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FISH STOCKING IN INLAND WATERS IN EUROPE AND CENTRAL ASIA

ISSUES AND SOLUTIONS

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ISSUES AND SOLUTIONS

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FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
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PREPARATION OF THE DOCUMENT

The Thirty-first Session of the European Inland Fisheries and Aquaculture Advisory Commission (EIFAAC), held in Killarney, Ireland on 22–24 June 2022, requested the preparation of EIFAAC/CACFish Fish Stocking Guidelines.[1] This document was prepared in 2024 to inform the development process of the Fish Stocking Guidelines.

The development of the EIFAAC/CACFish Fish Stocking Guidelines was included in the endorsed EIFAAC 2022–2024 work programme. The EIFAAC project on “Fish stocking guidelines, including general principles, best practices, economic aspects, interaction with natural stocks and safeguarding biodiversity” held a [virtual] project meeting on 17 October 2023, led by Derek Evans (United Kingdom of Great Britain and Northern Ireland) and attended by experts from five EIFAAC Member States. The EIFAAC and CACFish Secretariats agreed to involve the Angling Trust and the University of Hull Evans (United Kingdom of Great Britain and Northern Ireland) in the preparation of the guidelines.

On 17 May 2024 the EIFAAC/CACFish Fish Stocking Guidelines Consultation was held virtually to discuss the first draft guidelines, which were prepared by Prof Ian G. Cowx of the Angling Trust/University of Hull, following advice and contributions received from Members in early 2024. Information about the consultation, which was attended by 23 experts from 12 EIFAAC Members, is available here: https://www.fao.org/fishery/en/meeting/41461.

A presentation with the same title as this document was made by Prof Cowx at the EIFAAC International Symposium on ‘Building a sustainable future for inland fisheries and aquaculture in a time of multiple stressors’, held on 7 and 8 October 2024 in Pula, Croatia. The Symposium recommended, amongst others, to the Thirty-Second Session of EIFAAC that there is a “need for responsible management of stocking in inland water bodies, including stocking programmes and ad- hoc stocking”.[2] The Thirty-second Session of the European Inland Fisheries and Aquaculture Advisory Commission was held in Pula, Croatia, on 9–11 October 2024, and expressed appreciation for the work carried out by the EIFAAC project and endorsed the 2025–2026 work programme which includes the finalization of this document and the guidelines.[3]

This literature review was written by Prof Ian G. Cowx of the University of Hull International Fisheries Institute and the Angling Trust with support from Raymon van Anrooy (EIFAAC Secretary) and Haydar Fersoy (CACFish Secretary). Contributions were provided by participants in the EIFAAC/CACFish Fish Stocking Guidelines Consultation, and particularly by Robert Arlinghaus, Reinhold Hanel, Daniel Huehn, Lasse Marohn, Ronan Matson, Paul McLoone and Mark Owen. The document was formatted by Maria Eugenia Escobar (FAO).

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[1] **FAO**. 2022b. *Report of the Thirty-first Session of the European Inland Fisheries and Aquaculture Advisory Commission – Killarney, Ireland, 22–24 June 2022*. European Inland Fisheries and Aquaculture Advisory Commission. FAO Fisheries and Aquaculture Report No. 1383. Rome. https://doi.org/10.4060/cc1986en

[2] **FAO**. 2025. *Proceedings of the EIFAAC symposium on Building a sustainable future for inland fisheries and aquaculture in a time of multiple stressors, Pula, Croatia, 7-9 October 2024*. EIFAAC Occasional Paper No. 55. Rome.

[3] **FAO**. 2024. *Report of the Thirty-second Session of the European Inland Fisheries and Aquaculture Advisory Commission, Pula, Croatia, 9–11 October 2024*. FAO Fisheries and Aquaculture Report, No. 1464. Rome. https://doi.org/10.4060/cd3697en.

ABSTRACT

Fish stock enhancement through formal stocking programmes has long been recognized as an important tool to compensate the loss of productivity and diversity. Fish stocking is widely implemented across Europe and Central Asia to increase or maintain fish productivity. However, there are concerns about the benefits and successes associated with stocking fishes, as well as the potential risks, particularly with respect to ecological impacts from stocking, competition and predation, changes in ecosystem functioning, changes in community structure, disease transmission and losses of genetic integrity. Consequently, there is a need to review the factors that drive successes and failures of fish stocking programmes and the risks from stocking, so stock enhancement programmes are carried out in the most effective way.

