Chapter 9

Stocking for Pike Population Enhancement

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There are three basic strategies in the fisheries managers’ toolbox that can be used to protect or enhance fish populations (Arlinghaus et al. 2016). The first is enacting fisheries regulations, which manage fishing mortality (i.e., demand, chapter 12) and the other two are habitat management/restoration (chapter 10) and stocking, which attempt to enhance recruitment (i.e., supply). Stocking is the release of cultured or wild-caught fish into a different water body. It is widely used in inland and coastal fisheries for multiple reasons spanning from enhancement of recreational or commercial fisheries to conservation purposes (Cowx 1994, Arlinghaus et al. 2002, Lorenzen et al. 2012). This chapter focuses on stocking of northern pike \textit{Esox lucius} Linnaeus, 1758 (hereafter pike) as a way to enhance populations, i.e., increase pike abundance, biomass or catches. Stocking of pike for lake quality restoration purposes (e.g. to improve water clarity, Mehner et al. 2004, Brönmark and Hansson 2005) is reviewed in chapter 11 of this book. Here, we first provide an overview of pike stocking, e.g. reasons why pike are stocked, typology and some historical and quantitative aspects of pike stocking. We then review studies that have assessed the effectiveness of pike stocking for population enhancement and discuss important factors affecting the outcomes of stocking as well as the risks that may be associated with stocking pike. We end the chapter with recommendations for the future use of pike stocking as a fisheries management tool.

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9.1 DEFINING PIKE STOCKING

9.1.1 Typology and Motivations for Stocking

Depending on the objective and the status of the natural population, stocking-based population management can generally be classified into five basic types following Lorenzen et al. (2012) and Arlinghaus et al. (2015), which also apply to pike stocking.

1. Stocking for culture-based fisheries (equal to maintenance stocking in the terminology of Cowx [1994]) depends on the release of cultured fish to produce (and maintain) a fishery under conditions where there is a lack of natural recruitment and the fishery would cease to exist without stocking. The release of fish in culture-based fisheries follows the exclusive goal of improving or establishing fisheries. Stocking to establish culture-based fisheries is common for the pike congeneric muskellunge *Esox masquinongy* Mitchell, 1824 and ‘tiger muskellunge’ *E. lucius* x *E. masquinongy* (sterile hybrids) in the USA (e.g. Rust et al. 2002, Wingate and Younk 2007) yet remains rare for pike in both the USA and Europe. Muskellunge is a species of very high demand in the USA, but reproductive failures are very common (Johnson 1981, Kerr 2011). One of the main causes of poor recruitment in muskellunge is the high egg mortality related to anoxic conditions at the substrate-water interface where muskellunge preferentially spawn (Zorn et al. 1998). Pike, however, stick eggs above the substrate (preferably on submerged vegetation, chapter 3) where there are higher oxygen concentrations (Crane et al. 2015). In addition, reproductive traits of pike, e.g. staggered spawning and plasticity in spawning ground selection (Crane et al. 2015, Raat 1988), allow pike to reproduce in most waterbodies where they occur.

2. Stocking for stock enhancement is the continued release of hatchery-origin or wild-captured fish into naturally reproducing fish stocks. It implies that released fish have to cope with intra-specific competition from wild conspecifics. Stock enhancements are conducted to compensate for exploitation or habitat-induced recruitment shortages and are aimed at fostering fisheries (i.e., catch and/or yield; Lorenzen et al. 2012). Stock enhancement continues to be very common in pike management (e.g. Arlinghaus et al. 2015).

3. Restocking or stock rebuilding aims at supporting severely depleted populations (e.g. after fish kills) by the release of high densities of wild or hatchery-originated fish over a short period of time. The goal of stock rebuilding is conservation, but often with the intent that the stock can be used by fisheries after reestablishment. Stock rebuilding occurs regularly for pike populations, e.g. after winterkills (e.g. Kerr and Lasenby 2001).

4. Stocking for supplementation is the continued release of fish to reduce the risk of extinction in very small and declining fish stocks. It usually has a conservation focus rather than a fisheries focus. Releases occur in low to moderate densities to avoid further depression of the declining stock. Supplementation programs, where wild captured fishes are artificially raised and released, is widespread
in Atlantic salmon *Salmo salar* Linnaeus, 1758 and other salmonids but is very rare in pike, probably because pike successfully reproduce in many water bodies.

5. Introduction and translocation stocking is the release of fish into a water body from which the species is absent (outside or within its native range, respectively) with the aim of (re-)establishing a self-sustaining population and fishery after which stocking ceases. In Denmark, translocation of pike has, for example, been frequently conducted in newly established lakes (e.g. gravel pits) to create a fish community comparable to small natural water bodies (Skov et al. 2006). Similarly, in France, translocation of pike in gravel pits often occurs to establish and maintain fisheries (Zhao et al. 2016). Although introductions of pike have been common in the past (e.g. Pedreschi et al. 2014), nowadays they are increasingly rare due to conservation concerns. However, some anglers continue to illegally introduce pike into pike-less lakes to establish a fishery (Johnson et al. 2009; chapter 14).

Stocking for fisheries enhancement is often based on the deeply rooted belief among stakeholders that stocking elevates stock size and catches (Cowx 1994, Connelly et al. 2000, van Poorten et al. 2011, von Lindern and Mosler 2014). Stocking may also be chosen as a strategy based on the belief that it stabilizes population sizes with limited ecological risk and, hence, is a measure of conservation (Arlinghaus et al. 2015). The ultimate decision when implementing a stocking program depends on many social, ecological and economic components of the social-ecological system (e.g. the type of property rights, the degree of social norms, fishing pressure and the ecological status of the water body; Lorenzen 2014, Arlinghaus et al. 2015, 2016). Stocking is often preferred over alternative management approaches by dissatisfied, consumptive and avid angler types (Arlinghaus and Mehner 2005, van Poorten et al. 2011). However, in some countries, anglers prefer to catch wild pike (e.g. France, Armand et al. 2002), which may reduce the anglers’ demand for stocking. In other countries, anglers lack distinct preferences for wild over hatchery-originated pike in their catches (e.g. Germany, Arlinghaus et al. 2014). Coupled with the difficulty of discriminating stocked and wild pike after capture, this indifference may foster a reliance on stocking, notably among more locally managed fisheries in Central Europe, where decisions about stocking are exclusively made by angling clubs with little external input from authorities (van Poorten et al. 2011, Arlinghaus et al. 2015). Stocking is also popular among clubs and agencies for political reasons and has become a ritualized habit that is often conducted due to the difficulty of engaging in alternatives (e.g. fisheries regulation or habitat enhancement) for social or economic reasons (Lorenzen et al. 2010, Arlinghaus et al. 2015).

### 9.1.2 Historical Aspects and Pike Stocking Practices

In its native range, stocking of pike mostly relates to the stock enhancement type (#2 mentioned above), i.e., stocking of fish into wild, naturally recruiting stocks to increase yield above, or population abundance beyond, the level that can be
sustained by (often anthropogenically impaired) natural recruitment (Raat 1988, Cowx 1994, Welcomme and Bartley 1998, Lorenzen et al. 2012). Accordingly, there is a long history of pike stocking for enhancement in many industrialized countries. Evidence of pike stocking within its native range exists from the late 19th – early 20th century. For instance, Jones (1963) reported the existence of pike stocking in lakes located in Nebraska (USA) in 1889, and Charpy (1948) mentioned stocking occurring in the Untersee of Lake Constance (Germany) as early as 1902. One of the first pike hatcheries was created in 1892 in Denmark (Rasmussen and Geertz-Hansen 1998) where pike stocking for fisheries enhancement reached a peak in the 1930’s and remained important until the beginning of this century (Jacobsen et al. 2004). In France, the concerns of pike anglers about a global decline in wild populations led to the creation of a national grant for pike culture in the early 20th century (Chimits 1947). It is only since the mid-20th century that pike stocking has been more quantitatively documented (e.g. Krohn 1969, Snow 1974, Raat 1988, Halverson et al. 2008, Pierce 2012, Arlinghaus et al. 2015), and information about pike culture for stocking has been extensively published (e.g. Heuschmann 1940, Beyerle and Williams 1973, Bry et al. 1995, Nilsson et al. 2008).

