result of the typical higher interest of anglers in larger fish (Arlinghaus 2004a, 2004b) and the fact that most recreational fisheries are managed based on some variants of size and bag limits (Arlinghaus et al. 2002). Typically, minimum-size limits are applied that allow for harvest of species that have spawned at least once in a lifetime. Minimum sizes are usually set to ensure that (most of) the population has reached maturity and has spawned before being allowed to be harvested by anglers. Consequently, annual exploitation rates of popular angler species such as pike (*Esox lucius*) were found to be 2 to 9 times larger in large pike (> 50 cm) above the minimum size as compared to smaller individuals (< 50 cm) (Pierce et al. 1995). Comparatively low effort of 1.24 angler-hours/ha already removed 50% of the annual adult pike production in small lakes in the United States (Mosindy et al. 1987). In rainbow trout (*Oncorhynchus mykiss*) fisheries in Canada, Cox and Walters (2002) reported maximum exploitation rates of between 0.21 and 0.81%. In these lakes, critical angling effort was found to be in the low range of observed angling effort, which indicates that population overfishing may be possible. Recently, Post et al. (2002) found evidence of fish population collapses in four high profile recreational fisheries in Canada. Altogether, it has been suggested that selective angling mortality can be one of the most important variables in structuring freshwater fish populations (Beard & Essington 2000), typically reducing the mean age and size of the exploited population (Goedde and Coble 1981; Olsen and Cunningham 1989). However, it is important to note that there are also many examples of recreational fisheries where angling effort on adult fish is rather low and negative effects may be negligible (e.g., Beard et al. 2003 for walleye *Sander vitreum* fisheries in Wisconsin). Thus, the evolutionary effects of angling are not likely to impact every fishery.

The current call for an “evolutionarily enlightened management” (Ashley et al. 2003) demands in-depth studies in recreational fisheries, as life-history evolution may take place on contemporary (i.e. less than a few hundred generations, sometimes only decades) time scales under heavy exploitation (Conover and Munch 2002; Haugen and Vøllestad 2001; Koskinen et al. 2002; Stockwell et al. 2003). There are important

specificities of recreational fisheries that such an analysis of potentially angling-induced genetic change has to take into account:

1. Harvesting goals (e.g. escapement of a certain abundance of fish to reproduce, or quota systems) are rarely in place in recreational fisheries. There is almost no monitoring and no long-term data sets are available.
2. Angler predominantly target and remove top predators of the food webs such as pike, largemouth bass (*Micropterus salmonides*), walleye, or salmonids. Top predators encompass species that itself suffer from comparatively low predation pressure (e.g. predation by other piscivores) but are often dependent on the density of their prey. Larger mature individuals of these species that have survived bottlenecks in juvenile stages should be the fittest in the given environment.
3. Selectivity among mature animals above minimum size limit may be low (Mosindy et al. 1987; Raat 1991; Cox 2000). That is, a certain proportion of individuals of the whole (mature) stock is harvested each year with positively density-dependent mortality. Literature data on “moderate” exploitation (e.g. 20-80% of stock harvested per year) is available and should be taken for simulation.
4. Exceptions to the statement above are trophy fisheries, where only the largest fish are taken home and other fish are released. Hooking mortality in catch-and-release of smaller fish (smaller than trophy size, which is situational and dependent on the angler’s perception) may become important.
5. In recreational fisheries, there is probably no selective exploitation in spatially different spawning grounds to select for late maturation as proposed by Heino (1998) for cod (*Gadus morhua*). Thus, catching immature fish will always occur, although presumably at lower rates as compared to mature fish.
6. Immature fish are usually caught and released (legal requirement), although illegal harvest has been documented (Gigliotti and Taylor 1990; Sullivan 2002). Here, hooking mortality and non-compliance mortality is crucial and may be important for evolutionary change in maturation that is supposed to be lower if immature individuals are mostly below the size limit (Ernande et al. 2003). Literature data on hooking mortality and non-compliance mortality rates for some species is available.
7. In recreational fisheries, bycatch is usually negligible or returned alive to the water.
8. Catch-and-release makes fish harder to catch due to learning or change in behavior (Raat 1985).
9. Angling catchability (i.e. the proportion of stock vulnerable to angling) can be either negatively density-dependent (lake trout, Shuter et al. 1998) or density-independent (e.g., walleye, Hansen et al. 2000).