This report summarizes the main conclusions of a review of the benefits and impacts of stocking. It provides a framework to mitigate the negative impacts and maximize the benefits of fish stocking activities. The main recommendations for successful, environmental and socially acceptable fish stocking in fresh waters include:

- Clearly define the aims and specific objectives of fish stocking programmes and demonstrate potential economic and environmental benefits. It is important to weigh these against potential drawbacks or challenges.
- Prior to planning stocking, conduct a thorough evaluation of the rationale behind the action and explore alternative enhancement approaches such as habitat improvements or better fisheries management. Address any underlying causes for the underperformance of the fisheries before resorting to stocking. Prioritizing habitat improvement can offer sustainable, long-term gains with minimal ecological impacts.
- Review and address broader issues and constraints likely to impact on the long-term success of stocking programmes during project design and implementation. Stocking should primarily be considered for waterbodies heavily impacted by human activities, where natural fish populations are disrupted or eliminated, for example after a fish kill, or where habitat restoration is not feasible.
- When assessing fish stocking as a management tool, the pros and cons of all options should be evaluated, including the "do nothing" approach. Despite potential pressure for stocking from the public, all options should receive equal consideration. Regulators must evaluate long- term ecological implications of stocking beyond short-term economic or public gains, and consider the entire watershed and adjacent water bodies.
- Risk assessment protocols should evaluate the potential for fish stocking to introduce new parasites or diseases into recipient systems. Full consideration of potential adverse impacts on the environment, genetics of native stocks and ecological interactions is necessary. The precautionary approach should guide decisions, especially in areas of high conservation value, with special attention given to species sensitive to stocking.
- Appropriate monitoring should be implemented for all fish stocking activities to assess progress and outcomes, and reduce risks of unforeseen adverse effects in future endeavours.
- Species-specific guidelines should be developed, outlining effective protocols for deciding on stocking, implementation methods, and potential impacts.
- It is advisable that all stocking initiatives undergo thorough formulation and planning to prevent haphazard and often ineffective stocking efforts. The anticipated results of specific stocking endeavours should align with broader objectives within the fisheries sector, while acknowledging constraints that may hinder success.
- When assessing the viability of fish stocking programmes an evaluation of the most cost-effective options in relation to expected benefits should be undertaken. All too often, the strategy is to make do with existing circumstances, yet some forward planning could significantly enhance outcomes.
- Lastly, it is recommended that both existing and proposed fish stocking programmes undergo independent assessments to ensure comprehensive consideration of broader environmental, ecological, and socioeconomic factors.

CONTENTS

GLOSSARY

Definitions of terms used for the purpose of these guidelines were compiled from the FAO Term Portal Web site (http://www.fao.org/faoterm/en/) and FAO technical guidelines and documents, including: **a**: FAO (1996), **b**: FAO (2011), **c**: FAO (2008), and **d**: FAO (1997a).

Term	Definitions	Source
Aquaculture	The farming of aquatic organisms including fish, molluscs, crustaceans and aquatic plants with some sort of intervention in the rearing process to enhance production, such as regular stocking, feeding, protection from predators. Farming also implies individual or corporate ownership of the stock being cultivated. For statistical purposes, aquatic organisms which are harvested by an individual or corporate body which has owned them throughout their rearing period contribute to aquaculture.	**d**
Culture–based fisheries	A fishery in which the use of aquaculture facilities is involved in the production of at least part of the life cycle of a conventionally fished resource. Aquaculture is usually the initial hatchery phase that produces larvae or juveniles for release into natural or modified habitats	**a**
Enhanced fisheries	Fisheries that are supported by activities aimed at supplementing or sustaining the recruitment of one or more aquatic organisms and raising the total production or the production of selected elements of a fishery beyond a level which is sustainable by natural processes. Enhancement may entail stocking with material originating from aquaculture installations, translocations from the wild and habitat modification.	**b**
Enhancement	Any activity aimed at supplementing or sustaining the recruitment, or improving the survival and growth of one or more aquatic organisms, or at raising the total production or the production of selected elements of the fishery beyond a level that is sustainable by natural processes. It may involve stocking, habitat modification, elimination of unwanted species, fertilization or combinations of any of these practices.	**a**
Habitat enhancement	A fishery management tools with the sole purpose of providing better environmental conditions for desired species of fish, e.g. reconnecting habitats, re-meandering rivers, improving water quality.	**a**
Genetically modified organism (GMO)	An organism in which the genetic material has been altered by humans through gene or cell technologies. A genetically modified fish is usually a transgenic fish (i.e. a fish with a gene inserted from another organism in a manner that is not possible through natural processes)	**c**
Genetically selected organism	An organism produced by selective breeding.	**a**
Inland capture fisheries	The removal of fish and other aquatic organisms from natural or enhanced inland fisheries, but excluding aquaculture	**b**