Despite increasing evidence for the lack of positive stocking outcomes (see further below), pike stocking continues to be a popular management practice worldwide, especially in Europe and North America (FAO 2005). Most pike stocking has been performed with age-0 fish, usually free-swimming fry or fingerlings (1-30 cm in Total Length [TL]). For instance, in Michigan (USA) from 1979 to 2005, most pike (69%) were stocked as fry whereas stocking of adults remained marginal (0.06%, Diana and Smith 2008). Early life-stages have been used in pike stocking for three main reasons. First, releasing young fish is believed to be more cost-effective (see Johnston et al. 2015 for counter examples) because it is relatively expensive to raise predatory fish species such as pike to a larger juvenile or adult stage, mainly due to large losses resulting from cannibalism (Huet 1948, Bry and Souchon 1982; chapters 11 and 13). Second, early life stages are often assumed to be less domesticated and, therefore, better adapted to survive under natural conditions than later life stages that have been exposed to culture conditions for longer periods (Lorenzen et al. 2012, Hühn et al. 2014). However, good empirical evidence for this statement is so far lacking (but see Szczechkowski et al. 2012). Third, early life stages are preferably used for pike stocking because the loss of spawning grounds is often outlined as one of the main sources of decline of wild populations (Casselman and Lewis 1996, Farrell et al. 2006, Arlinghaus et al. 2015, chapter 10).

It is impossible to provide precise estimates of the number of waterbodies around the globe where pike have been or are currently stocked as data is scarce. We here provide some examples that can help showcase some figures. In Poland, about 85% of the lakes (average number of lakes studied: 2,453) were stocked with pike between 2001 and 2007 making pike the most frequently stocked species (Mickiewicz and Wołos 2012). In Scandinavia, where stocking primarily targets salmonids, pike is the seventh most stocked species. Pike are stocked in about 1,500 lakes in Norway (0.4% of Norwegian lakes), about 625 lakes in Sweden (1.1% of Swedish lakes) and about 200 lakes in Finland (0.7% of Finnish lakes).
(Tammi et al. 2003). In Germany, the total volume of pike stocked by organized anglers was about 124 t or 4.7 million pike in 2010 (Pagel, unpublished data). Pike contributed about 3% (according to both biomass and abundance) of the fish stocked in lotic water bodies, and about 4% (biomass) and 10% (abundance) of the fish stocked in lentic water bodies (Arlinghaus et al. 2015). In the USA, Fish and Game Agencies and the U.S. Fish and Wildlife Services stocked 9,994.6 t of pike in 2004 representing about 0.6% of the total biomass of fish stocked (Halverson 2008). Despite pike not being the most stocked species across the northern hemisphere, the amount of pike released and thus the financial cost of pike stocking is still substantial. In this context, concerns questioning the efficiency and usefulness of pike stocking have been repeatedly raised in many countries (e.g. Schreckenbach 1996, Pierce 2012, Mickiewicz 2013, Hühn et al. 2014).

9.2 OUTCOMES OF PIKE STOCKING FOR STOCK ENHANCEMENT

9.2.1 Population Dynamics and the Role of Fishing Pressure

Thorough understanding of pike stocking demands a careful understanding of population dynamics and processes, in particular density dependence. In many fish, such as pike, ontogenetic changes in size and morphology relate to shifts in key stage-specific population regulatory mechanisms (Lorenzen 2005). The key regulatory processes are size- and density-dependent mortality as well as density-dependent growth (chapter 6). Mortality is size-dependent throughout the life cycle of fish and is generally inversely proportional to length (McGurk 1986, Lorenzen 1996b, 2000), particularly in esocids (Lorenzen 2000, Haugen et al. 2007). It is generally assumed that eggs and larvae suffer high density-independent changes of vital rates (e.g. hatching, growth and survival rates; Myers and Cadigan 1993a, Leggett and DeBlois 1994). For instance, Eckmann et al. (1988) found that both temperature and wind were the main factors affecting the variance in whitefish Coregonus lavaretus Linnaeus, 1758 larvae abundance in Lake Constance (Germany, Switzerland, Austria) and, as mentioned earlier in this chapter, low oxygen concentration at the water-substrate interface is a source of high mortality in muskellunge eggs (Zorn et al. 1998, Crane et al. 2015). Juveniles mainly suffer density-dependent mortality directly from predation or starvation (Elliott 1994, Hazlerigg et al. 2012) or, indirectly, from the interplay between size-dependent mortality and density-dependent growth (Shepherd and Cushing 1980, Post et al. 1999). In larger juveniles and, in particular, in adults, the density dependence is often manifested in regulation of growth and condition rather than in mortality (Walters and Post 1993, Post et al. 1999, Lorenzen and Enberg 2002, Lorenzen 2005, 2008). As fish grow, there is also a transition from intra-cohort to inter-cohort density dependence (Walters and Post 1993, Lorenzen 1996a). These changes are certainly gradual but, in practice, distinct phases of intra-cohort density-dependent mortality and inter-cohort density-dependent growth are often assumed. Recruitment can be defined as the transition from one phase to the next (e.g. Lorenzen 2005). Below,
in this section, recruitment refers to this meaning since it deals with population
dynamic principles. Yet, in fisheries and throughout this chapter (apart from this-
section), recruitment is defined as the size when the fish enters the fishery.

In fish, the high variability in egg production and mortality of eggs and
larvae is generally believed to account for a large part of the overall variability in
recruitment (Beyer 1989, Rothschild 2000). However, density-dependent mortality
of juveniles tends to mitigate the variability created at early life stages (Myers-
and Cadigan 1993b, Elliott 1994), and, therefore, also strongly affect outcomes of
stocking fry or juveniles (Walters and Juanes 1993, see Hühn et al. [2014] for an
example in pike). Using models, Minns et al. (1996) showed that the recruitment
rate of juvenile pike is usually most constraining for adult stock size suggesting that
measures increasing juvenile habitat should be more sustainable to increase the pike
stock size relative to stocking juveniles. Density dependence at the recruited stage
affects the current biomass of the recruited stock and the production (and possibly
the quality) of eggs (Lorenzen 1996a, Lorenzen and Enberg 2002, Lorenzen 2005,
see Edeline et al. [2007] for examples in pike). In highly variable fish populations,
strong year classes are often followed by weak recruitment and vice-versa in
response to multiple dimensions of density dependence (Marshall and Frank 1999:
chapter 6). However, pike populations seem to show more stable dynamics overall
compared to other piscivores, most likely due to strong inter-cohort population
regulation through cannibalism (Persson et al. 2004, 2006, van Kooten et al. 2010,
chapters 6 and 8). The effectiveness of stocking for enhancement should thus
increase as more advanced life stages are stocked (Rogers et al. 2010), but even in
the adult stages, compensatory processes are bound to act and ultimately limit the
extent to which abundance and biomass can be enhanced (Secor and Houde 1998,
Lorenzen 2005).