10. Due to high mobility and efficiency of anglers, it is assumed that the whole stock of fish is vulnerable to anglers. However, some fish may be temporarily not vulnerable, e.g. satiated fish (Cox and Walters 2002).
11. Mortality of mature (e.g. above minimum size) individuals in recreational fisheries may lead to high abundances and productivity of smaller fish not desired by anglers (Pierce et al. 1995). Thus, although individual growth rates of smaller fish may increase due to increased prey abundance or decrease due to competition or reduced size-at-maturation, the productivity of the whole stock may be stable, but mean size in the population will decrease. Potential new resources available due to reduced density will be consumed by the smaller variety of the same species or by other species. Higher abundances of smaller fish will reduce economic benefits and induce angler dissatisfaction. Anglers may ultimately leave the fishery or respond by enhanced stocking, thus confounding the detection of fish stock declines. Biomass of desired size classes will be greatly reduced in the long-term. Some fish species such as pike show signs of self-regulation via cannibalism.
12. Angling vulnerability was found to be a heritable trait in largemouth bass ($h^2 = 0.34$, Phillip et al., unpublished manuscript). Relative to other traits that are known to be heritable, angling vulnerability appears to have one of the higher heritabilities. The response to selection increased with each generation, and was found to be correlated with a cumulative selection differential reflecting the increased magnitude of difference between highly vulnerable and less vulnerable fish with each successive generation. Highly vulnerable and less vulnerable bass differed in important fitness traits (Cooke, unpublished manuscript). Angling vulnerability covaried with factors including higher metabolic rates, reduced metabolic scope and increased parental care activity. However, growth rates of highly vulnerable and less vulnerable fish were not different. Angling may lead to “mortality of the fittest” if highly vulnerable fish are selectively removed.

Research questions

In my summer project I plan to focus on the following questions:

1. Under the conditions encountered in most angling fisheries (explained above), is genetic change for younger age-at-maturation, smaller size-at-maturation, increased reproductive effort, or reduced growth rate conceivable?
2. Which of the traits mentioned above experience the strongest selection differentials in fish populations typically exploited by anglers? The fish species chosen for a case study will be pike (*Esox lucius* L.) which is highly demanded by many anglers in the temperate regions (e.g., Arlinghaus and Mehner 2004).

Methods and work plan

The approach used in this project is twofold.

First, a detailed model of the population dynamics of pike will be constructed that integrates the functional relationships between selected adaptive traits and the population demography as a whole given certain (natural and fishing) mortality rates in a particular pike fishery. Deterministic matrix population models for structured populations will be used (Caswell 2001). The advantage of this approach is that matrix models are relatively easy to construct. They classify a population into discrete stages (e.g. age or length classes) and project abundance in these stages in discrete time. All individuals within a stage are treated as identical, which may or may not be a useful simplification. In the first analysis an age-structured population model will be constructed. The matrix population model will be parameterized for northern pike as one of the most important recreational fish populations in Central Europe (Arlinghaus 2004b) and parts of North America (Pierce et al. 1995). Biological information on pike is available and will be used for the model (Raaf 1988; Craig 1996). After constructing the population matrix, the model will be iterated until a certain equilibrium level is achieved, i.e. population characteristics do not change or fluctuate any more. This stationary case determines the age distribution of the resident population, and thus determines the environment in which the evolution in response to fishing impact takes place.

In the second step, reproduction ratios (R_0 ; describing the expected number of offspring produced by a female over her life span) will be calculated for variants of the trait under consideration (e.g. age-at-maturation). In other words, as age-at-maturation is varied in the original matrix population model, R_0 in dependence of the trait and the distribution of the trait in the population (frequency-dependant selection) can be calculated. This information is used to estimate the selection differentials for the different traits by weighting the distribution of the different trait values with R_0 for that given trait value and subtracting from it the mean trait value in the resident population. The outcome of this deterministic simulation can thus provide qualitative insights into the dynamics of selected traits that were previously found to be adaptive under commercial exploitation and are now considered under conditions of angling.

Concerning the planned time schedule, the first month should be devoted to building the matrix population model and compiling literature data. In the second month, simulations should be run, while the third month should be devoted for report preparation and result presentation.

Relevance and link to ADN's research plan

This project links directly to ADN's research focus on *Fisheries-Induced Adaptive Change*.

Expected output and publications

This work is intended for publication as a co-authored research article. Either a modeling paper should be prepared or an essay be written.

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