Term	Definitions	Source
Naturally reproductive stock component	In fisheries enhanced through stocking, that component of the total stock that is maintained by natural reproduction. This component may include organisms derived from natural reproduction of stocked fish.	**b**
Re-introduction	Release of specimens of a taxon into a part of its former native range in which that taxon had become extinct in historical times.	**a**
Recreational fishing	Any fishing for which the primary motive is leisure rather than profit, the provision of food or the conduct of scientific research and which does not involve the sale, barter, or trade of part or all of the catch.	**a**
Stock enhancement	Activities aimed at supplementing or sustaining the recruitment, or improving the survival and growth of one or more aquatic organisms, or at raising the total production or the production of selected elements of the fishery beyond a level that is sustainable by natural processes. In this sense, stock enhancement includes enhancement measures that may take the form of: introduction of new species; stocking natural and artificial waterbodies, including with material originating from aquaculture installations; fertilization; environmental engineering including habitat improvements and modification of waterbodies; altering species composition including elimination of undesirable species or constituting an artificial fauna of selected species; genetic modification; and introduction of non-native species or genotypes.	**a**
Stocking	The practice of placing aquatic organisms into natural or modified waterbodies. Stocked material may originate from aquaculture facilities or translocations from the wild.	**b**

1. INTRODUCTION

The stocking, transfer or introduction of fish species are frequently used by fisheries owners, managers and scientists throughout the world in an attempt to improve the quantity or quality of catches (Cowx, 1994, 1999; Welcomme and Bartley, 1998; Molony *et al.*, 2005). Many thousands of stocking events, involving millions of individual fish, take place annually in managed fisheries, especially recreational or culture-based fisheries, or for conservation purposes. Stocking is often used to compensate for the loss of fish productivity and diversity, and is widely implemented to increase or maintain fish stocks and improve fisheries, often because it is considered the easiest way to maintain yields.

Despite widespread stocking of fish globally, there are concerns about the potential risks associated with stocking and introducing fishes, particularly with respect to ecosystem functioning, changes in community structure, disease transmission and loss of genetic integrity (Cowx *et al.,* 2023; Claussen *et al.,* 2023). These can have serious implications for water bodies that have protected status or support plant or animal species of conservation importance. Fisheries managers, conservationist and user groups are aware of the possible impacts of stock enhancement programmes, both in terms of the effects on ecosystem functioning and the likelihood of improvements in stocks.

Unfortunately, information on the impacts of stock enhancement programmes is sparse, largely because of a lack of systematic monitoring and dissemination of information on the outcomes. (Cowx, 1998; Arlinghaus *et al.*, 2002; Lorenzen, 2014; Cowx *et al.,* 2023). Relatively few programmes have been properly evaluated and evidence suggests, with the exception of culture-based fisheries, stock enhancement exercises rarely lead to any long-term tangible benefits (Cowx, 1999; Lorenzen, 2008, 2014; Cowx *et al.,* 2023; Hühn *et al.*, 2023; Radinger *et al.*, 2023). Weaknesses in success of many programmes appear to result from indiscriminate stocking without well-defined objectives or prior appraisal of the likelihood of success (Cowx, 1994a; Lorenzen, 2014). Nevertheless, if stocking programmes are designed to achieve defined objectives and implemented following best-practice guidance, it should be possible to improve success rates and minimize or mitigate any detrimental effects. It should also be possible to identify situations where, because of risks to the wider ecosystem, it is inappropriate to undertake stock enhancement programmes.