Fishing-induced mortality affects fish population size, size structure, and
dynamics through density dependence and demographic changes (e.g. Darimont
pressure and the resulting harvest intensity has the potential to strongly affect the
outcomes of stocking (e.g. Lorenzen 2005, 2008, Camp et al. 2017, Garlock et al.
2017). This might be especially true in pike which are very vulnerable to harvest
(e.g. 12-50% [McCarragher 1957], 3-39% [Snow 1974] and 63.9% [Beyerle 1980]
annual harvest rate; chapter 12). High local harvest pressure affects the structure
and dynamics of the stock-enhanced population which may both promote or
hinder the outcomes of stocking (Arlinghaus et al. 2016). Harvesting can reduce
the mortality of stocked fish by removing predators or cannibalistic conspecifics
and, thus, positively affect stocking outcomes of the target species (Botsford and
Hobbs 1984). Harvesting can also increase the growth of fish that are stocked
by reducing inter- and intra-specific competition for food. As a result, successful
stocking can increase the net productivity of fisheries (often expressed as yield)
beyond the level achievable by harvesting the natural component of the population
alone (Lorenzen 2014). However, fishing can also reduce the efficiency of stocking
by quickly removing stocked fish (e.g. Baer et al. 2007) then reducing the duration
of additive effects, or affecting future natural recruitment negatively by removing
large spawners (Botsford and Hobbs 1984, Hixon et al. 2014). In some cases, the
quick exploitation of stocked fish can also be advantageous. For instance, in the case of unintended overstocking (i.e., when the number of released fish is far beyond the carrying capacity of the system), fast removal of stocked fish through harvest can help the population return to a healthy equilibrium. When stocking mature fish, strong harvest of stocked fish also has the potential to reduce risks of interbreeding between stocked and wild fish (Lorenzen et al. 2012) if stocked fish are more vulnerable to harvest than their wild conspecifics. Interestingly, Beyerle (1980) reported harvest rates of stocked pike (61.9-70.5%) twice that of wild pike. To sort out the positive or negative potentials of locally high fishing pressure, appropriate release and harvest experiments, considering the socio-economical context of the fisheries (e.g. commercial vs. recreational fisheries), are needed (Botsford and Hobbs 1984, Lorenzen 1995, Lorenzen 2005, Johnston et al. 2015), but these have rarely been conducted in pike fisheries (see Hühn et al. [2015a] for an exception).

9.2.2 Methods to Estimate the Enhancing Effects of Stocking

Pike stocking was, and locally continues to be, a common measure used to manage pike populations. Therefore, it is of crucial importance for fisheries management to assess the outcomes of pike stocking in terms of its contribution to the stock, catches or yield (Lorenzen 2005, Rogers et al. 2010). Ideally, the evaluation of enhancements should be done by comparing measures of abundance or relative abundance (e.g. Catch Per Unit of Effort [CPUE] or effort-standardized catches before and after stocking in stocked and control water bodies/sites ([Before-After-Control-Impact approach, BACI], Smith 2002). However, for many reasons (e.g. technical and financial) such optimal study design has rarely been implemented (Hilborn 1999, see Hühn et al. [2015b] for an exception related to pike stocking). An alternative way to estimate the efficiency of stock enhancement is the analysis of (long) time series where stocking periods alternate with non-stocking periods resulting in before-after-designs without temporal controls. For instance, Jansen et al. (2013) gathered 62 years of angling CPUE data using angler logbooks to assess the effect of stocking pike fry and commercial fisheries on the pike population in Lake Esrom (Denmark). However, this approach is often limited by the number of volunteers willing to engage in the surveys, and by the difficulties in maintaining rigor in data collection over a long-term period. For this reason, most studies on pike stocking outcomes are unreplicated single-ecosystem studies (e.g. Dorow 2005, Klein 2011).

Mark-recapture studies are a further alternative to study stocking outcomes; they usually report the recapture ratio (number of stocked fish caught divided by number stocked) or the share of stocked fish as a proportion of the total (stocked and wild) fish catches as measures of stocking success (e.g. Kerr and Lasenby 2001, Gronkjaer et al. 2004). Based on five pike stocking experiments in North American water bodies, Kerr and Lasenby (2001) observed that anglers could expect to harvest 3.2% to 65.3% of stocked pike. Snow (1974) found that 6.6% of the pike (26.5-58.0 cm) stocked were caught by anglers in Murphy Flowage (USA). Beyerle (1980) reported that stocked fingerlings represented 15.8% to 36.3% of angler’s catches in
Long Lake (USA) and Snow (1964) reported that pike stocked in 1963 represented 34.2% of the total catches over five years (annual catch rate decreased from 64.9% to 0.5% after stocking) in Murphy Flowage (USA). Krohn (1969) reported that the proportion of stocked pike in total pike population (estimated by spring and fall netting) ranged from 33.3% to 94.0% in Murphy Pleasant Lake (USA), 12.6% to 94.1% in Silver Lake (USA), and 0% to 75% in Golden lake (USA). These measures provide some insights into stocking success and fitness-related traits of stocked fish. For instance, catch rate provides a minimum estimate of survival and, if size data are collected, information on growth. However, such mark-recapture studies do not normally provide information about the additive effects arising from stocking (Hilborn 1999) or if recruitment is impaired (Hühn et al. 2014), although this information is central to evaluate both the ultimate effectiveness of stocking as a fisheries enhancement measure and its impact on the wild population.

Overall, there are surprisingly few empirical studies quantifying how pike population abundance and biomass are affected by stocking, even though enhancement is often the main purpose of pike stocking. Lack of non-stocked control sites and pre-stocking information, insufficient replication or contrasts, and inappropriate experimental design often limit the strength of inference that can be drawn from most published evaluations of stock enhancements using stocking (Hilborn 1999, Walters and Martell 2004).

9.2.3 Outcomes of Stocking in a Size-Specific Context

Lorenzen (2000, 2005) proposed that most stocking experiments can be analysed and interpreted on the basis of allometric mortality–size relationships and that simple models can be constructed to study the outcomes of stocking before actually engaging in the practice (see Rogers et al. [2010], Johnston et al. [2015], and Garlock et al. [2017] for applications). Because the size of stocked fish crucially determines the additive effects to be expected from stocking (Lorenzen 2005, Rogers et al. 2010), we will below review results of pike population enhancement experiments in relation to the size (or life stage) at stocking. Several terms describe the different phases of pike ontogeny (e.g., eleutheroembryo, prototerygiolarvae, perygiolarvae; Raat 1988). In practice and in the stocking literature, these terms are often simplified to the detriment of clarity (e.g. it is often unclear what pike fry or pike fingerling means in terms of size). For our review, we adopted terminology used by the Food and Agricultural Organization (FAO) in their glossary for aquaculture (http://www.fao.org/faoterm/en/). Accordingly, fry describe fish from the beginning of exogenous feeding (i.e., from the end of the hanging phase, ~1 cm) to the advanced juvenile form where the phenotype resembles adults (marked by complete differentiation of organs and scalation, ~7 cm). Fingerlings describe age-0 fish older than fry to age-1, regardless of size (~7-30 cm). The term ‘adult’ is used in the below review for sexually mature individuals. In pike, age and size at maturation varies with growth rate (and hence geographical latitude and fishing mortality due to relaxed density-dependence in exploited stocks; Diana 1983). Hence, one-year-old pike can be sexually mature (e.g. in some lakes in
the Netherlands, 19 cm for males and 30 cm for females; Raat 1988). Therefore, for simplicity, we considered pike to be adult at a TL > 30 cm, although such individuals may have been referred to as fingerlings in some papers.

### 9.2.3.1 Outcomes of Stocking Fry

Vuorinen et al. (1998) reported that stocking of pike fry (~1 cm TL) in Lakes Rahtijärvi and Siilinjärvi (Finland), which hosted a natural stock of pike, did not increase juvenile pike density. Jansen et al. (2013) found that pike fry stocking in the self-sustained population of Lake Esrom (Denmark) did not increase angler catches between 1949 and 1969. Klein (2011) analysed the pike yield between 1990 and 2009 of three fry-stocked and three un-stocked large German pre-alpine lakes and found that mean pike yield gained by commercial fisheries varied across lakes but

![Figure 9.1](image_url) 

**FIGURE 9.1** The additive effects of stocking on the density of pike fry over natural reproduction (control) three weeks post-stocking measured by electrofishing (A) and the age-0 pike density in the same ponds, four months post stocking, assessed by draining (B). In one treatment group, a naturally reproducing pike population was established and additionally stocked with hatchery-reared pike fry (stocking in the presence of natural reproduction). This treatment was contrasted to a second treatment group (control) characterized by a naturally reproducing pike population without stocking, and a third group of stocking pike fry in populations that failed to reproduce naturally (stocking in the absence of natural recruitment) as an example for restocking of pike (or culture based stocking). All treatment groups were replicated four times (N = 12 ponds total). The figure shows the absence of additive effects in populations with natural reproduction (stocking in the presence of natural reproduction vs. control) and that stocking of pike fry in systems with negligible or lacking natural reproduction can generate a year class strength comparable to that produced by natural reproduction (stocking in the absence of natural reproduction vs. control). Figures modified from Hühn et al. (2014).

*a and b indicate significant differences between treatment groups. Error bars represent standard errors.*
was unaffected by stocking at a biomass density of 0.1-1.2 kg/ha. Grimm (1982) studied shallow lakes and found that three years of fry (4-6 cm fork length, FL) stocking did not increase the abundance of pike up to 41 cm (FL) relative to the abundance of larger pike reported from four years pre-stocking in the same shallow lakes Jan Verhoefgracht, Fortgracht, Kleine Wielen and Parkeerterreinsloot (Netherlands). Hühn et al. (2014) reported from experimental ponds that stocking fry into naturally reproducing pike stocks failed to generate additive effects, i.e., there was a failure to elevate year class strength over unstocked controls after few weeks post-stocking (Fig. 9.1). In Lake Halle (Denmark), Skov et al. (2011) reported that stocked pike fry were replaced by wild pike over the duration of the season, indicating larger mortality of stocked fry relative to wild recruits. In fact, the proportion of stocked pike in the population dropped from about 65% soon after stocking to about 15% four months after stocking. Hühn et al. (2014) also found that the stocked pike fry established in the juvenile pike populations without producing additive effects at the year-class level, thereby reporting a partial replacement of 31.4% of natural recruits by stocked fry pike in late summer (Fig. 9.1B). A replacement effect can also be hypothesized in the studies by Grimm (1982, 1983) as the author did not find any additive effect of stocking even though stocked pike amounted to among 3 to 67% of the total cohort.

In conclusion, it appears that stocking fry in waters with established pike populations has very short-term effects on pike population density and rarely succeeded in increasing pike stocks, a finding also mentioned by others (Margenau et al. 2008, Larsen et al. 2005; chapter 11). It can, thus, be concluded that stocking of pike fry has limited potential for stock enhancement.

9.2.3.2 Outcomes of Stocking Fingerlings

Relative to pike fry, the stocking literature about pike fingerlings is scarce. Grimm (1983) mentioned that the contribution of stocked fingerlings (18-23 cm FL) to the population of Lake Parkeerterreinloot (Netherlands) was absent. In small lakes (< 12 ha) in Germany with naturally reproducing pike populations, Hühn et al. (2015b) reported that stocking large fingerlings (average TL: 208 mm ± 29 Standard Deviation [SD]) increased the age-1 cohort in spring following stocking (at age-1), but stock size decreased one year post-stocking to levels comparable to the pre-stocking situation and to unstocked controls (Fig. 9.2A). The lack of additive effects of enhancement by fingerlings was further confirmed one and a half year post-release in the age-2 cohort (Fig. 9.2B). The lack of additive effects was independent of the habitat quality of lakes in terms of availability of structure (Hühn et al. 2015b). However, similar to the pond study (using fry) mentioned above (Hühn et al. 2014), some of the stocked fingerlings established in the populations without increasing the pike stock, again documenting a partial replacement of wild recruits by stocked pike. Stocked fingerlings have been reported in other studies to prevail in receiving populations to some extent. For example, Beyerle and Williams (1973) observed that marsh-reared stocked pike fingerlings (6.4-8.9 cm and 10.2-45.2 cm) remained, on average, longer than the wild pike of the same year-classes and represented 62% and 76% (ranging from 50% to 77% and 66.7 to
81.7%, respectively) of pike collected over three autumn electrofishing samplings in Long Lake (USA).

In conclusion, stocking fingerlings into naturally recruiting populations seems to result in a short-term increase of the stocked cohort, but additive effects at the population level are unlikely. In addition, the stocking may imply replacement effects where stocked pike (and their genes; chapter 7) are established in the population. Therefore, similar to the case of pike fry, the stocking of pike fingerlings seems to have limited potential for fisheries enhancement.

**FIGURE 9.2** Mean catch-per-unit-effort (CPUE, number of pike caught per 50 m shoreline electrofishing) of age-1 pike (A) and age-2 pike (B) in the year pre- and post-stocking (following a before-after-control-impact design). The bars show the mean CPUE of three treatments and also the composition of the cohort in terms of wild and stocked individuals. Small artificial lakes (< 12 ha) with naturally reproducing pike populations were stocked with a low stocking density (35 age-0 individuals/ha) or high stocking density (70 age-0 individuals/ha) of pike fingerlings, alongside an unstocked control group (N = 6 lakes per treatment). Age-0 pike abundance was assessed twice a year, in spring and fall, before and after stocking at the age-1 level (A), and again at the age-2 level (B). The experiments were conducted in 18 small gravel pits in Germany.

*indicates significant differences of treatment groups relative to controls. Error bars represent standard errors. Figures modified from Hühn et al. (2015a).

### 9.2.3.3 Outcomes of Stocking Adults

Similar to the case with fingerlings, there are only a few studies on the outcomes of stocking adult pike for stock enhancement. In Murphy flowage (Wisconsin, USA), Snow (1974) reported that stocking pike adults (25-55 cm TL) into a self-sustaining pike population doubled pike density, resulting in increases in angler catches (from 3.9 adults/100 angling hours before stocking to 7.2 adults/100 angling hours after stocking) in the first season after stocking. However, in the absence of continued
stocking, the pike stock declined two years after stocking to reach values recorded before stocking (or even below). The authors also reported detrimental effects of stocking on total harvest and abundance of large pike (> 66 cm), presumably due to density-dependent effects on growth and mortality. In particular, the strongly elevated density increased mortality (annual natural mortality rate of 22% before stocking and 81% after stocking), presumably caused by a parasitic infection believed to have been introduced at the time of stocking, as well as emigration of stocked pike. In another study, Carlander (1958) observed that 20% of the stocked adult pike (~ 25-41 cm) were captured within the first six weeks of the next fishing season, and Snow (1974) also observed that 78% of the stocked adult pike (26.5-58 cm) were reported in the catches by anglers in the first year after stocking. These values are substantially higher than the recapture rates previously reported for pike fry stocking (e.g. Dorow 2005) suggesting that stocking adults could strongly affect angler catches in the short term after release. Snow (1974) observed that two years after stocking (at a population size comparable to before stocking), stocked adult pike still represented 21% in abundance and 29% in biomass of the total pike stock suggesting partial replacement of wild pike. In the river Lot, Guillerault et al. (2012) found that the majority of anglers' captures of stocked pike (28-82 cm TL) occurred within a year after stocking, but some fish stayed up to three years in the river after stocking. Stocking of adult pike thus has the potential to increase catches in the short term and maintain or possibly increase the abundance of pike spawners in the long term. However, in a single-lake experiment with mature pike (36-70 cm TL), Hühn et al. (2015b) observed that the probability of spawning successfully in the first spawning season post-stocking was lower for stocked pike compared to resident controls. Moreover, Hühn et al. (2015b) reported that the per capita offspring production in the wild was lower for pike stocked from foreign sources relative to the offspring production of resident pike. The reduced reproductive fitness of non-local and stocked pike relative to resident pike (which was approximated 57% lower fitness, Hühn et al. 2015b) is in line with studies on salmonids (e.g. Araki et al. 2007) suggesting that stocking non-local adults may ultimately harm offspring production in the pike population.