Consequently, there is a need to better understand the impacts of stocking on wild fish populations and communities to underpin development of guidelines that accommodate risk and uncertainty from stocking, as well as considering other measures that can improve the status of water bodies and the aquatic fauna they support, including fish (Lorenzen, 2014; Arthur *et al.*, 2023; Cowx *et al.,* 2023; Fiorella 2023). The latter include water quality improvement measures, habitat restoration and improving connectivity between habitats. Such information is required so decisions on stock enhancement programmes can be made in an environmentally friendly, socially acceptable and economically justified manner. (Blankenship and Leber, 1995; Claussen *et al.,* 2023; Cowx *et al.,* 2009, 2023; Lorenzen, 2014; Lorenzen *et al.,* 2010).

This report provides an overview of the state of knowledge on fish stocking with particular reference to Europe and Central Asia, and a review of the potential impacts of stocking of native fish populations and communities and reasons why fish stocking programmes do not achieve their desired objectives. This is coupled with potential mechanisms for mitigating these problems. The goal is to provide support information to promote guidance on fish stocking in the region that addresses the negative impacts and maximize the benefits of fish stocking activities.

2. COMPONENTS OF FISH STOCK ENHANCEMENT

2.1. Characteristics of inland fisheries

Inland fisheries play a crucial role in supporting livelihoods and food security worldwide, while also contributing significantly to recreational activities (Arlinghaus *et al.,* 2002; Funge-Smith and Bennett, 2019; Welcomme *et al.,* 2010). Although global reports indicate a steady increase in inland fisheries harvests (Funge-Smith and Bennett, 2019; FAO, 2022a), most fisheries are facing significant pressure from various stressors (Reid *et al.,* 2019). Current trends in the use of inland waters for fisheries suggest that production potential is constrained by two main factors (Figure 1). First, the declining quality of aquatic environments—due to eutrophication, pollution, and habitat alteration—has impaired the ability of native fish communities to adapt and sustain their diversity, structure, and biomass. Second, inadequate fisheries management has left many fish species unable to naturally compensate for overfishing or unsustainable fishing practices.

To address this crisis, an array of interventions has been implemented, focusing on the complex interplay of physical, chemical, and biological factors that influence fish communities and population dynamics (Figure 1). Four broad strategies are commonly employed: (1) traditional fisheries management; (2) protection of key fish habitats to ensure sustainable stock recruitment and conservation of threatened species; (3) restoration and improvement of key habitats; and (4) supplementation through stocking and introductions of fish (Blankenship and Leber, 1995; Cowx and Gerdeaux, 2004; Arlinghaus *et al.*, 2016).