In conclusion, stocking of adult pike is likely to be successful for restocking and short-term enhancement of catches and may possibly also elevate adult stock sizes. However, strongly boosting stock sizes beyond natural carrying capacity may lower growth rates and could affect individual fish condition by reducing egg sizes and reproductive output. Further studies are needed to test these predictions in the wild.

9.2.4 Synthesis of Pike Stocking for Stock Enhancement

Stocking pike into self-recruiting populations often fails to increase the pike stock, especially when fry or fingerlings are stocked, but even then replacement effects are likely. The likelihood of generating additive effects of pike stock enhancement is higher when large adult pike are released. Because larger pike have strongly increased survival compared to smaller conspecifics (Haugen et al. 2007), larger pike prevail longer in the ecosystem after stocking compared with smaller conspecifics.
(Fig. 9.3). However, even for larger pike, density-dependent processes will reduce the stock-enhanced pike population in the long term (e.g. altering fish growth-rates and fish condition; Lorenzen 2005). Still, a successful stock enhancement with stocking of adults could result in elevated densities that prevail longer than is the case with the release of smaller conspecifics, but this is most likely to eventually fall back to a population density defined by the ecosystem’s carrying capacity (e.g. due to elevated hunger and higher catchability of fish and, generally, compensatory mechanisms).

FIGURE 9.3 Effect of size at stocking on the pike stock (solid line) in naturally recruiting populations (C.C. = carrying capacity). The arrow represents the stocking event. The darker the dashed lines the larger the fish stocked (e.g. light grey: fry, dark grey: fingerlings, black: adults). The duration of additive effects increases with increasing fish size at stocking.

9.3 FACTORS AFFECTING PIKE STOCKING OUTCOMES

The above review of pike stocking outcomes has revealed the overarching importance of size at stocking for the additive benefits from stocking. The reviewed studies have also revealed other ecological issues that can affect stocking outcomes. The following section synthesizes the available pike literature and presents factors/variables that affect the success (and failure) of pike stocking. Many of these variables relate to limiting post-stocking mortality which is of crucial importance for improving fisheries and population management in stock enhancements (Lorenzen et al. 2012). Four keys issues are presented in a hierarchical order as proposed by Arlinghaus et al. (2015):

1. degree of natural recruitment,
2. degree of ecological and genetic adaptation (e.g. degree of domestication and genetic background) of stocked fishes,
3. size at stocking and stocking density, and
4. handling, transport and acclimatization.

9.3.1 Natural Recruitment

stocking pike is most likely to generate additive effects when the fish are stocked in ecosystems where natural recruitment is very low or absent. Souchon (1980) demonstrated that, at moderate stocking rates (up to 5 individuals per m²), the biomass and density of pike was a direct function of the initial fry stocking density in ponds that otherwise lacked pike. Relatedly, Hühn et al. (2014: Fig. 9.1) showed that stocking pike fry in ponds which lack natural reproduction resulted in age-0 pike densities comparable to levels emerging from natural recruitment in the absence of stock enhancement. In natural lakes, Sutela et al. (2004) reported successful stocking of pike fry (~ 10-15 mm TL) in terms of increase of fry density if natural recruits were extremely scarce or absent. Similarly, the stocking of adult pike in ponds or lakes otherwise lacking a pike population repeatedly resulted in the production of juveniles and the establishment of a pike population (chapter 14). For instance, Bry and Souchon (1982) reported that even few individuals (one female and two males, 170-750 g) produced ample juveniles in ponds although the production of young pike was less consistent than when relying on stocking of pike fry.

As reviewed in previous sections, in the cases of pike fry and fingerling stocking, the additive effects of stocking are much more uncertain and, in most cases, non-existent when wild conspecifics are already present in the ecosystem (Wysuajak et al. 2001, Lorenzen 2005, Schreckenbach 2006, Hühn et al. 2014, 2015a). For instance, Beyerle (1971) reported that post-stocking survival of fingerlings in two lakes (5 ha and 2.3 ha) in Michigan (USA) decreased from 44-60% during the first stocking in the absence of natural recruitment to only 0.8-9.2% when the stocking was repeated three years later after establishment of a pike stock. Similarly, in Danish lakes where pike fry were stocked for biomanipulation purposes, survival was less than 10% after 40 days (Skov and Nilsson 2007, chapter 11), and survival was highest in lakes where no wild pike were present (Skov et al. 2006). The reason for the lack of long-term stock enhancement effects of stocking juvenile pike in reproducing stocks probably relates to the strong compensatory mortality of juveniles (Lorenzen 2005, Hühn et al. 2014). The resulting recruitment bottlenecks are strongly size-dependent in cannibalistic pike (Grimm and Klinge 1996, Haugen et al. 2007) which is why stocking of juveniles in self-reproducing stocks is usually bound to fail and lead to very high mortality of the stocked pike (Skov et al. 2011).

For instance, Hühn et al. (2014) demonstrated stocked pike fry to generally have lower fitness (measured as growth rate and survival) when forced into competition with natural recruits of the same genetic origin and size.

A range of ecological factors affect natural pike recruitment and, hence, the prospect for successful pike stocking, most notably the presence of structured habitat used for spawning and for shelter and food availability (Raat 1988, Casselman and Lewis 1996, Grimm and Klinge 1996, chapter 10). Whereas Grimm (1981b, 1983) suggested a limited effect of prey fish density on pike density in natural waters, trophic resource availability (i.e., abundance of prey) has the potential to strongly affect intraspecific competition and cannibalism, notably when the timing of stocking does not match with the natural production of prey (Skov et al. 2003, Skov and Nilsson 2007). Maloney and Schupp (1977) reported that pike stocking may fail when prey fish density is low (in this case, perch Perca
flavescens" Mitchell, 1814) especially in the presence of other predatory species (in this case, walleye Sander vitreus Mitchell, 1818). Flickinger and Clark (1978) also reported that survival of stocked pike fry (50 mm) was dependent on forage fish availability. In addition, in Cave Run Lake (USA), Axon (1981) found that fluctuations in a stocked muskellunge population were primarily due to changes in the abundance of the primary prey species (in this case, gizzard shad Dorosoma cepedianum Lesueur, 1818). Skov et al. (2003) showed in pond experiments that cannibalism among fry (20-31 mm TL) was markedly more frequent in the absence of alternative prey, at least when the variation in stocking length was relatively high. The type of food available also influences pike survival. For instance, Beyerle (1978) showed that pike stocked in ponds with bluegill (Lepomis macrochirus Rafinesque, 1819) had, on average, a lower survival rate than pike stocked in ponds with fathead minnows and golden shiners (Pimephales promelas Rafinesque, 1820 and Notemigonus crysoleucas Mitchell, 1814, respectively). Apart from these examples, studies that highlight the importance of food type and availability for pike stocking outcomes remain scarce. Timing of stocking is then an important variable by affecting the availability of refuge, food, and the relative size of stocked and wild pike. Grønkjær et al. (2004) reported that pike stocked early in the season showed significantly higher survival than their conspecifics stocked three weeks later and suggested that the late stocked fry were outcompeted or predated upon by larger wild conspecifics. The situation may be different when adults that are no longer (or much less) under cannibalistic control (Haugen et al. 2007) are stocked. However, the additive effect of stocking adults in naturally-reproducing stocks is likely to increase catches but will not necessarily increase recruitment as the new recruits are, again, forced through density- and size-dependent bottlenecks (Lorenzen 2005).