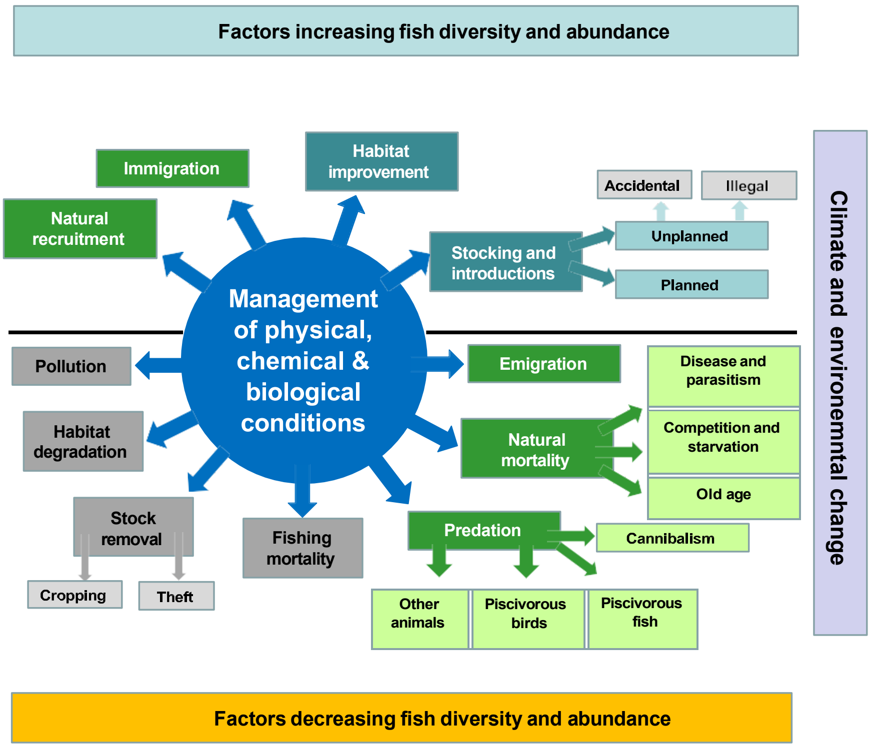

Figure 1. Factors influencing the abundance, size and diversity of fish in a water body. Note: while stocking may increase the abundance of the target species in the short term, the long-term perspectives may be a net deterioration of stocks.
Source: adapted from Cowx, I.G., Funge-Smith, S.F. & Lymer, D. 2015. Guidelines for fish stock enhancement practices in the Lower Mekong Basin. In: *Responsible stocking and enhancement of inland waters in Asia.* FAO Regional Office for Asia and the Pacific, Bangkok. RAP Publication 2015/11, pp. 5–84. http://www.fao.org/3/a-i5303e.pdf#

Traditional fisheries management tools are generally categorized as either 'input' or 'output' regulations, and include gear and size restrictions, seasonal closures, quotas and bag limits, and access restrictions, taxes levies and property rights. Although such approaches can work, stock recovery is often perceived as too slow and changes in traditional management (e.g. no-take zones; Crowder *et al.,* 2000) are unpopular or unacceptable (Burton and Tegner, 2000). Traditional management tools are also unlikely to be effective where the habitat has been severely degraded (Cowx and Welcomme, 1998).

Habitat protection, including fish conservation zones and other protected areas, are a major intervention to protect key life stages of individual species from exploitation or target key habitats for the conservation of threatened species (Acreman *et al.,* 2019; Loury *et al.,* 2017). They comprise specific reaches or zones of rivers and lakes and can be both formal and informal management actions. Unfortunately, most existing protected areas are not specifically orientated around riverine or aquatic environments, and few have fish as their primary species group to protect.

Habitat rehabilitation and restoration tools are widely applied in industrialized countries and have become integral to national and regional legislation. For example, the European Union Biodiversity Strategy for 2030 (EU, 2020) to restore degraded ecosystems, with ambitious targets for the restoration of degraded terrestrial and marine ecosystems, including 25 000 kilometers of rivers to be restored to a free-flowing state. These restoration targets typically focus on enhancing the availability and quality of critical habitats for at least some life stages of target species (see Cowx & Welcomme, 1998). Approaches may include improving river connectivity through fish passage facilities, reconstructing habitats, or installing artificial structures like low weirs or backwater ponds. Although rehabilitation is becoming increasingly popular, evaluation of its effectiveness is generally lacking (Cowx and Gerdeaux, 2004; Angelopoulos *et al.,* 2017).

Stocking refers to the manipulation of fish stocks by addition of material, usually of a desired species, to improve fishery productivity (catch rates) or diversity of the fishery. There is a continuum in intensity of stocking practices from basic stocking through to intensive aquaculture that progressively increases fishery productivity per unit area of water through increasing human manipulation of essential parameters of the fish assemblage (Figure 2). Stock enhancement is popular because of its perceived simplicity, but it comes with considerable risks (see Section 3) and uncertainty of outcome (Welcomme and Bartley, 1998a,b; Cowx *et al.,* 2023). This aspect of stock enhancement is the main focus of this review, but it is important to recognize that **stocking is not the sole mechanism for short- and / or long-term improvements of fish stocks** (Radinger *et al.,* 2023; Welcomme *et al.,* 2015).