The presence of structured habitats, essential in each life-stage of pike (chapters 2, 3 and 10), is of main importance for the survival of young pike. Shore vegetation, especially macrophyte cover, provides shelter against cannibalism (Grimm 1981a, 1983) and predation (including predation by piscivorous birds; Cucherousset et al. 2007) and serves as habitat for prey (Casselman and Lewis 1996). In lentic systems, the littoral area generally limits recruitment and, thus, stock size (Grimm 1983, 1989, Pierce and Tomoko 2005). Grimm (1994b) reported that an optimal recruitment requires 15-30% of the lake area covered by submerged or emergent vegetation (either temporarily or permanently). Grimm and Klinge (1996) reported, from studies in shallow vegetated ponds and lakes, that any increase in the population (from stocking) above the carrying capacity of the system will quickly be removed by cannibalism or displacement, rendering the likelihood of a positive stocking outcome, in terms of elevation of recruitment, unlikely if sufficient recruits are available. While vegetation cover and vegetation structure affects cannibalism among pike, allowing segregation or overlap between habitats of different size classes (Grimm and Backx 1990, chapters 3 and 5), the degree of cannibalism broadly depends on the biomass of larger conspecifics (Grimm 1981b, 1983, 1994a, Persson et al. 2006, Sharma and Borgstrom 2008). Interestingly, Pierce (2010) could not find that conservation of large fish decreased the abundance of smaller conspecifics, possibly because he studied large systems.
where juveniles and adults may no longer share the same habitats, to the same extent, as in smaller systems (e.g. shore pike vs. lake pike, Grimm 1994a). Hünn et al. (2015a) reported that in lakes that offer poor habitat, stocking of juveniles did not elevate stock size of age-2 fish due, most likely, to cannibalism. In fact, the natural pike population sizes varied with the availability of structured pike habitat, but the lack of additive effects of juvenile pike stocking was independent of habitat structure; in “poor” or “good” pike lakes, the final pike stock size was independent of stocking intensity (Hünn et al. 2015a).

In conclusion, an increased pike density can only be achieved by stocking if the natural stock is low (e.g. due to high fishing pressure or weak natural reproduction) and, at the same time, a sufficient forage base and a sufficient quantity of appropriate and unsaturated habitats is available (Grimm 1981a, Skov et al. 2011). Prolonged additive effects on year-class strength are highly unlikely when relying on stocked fry or juveniles in naturally reproducing populations (Hünn et al. 2014a, 2015a) unless there is weak recruitment and, consequently, few natural young pike. If one relies only upon stocking adults, adult stock size might be elevated (see size section below for details) but not necessarily result in increased future recruitment.

9.3.2 Eco-Genetic Adaptation

Ecological and genetic adaptation to the conditions of the receiving environment is fundamental for successful stocking by affecting survival and recruitment success post-stockling. Rearing in aquaculture facilities, such as hatcheries, induces a domestication syndrome in the cultured organism that involves both phenotypic developmental responses and genetic selection (Lorenzen et al. 2012). Aquaculture often leads to the development of domesticated strains, notably in the case of captive brood stock or when certain traits (e.g. growth, colouration patterns) are selected. However, domestication effects and consequent loss of fitness in the wild can, and usually does, occur even when intentional selection is avoided (Lorenzen et al. 2012). While natural evolutionary forces favour local adaptation in wild populations (Eschbach et al. 2015, Bekkevold et al. 2016), natural (and artificial) selection in aquaculture systems, as well as developmental adaptation to rearing environments, tends to increase fitness in the aquaculture system but leads to maladaptation of stocked fishes to natural conditions and, therefore, reduced fitness in the wild (Price 2002, Lorenzen 2006, Lorenzen et al. 2012).

Independent of genetic selection and adaptation, rearing conditions and time in artificial environments (hatching jars, tanks and raceways, and presumably, to a lesser degree, in ponds) strongly influence the survival of stocked fish by affecting their ability to cope with their new environment. Hünn et al. (2014) showed that pike that were artificially spawned from the same wild-living brood stock as those naturally spawning in ponds had lower growth and elevated mortality when stocked with wild fry (Fig. 9.4). This occurred despite that the stocked individuals were reared in captivity, even for a very short period (until the free-swimming phase). No differences in fitness components were seen when the fry were stocked without naturally-spawned fry (Fig. 9.4) indicating that the forced competition invokes the fitness depression to emerge. The reduced fitness of stocked fish is
FIGURE 9.4 Mean total length of naturally-recruited and hatchery-reared age-0 pike from a replicated pond experiment. In the two bars on the left, growth of naturally-recruited pike without additional adding of hatchery-reared pike fry (control) is compared with fish from ponds with hatchery-reared fry only (stocking in the absence of natural recruitment). To the right, fish from ponds containing both naturally-recruited and hatchery-reared age-0 pike of the same genetic background in a competitive situation (stocking in the presence of natural recruitment) is compared. Fish are sampled in July.

* indicates significant difference. Error bars represent standard errors. Figure modified from Hühn et al. (2014). See caption of Fig. 9.1. for further details on the study design.

Driven by multiple, morphological, physiological and behavioural factors, which can be partially mitigated by husbandry approaches such as rearing in semi-natural conditions, enrichment of the aquaculture environment, or life skills training (Lorenzen et al. 2012, Näslund and Johnsson 2014). Moreover, in hatcheries, non-natural selection forces lead to very high survival rates and successful hatching of individuals that have naturally low fitness. Finally, circumventing sexual selection can lead to fitness depression and genetic effects that might reduce survival in the wild as shown for salmonids (Thériault et al. 2011). However, this statement needs a proper empirical assessment in pike. Most importantly, behaviours associated with food selection, food acquisition and social interactions are unlikely to properly develop during the early ontogeny in hatchery conditions as observed in several salmonids (e.g. Brockmark et al. 2007, Brockmark and Johnsson 2010). Szczechowski et al. (2012) showed in an experiment in ponds that growth of hatchery-reared pike, from the same genetic strain, was inversely related with duration of time held in the tank. This suggests that longer durations of time in captivity reduces performance of stocked pike in the wild as proposed in salmonids (e.g. Baer 2008). Franklin and Smith (1963) also found that stocked
pike produced in marshes containing a large diversity of prey displayed a higher survival than pike reared under standard hatchery conditions. This suggests that pike reared in ponds prior to stocking may have higher survival after stocking than those reared in artificial aquaculture facilities. In support of this statement, Gillen et al. (1981) reported that pellet-reared congeneric muskellunge were slow to shift their diet toward forage fish during ontogeny. Although rearing pike used for stocking on pellets is not common (as most rearing happens in ponds), the example shows how husbandry methods that do not promote the development of natural behavioural and other ecological traits can contribute to low fitness of stocked pike compared with wild conspecifics. Decreased foraging efficiency of stocked pike in the wild might then lead to suboptimal growth and subsequent increased mortality of stocked pike when forced into competition with similarly-sized conspecifics (Skov 2002, Skov et al. 2011).

Besides (non-genetic) domestication effects, genetic maladaptation of translocated fish to conditions in the receiving environment is also likely to affect stocking outcomes, but it is often difficult to differentiate purely genetic from ecological maladaptation, hence the term ‘eco-genetic’ adaptation in this section. For example, from 1993 to 2002, nearly 400,000 translocated freshwater pike fry were stocked to compensate for population declines in brackish waters of Denmark. Using a molecular-based approach, Larsen et al. (2005) found that only 0.3% of the genetic material originated from stocking of pike fry (population admixture analysis), documenting poor survival of stocked fish in their new environment. The low fitness of stocked fish was presumably caused by maladaptation of the freshwater stocked pike to the receiving ecosystem (brackish water), but it is unclear whether the results were caused by poor tolerance to high salinity (genetically-based physiological adaptation) or other factors such as the presence of strong natural recruitment.