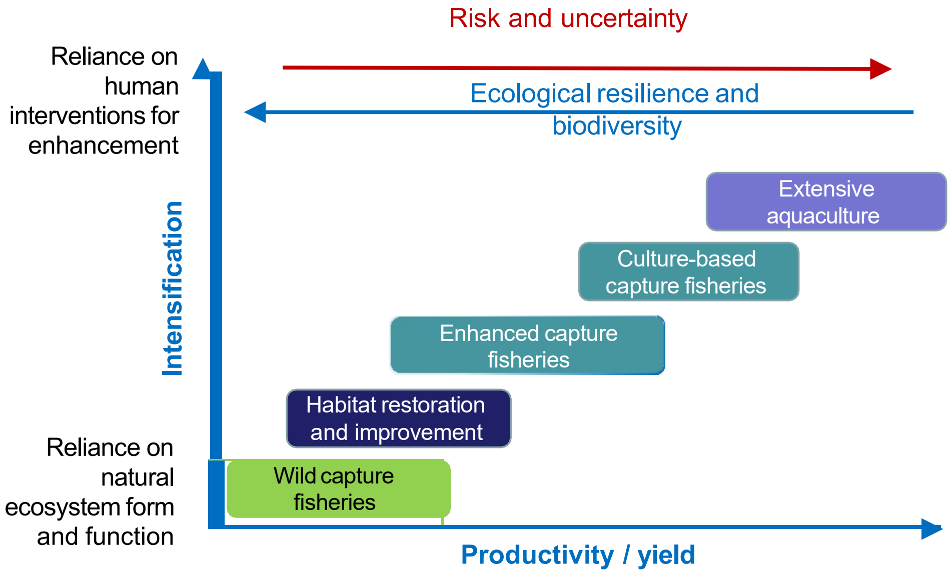

Figure 2. Production from different capture and culture systems

Source: adapted from Cowx, I.G., Funge-Smith, S.J. & Lynch, A.J. 2023. Stocking fish in inland waters: Opportunities and risks for sustainable food systems. *Fisheries Management and Ecology*, 30, 555–563. https://doi.org/10.1111/fme.12656

2.2. Stocking as a management tool

Stocking is one of the most common and widespread tools used by fisheries owners and managers to improve fish catch and yield (Cowx, 1994). Stocking is defined by The Food and Agriculture Organization of the United Nations (FAO, 1997b) as "a technical intervention in existing aquatic resource systems, which can substantially alter its environmental, institutional and economic attributes", and the FAO Glossary defines stocking as: "any activity aimed at supplementing or sustaining the recruitment, or improving the survival and growth of one or more aquatic organisms, or at raising the total production or the production of selected elements of the fishery beyond a level that is sustainable by natural processes".

Most countries report stocking to some degree as more conventional approaches to fisheries management (e.g. quotas, closures, effort reduction, landing size regulations – see Section 2.1) or their weak implementation have failed to prevent deterioration of fish stocks or loss of biodiversity. This approach is often used to respond to degraded natural fish populations as a result of habitat degradation or heavy fishing pressure, or just to increase the fish stocks in general. In this context, stocking is an attempt to fix a problem, either real or perceived. As a consequence, demands for stocking are likely to increase with systemic overexploitation of stocks and degradation of habitats, especially from damming of rivers, disconnection of wetland habitats, alteration in flow characteristics and water quality problems, or because the demand for aquatic foods increases.

Depending on the problem, stocking can be considered to be either a permanent or temporary solution, and, more-or-less, can be divided into three main categories, although a number of terminologies are applied throughout the fisheries sector (**Table 1**).

Mitigation or compensation

This encompasses stocking with fish carried out as a voluntary exercise or statutory function to compensate for a disturbance caused by human activities against lost production, such as reservoir construction, land drainage works or similar habitat perturbation. However, stocked fish may be released into unaffected parts of the water body, and the impact on the wild stocks in these areas must be considered. Many traditional, long-term stocking programmes are carried out for mitigation or compensation. In such cases, stocking is often viewed as a permanent solution (i.e.

it must be done on a continual, usually annual, basis) and is unlikely to lead to establishment of a self-sustaining natural population because the underlying reasons for stocking have not been addressed. The degree to which the fishery is dependent on stocking depends on to what extent the ecosystem has been modified and can range from 'total', where the native stock would disappear without support, to 'partial', where the stock would be reduced to a proportion of that which might be expected if the system was un- impacted.

Enhancement

Enhancement stocking is the principal method used to maintain or improve stocks where production is actually, or perceived to be, less than the water body could potentially sustain. Often, the reasons for the poor stocks cannot be identified and/or removed, or there is a desire to increase populations (usually for exploitation) to levels greater than those that can be achieved naturally. Typically, this type of stocking is used where those exploiting the fishery have expressed dissatisfaction with the quality of fishing, or to enhance stocks in parts of the water body where access is restricted by barriers. It also includes activities carried out to strengthen the quality and quantity of the spawning stock of a given species so as to improve natural reproductive potential. This can be for improvement of yield from a fishery or for conservation purposes where the natural breeding component is considered inadequate to maintain the stock at sustainable levels (see below).

The majority of stocking probably falls into this category, and it is driven by complaints about angling quality or desire to improve output from a particular water body. However, in many cases the state of the stock has been unduly pessimistic, resulting from natural fluctuations that can have a profound effect on fish populations, or estimates of potential production have been unrealistically high. If production is limited or driven by natural population cycles, it is unlikely that stocking will have a beneficial long-term effect.