Hühn et al. (2015b) reported that stocked large mature pike that were translocated from two lakes located only a few kilometers from the stocked water body showed strongly reduced reproductive success after stocking compared with their local wild conspecifics. The lower fitness might prevent (or lower) genetic replacement effects (as in the case of Larsen et al. 2005), but Hühn et al. (2015b) also found that the foreign stocks produced viable hybrids despite having a lower per capita reproductive fitness. If these hybrids survive and reproduce themselves, the reproductive performance of the entire pike population could be altered by replacement of wild pike by less well-adapted foreign fish (e.g. if pike are stocked larger than their wild conspecifics) or hybrids that can have lower reproductive performance (see Chileote et al. [2011] and Araki et al. [2007] for an example, in salmonids). Both Eschbach et al. (2015) and Bekkevold et al. (2016) show that local pike stock often shows divergent genetic signatures from those expected from the catchment suggesting local loss of native biodiversity regularly happens due to stocking. Hybridization between strains has been observed for other species which often shapes colonization dynamics and evolutionary trajectories (Araki et al. 2007, Fraser et al. 2011). However, hybridization can also be advantageous outside the natural range or in altered environments by induced evolutionary novelty (Abbott et al. 2013, Eschbach et al. 2014). Despite this ongoing discussion.
it is safe to assume that the fitness of stocked fishes is usually lower for non-local strains. Therefore, a clear recommendation is to rely on offspring from the same ecosystem or the same catchment to avoid genetic mixing and maximize the likelihood that stocked fishes have high fitness (Arlinghaus et al. 2015).

9.3.3 Stocking Size and Stocking Density

As reviewed above, the size at stocking strongly affects stocking outcome and the probability of generating additive effects particularly by affecting mortality post-stocking. Stocked individuals may face wild conspecifics that are often competitively superior (e.g. Skov et al. 2011), either because of higher competitive ability (resource-holding potential), or by motivation for defense of refuges (value asymmetry, i.e., prior residency advantage; e.g. Huntingford and de Leaniz 1997, Rhodes and Quinn 1998). Post-stocking survival of pike should increase with individual body size at stocking (e.g. Cucherousset et al. 2007), as in many other fish species (Lorenzen 2000), since in pike, cannibalism is strongly size-dependent (Grimm 1981b, 1994, Haugen et al. 2007) and even small size differences matter (e.g. Grimm and Backx 1990, Skov et al. 2011). Gronkjær et al. (2004) demonstrated that stocked pike fry may well survive competition with wild recruits, in particular, when the stocked individuals are larger than their wild conspecifics. Skov et al. (2011) demonstrated that the movement of stocked pike fry after release was inversely related to the size at stocking suggesting that larger pike fry out-competed smaller pike by restricting them to suboptimal habitat, social stress, and risk of cannibalism. Snow (1974) also reported that intense stocking resulted in emigration of stocked pike because of competition with wild pike. Skov et al. (2003) found that mortality of stocked pike increased with the level of body size heterogeneity within the cohorts as larger pike forage on smaller individuals (i.e., cannibalism). Overall, fish that are stocked larger and are developmentally advanced, relative to the naturally produced pike of the same cohort, have better chances of survival (Beyerle and Williams 1973, Grimm 1982, Raat 1988). Interestingly, earlier spawning and emergence of larvae is often outlined as a reason of pike dominance on sympatric congenereic muskellunge (Inskip 1986). Note, however, that an increased survival of stocked fishes must not necessarily elevate the probability of generating additive (stock-enhancing) effects. By contrast, elevated survival of stocked fishes, particularly when releasing juveniles, might simply mean that the degree of replacement of wild fish by stocked fish increases without necessarily elevating year-class strength (Fig. 9.1 and 9.2). Moreover, poor ecological adaptation can reverse the size-advantage on survival, as, for example, documented when comparing the survival of glass eel with the survival of (larger) stocked farm eels (Anguilla anguilla Linnaeus, 1758; Simon and Dörner 2014). The fish size at stocking seems to be of less importance when natural recruitment is lacking. Under such conditions, the stocking of pike fry can generate year class strengths according to prevailing ecological conditions.

Stocking density directly affects the level of intraspecific competition for food and habitat, the risk of cannibalism, and post-stocking mortality (Bry and Gillet 1980, Wright and Giles 1987, Edeline et al. 2010). Pike stocking densities reported in the literature are highly variable (e.g. for fry: 0.11 individuals/m² [van
Donk et al. 1989] or 6.3 individuals/m² [Skov et al. 2003] and, for fingerlings, 0.001 individuals/m² [Beyerle and Williams 1973] or 0.22 individuals/m² [Szczechkowski et al. 2012]) depending on the life-stage of stocked pike and habitat availability. For fry, a stocking density of 5-6 individuals/m² is commonly used (Bry and Souchon 1982, Wright and Giles 1987, Skov et al. 2011, Hühn et al. 2014). The highest stocking densities are often reported from stocking as a lake restoration measure (see chapter 11 for further discussions). For fingerlings, values reported in the literature often suggest to release about 30 individuals/ha (Baer et al. 2007). However, all populations of fishes, in particular pike, are density-regulated (Lorenzen 2005, Haugen et al. 2007) such that an increased density of stocked juveniles usually means elevated density-dependent mortality and strong self-regulation towards carrying capacity. The situation can be different when recruited (large) fish are stocked (Johnston et al. 2015) where the population size is mainly regulated by density-dependent growth and less by density-dependent mortality (i.e., cannibalism; Lorenzen 2005). Under these circumstances, additive effects of stocking and, at least, increased catches in the short-term could also be conceivable (Lorenzen 2005) in pike (Fig. 9.3).

9.3.4 Handling, Transport and Acclimatization

Finally, the stocking procedure, itself, can strongly affect the success of stocking (Wahl 1999). Stress caused by handling and transportation (e.g., duration of transport, density in holding tanks, temperature differences among transport tanks and ecosystem, unsuitable environmental conditions in the tank) can generate direct and indirect mortality (e.g., Gomes et al. 2003, Braun et al. 2010). For example, Hühn et al. (2015b) demonstrated that stocking stress associated with capture, transport, netting and release into a novel environment resulted in a stress-induced mortality of at least 10% even when adult pike (36-70 cm TL) were stocked. The mortality happened within the first winter following release independent of the origin of fish (Fig. 9.5). However, other studies have revealed that esocids are rather resilient to a range of stressors during transport and that acclimatization procedures (e.g., previous exposure to natural food) do not substantially improve post-release survival in the congenereous muskellunge. Mather and Wahl (1988) found elevated mortality (3.3% ± 5.8 SD) of pike (21 cm mean TL) when stocked at temperatures above 25°C. At the same time, the authors reported little mortality even after a rapid temperature increase of 10°C between transport tank and the temperature of the lake. Yet, when the temperature differences was about 15°C, almost a complete mortality (98%) occurred after stocking suggesting that severe thermal stress is more important for the post-stocking survival of 0+ pike than either handling or transport-induced stress (Mather et al. 1986, Mather and Wahl 1988).

To limit indirect mortality associated with handling and transportation, acclimation of fish to the water temperature and water chemistry, prior to release, has been suggested in a range of species (see Wahl [1999], Brennan et al. [2006], Baer and Brinker [2008] for examples in other fish species), but no research is available in pike. Research in the congenereous muskellunge and tiger muskellunge has also failed to find significant survival benefits when fishes were previously
exposed to predators (in this case, largemouth bass Micropterus salmoides Lacepède, 1802; Wahl et al. 2012). Furthermore, survival post-release was the same when fishes were released during the day or during the night (assuming less predation mortality during the night-time; Stein et al. 1981). However, it was found that feeding experience increased survival post-release compared to naïve (only pellet-fed) esocoids (muskellunge or tiger muskellunge; Szendrey and Wahl 1995), and that adding of artificial vegetation to rearing tanks improved behaviour consistent with increased survival in the wild (Einfalt et al. 2013). Hence, acclimatization procedures prior to stocking and reduced stress during transport promises to increase the likelihood of positive stocking outcomes. To minimize the immediate mortality post-release, it can be suggested to distribute pike along the bank in shallow (< 2-3 m, or very shallow (15-30 cm) for fry) highly vegetated areas to provide shelter, when predators are less active (e.g. during the evening to avoid avian predation) (e.g. Kerr and Lasenby 2001), despite the lack of evidence in support of these recommendations.

FIGURE 9.5 Survival of control fish (native pike) compared to a native group of pike (KL Döllnsee) that were handled and transported to simulate stocking stress and two groups of pike originating from two foreign nearby lakes (Groß Vätersee and Wuckersee) after stocking in fall. Control fish were caught, tagged and released immediately in the native water body. All fish (adult pike) were tagged with acoustic transmitters to estimate survival. Comparisons were made over different observation periods post-stocking. Figure modified from Hühn et al. (2015b).

9.4 ECOLOGICAL AND CONSERVATION RISKS ASSOCIATED WITH PIKE STOCKING

Although stocking of pike could offer multiple benefits for fisheries and conservation, the practice can also have negative impacts on the receiving ecosystems as well as the users. For instance, high expectations by anglers about stocking-induced increases in stock sizes can increase fishing pressure and reduce angler satisfaction
through overexploitation of the fish stock or overcrowding of stocked sites (Krohn 1969, Post et al. 2002, Fayram et al. 2006, Lorenzen et al. 2012). Stocking might also modify ecosystem functioning, and this is particularly true in the case of pike which is a keystone predator in many ecosystems (chapters 8, 11 and 14). Stocked pike compete with other predatory fish for prey, and successful increases in stock sizes (for example due to the release of recruited fishes), may reduce the abundance and growth of wild conspecifics and other predatory fish through predation (Snow et al. 1974, Maloney and Schupp 1977). Increased competition with stocked pike can also increase the vulnerability of other species to angling as demonstrated for walleye (Wesloh and Olson 1962). In addition, stocked fish may carry pathogens. For example, Snow (1974) reported that stocking of pike led to high mortality of wild pike from parasitic infections (Myxobolus sp.). The infections affected both stocked and wild pike, but larger wild pike were disproportionately affected as these fish did not emigrate after stocking.

Another key problem relates to genetic pollution by stocked individuals as surviving individuals can contribute to the wild population by reproducing with wild conspecifics, thereby, introgressing genes into local stocks. Introgression of foreign genes into local gene pools can lead to the loss of the local stock due to genetic swamping by numerically abundant stocked fishes spawning with numerically less abundant wild conspecifics (Laikre et al. 2010). In many European countries, stocking is commonly performed by local stakeholders in a self-organized manner where the source population used for stocking is largely uncontrolled and determined by supply-demand factors in commercial hatcheries (Arlinghaus et al. 2015). This is despite the fact that recent investigations have shown the existence of different genetic pike strains, at least at catchment levels in Europe (Pedreschi et al. 2014, Eschbach et al. 2015, Bekkevold et al. 2016; chapter 7). For instance, Launey et al. (2006) conducted a study in 11 rivers in France and demonstrated the occurrence of genetic introgression from farmed pike (originating from Poland and Czech Republic, which are among the main pike-exporting countries in Europe) in the natural populations. In addition, pike stocking may alter the genetic integrity of other species of pike. Denys et al. (2014) showed evidence of hybridization between E. lucius and Esox aquititanus [Denys et al. 2014] in France, and Gandolfi et al. (2017) showed evidence of hybridization between E. lucius and Esox cisalpinus (Bianco and Delmastro 2011) in Italy. By contrast, in Finland, most pike fry produced come from eggs of fish caught on the spawning grounds in the wild (FAO 2005). In Denmark, age-0 pike used in stocking programmes are the progeny of wild parents (25 males and 25 females crossed) captured in lakes within the geographical vicinity (< 200 km) of the target ecosystem to conserve local adaptation of fish and conserve local genetic composition (Skov et al. 2011).

9.5 CONCLUSIONS

Our review suggests that pike stocking produces very different outcomes depending on the state of the ecosystem and the genetic source and size of
the pike that are stocked. One of the key factors for stocking success from a fisheries perspective is that pike have to be stocked at sizes large enough to bypass strong density-dependence mortality particularly in the juvenile life-stage. Pike stocking for enhancement has shown very poor long-term efficiency, especially when relying on juveniles as stocking material. Juveniles and small adults of pike (< 50 cm) are associated with structured vegetation where strong competition for food and shelter, predation, and cannibalism drive pike abundance. Hence, in naturally recruiting stocks, stocking pike smaller than 50 cm in stock enhancement projects will rarely lead to long-term increases in the stock and may, if at all, only boost catches in the short term. Releasing juveniles in recruiting stocks can, thus, no longer be recommended without careful appraisal of risks and potential benefits. By contrast, stocking in waters naturally lacking pike (i.e., introductory stocking, re-stocking or culture-based stocking) is often very successful in establishing a fishery no matter which size classes are stocked (see also chapter 14). However, immediate success in establishing a population or year class does not imply that the newly established pike will provide good quality fisheries over a long-term period unless the reasons for the poor recruitment are addressed through habitat improvement. The situation is different with stocking large (recruited) pike if the goal is to maintain high catches (e.g. Snow et al. 1974). Stocking of adults seems to be the only tool that can elevate catches in self-recruiting stocks (Johnston et al. 2015). Even then, no positive effect on future recruitment is to be expected because of compensatory mechanisms, lower fitness of stocked fishes and their offspring, and because the new recruits will, again, be forced through the same habitat bottlenecks that were likely responsible for motivating the stocking exercise. Therefore, stocking of adult pike seems to be a sensible option when a significant local fishing pressure is present to take advantage of the strongly elevated stock size by elevated catches or for restocking programs after fish kills to “buy” time for a new natural recruitment.

To conclude, it appears that in ecosystems where pike naturally reproduce, stocking may be superfluous because of (i) the absence of additive effects in terms of increasing stock size and subsequently fisheries yield, especially when stocking young-of-the-year fish, and (ii) the partial replacement of wild pike by stocked individuals, implying the risk of genetic introgression and loss of local gene pools (Hühn et al. 2014, 2015b). In general, we believe, based on the data reviewed in this chapter, that in ecosystems were natural pike populations are depressed, stocking pike (i.e., larger adult pike) is a way to treat symptoms and, if stocking is meant to support fisheries, maintain catches. However, if managers are looking for the “full cure” they should direct their attention to fisheries regulations (chapter 12) and/or habitat improvement (chapter 10) as alternatives to pike stocking (Arlinghaus et al. 2016). This conclusion is, of course, not new and has previously been expressed by Grimm (1983) more than 30 years ago. He evaluated several stocking attempts of both fingerlings and adult pike in Dutch lakes and concluded that “habitat-engineering rather than stocking may be the answer to the problem of maximizing pike populations” (chapter 10). Based on our review, this seems, indeed, to be the most promising way forward.
In systems were pike stocking is chosen as a management tool we suggest paying attention to the following suggestions.

- Pike should be stocked as large as needed to outgrow recruitment bottlenecks.
- Stocked pike may best originate from complex natural/semi-natural environments (i.e., lakes and ponds rather than tanks) because such fishes are likely more adapted to natural settings.
- Stocked pike may best originate from the same gene pool as wild individuals to maintain the genetic integrity of wild populations and avoid the disruption of local adaptation.
- It is of high importance to account for the health and sanitary status of fish used for stocking. Transportation and handling should be minimized and proper acclimation prior to release considered.

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