Table 1. Range of terms used to describe stock enhancement activities

Term	Definition
Restocking	
Aquaculture-based fisheries enhancement [i]	All forms of fisheries enhancements involving aquaculture technologies, including conservation, culture-based fisheries, stocking and ranching
Mitigation or compensation [m]	Production and release of fish to restore stock to original levels
Enhancement [c,m,i]	Production and release of fish to increase stocks above original levels
Ranching [a,d,k]	Production of early life-stages of species in a hatchery for eventual release into natural or modified habitats to be subsequently harvested
Reintroduction [j]	Temporary releases of cultured or captured fish with the aim of reestablishing a locally extinct population
Stocking [b,d]	Supplementing natural recruitment with injection of external material
Stock recovery [g]	Production and release of fish for inter-generational benefit
Augmentation	
Augmentation [b,d]	Production and release of fish to compliment natural recruitment where available habitat is below carrying capacity
Culture-based fisheries [i,j]	Release of cultured organisms that do not recruit naturally in the target system, aimed at increasing fish production and/or abundance.
Habitat-based fisheries enhancement [e,n]	Production and release of fish to (re)colonise new/artificial habitats
Mitigation [b,d]	Stocking of fish into new/modified habitat to compensate for a decrease in a fishery
Supplementation [i,j]	The release of cultured fish into very small and declining populations with the aim of reducing extinction risk and conserving genetic diversity
Addition/creation	
Introduction [b,l]	Production and release of non-native fish species to create new fisheries for the public good
Translocation [h,n]	Deliberate movement of organisms from one site for release in another, carried out for conservation or production purposes. Involves at least temporary holding in aquaculture facilities and overlaps with many forms of aquaculture-based enhancement

Sources: See References.
[a] Arnason (2001); [b] Bartley (1999); [d] Cowx (1994); [e] Cowx and Welcome (1998); [g] Harada and Matsumiya (1992); [h] IUCN (2013); [i] Lorenzen (2014); [j] Lorenzen *et al.* (2012); [l]Petr (1998); [m] Radtke and Davis (2000); [n] Young (1999)

When stocking for enhancement is considered a permanent, on-going, solution, it can be defined as culture-based or 'ranching' (supplementing natural juvenile recruitment through the growth of stocked fish) or, in the case of recreational fishing, 'put-and-take' (stocking of fish into a water body for the express purposes of catching and removing for consumption). As a permanent solution, this strategy requires continuous application to maintain the desired fishery. This strategy is particularly favored in situations where it is not considered desirable to introduce a permanent element to the fauna and where stocks would eventually die out without new material being added. Typical of this strategy is stocking of rainbow trout (*Oncorhynchus mykiss*) and Chinese carps (grass, bighead and silver carps).

Restoration

Stocking for restoration is carried out after a limiting factor on stock recovery or improvement has been removed or reduced. An example may be a long-term improvement in water quality, habitat improvements, the easing of passage for migratory fish or a reduction in fishing pressure. All restoration stocking must be based on reliable evidence that such populations existed in that catchment, or water body, in the past.

Restoration stocking should not take place until known limiting factors have been removed or ameliorated. However, situations may exist where it is necessary to initiate stocking in parallel with other habitat or fisheries management actions. Used in parallel, this can accelerate the stock recovery and/or secure continued support for restoration. Stocking programmes of this type should be a temporary measure and require a more active management strategy for the aquatic ecosystem and its fish populations. The ultimate objective is to create a fish stock and aquatic ecosystem that are self- sustaining.

Conservation

Many fish species are under considerable threat of extinction and stocking can be used to maintain these species. This is generally confined to those fish species or populations that are considered rare or threatened, typically salmonids, sturgeons and eel, although there is some conflict of interest where the species is also exploited. This is allied to mitigation stocking but is usually more conservation- orientated in its intent. Stocking may take place into habitat refugia or other areas not subject to the threat, but often the species has to be maintained through continuous inputs of new material from hatcheries in areas where the threat still persists. Conservation stocking is also used to enhance populations of other rare or threatened fauna, e.g. otter and bittern, which depend on the fish stocks.

Creation of new fisheries

Increasingly introductions into natural waters are an accident through escape, colonization or establishment of an introduction made for aquaculture. Where introductions are made as a management tool for commercial and recreational fisheries, the aim is to insert a new element into the community for one of the following reasons:

- *Establish new fisheries* that are more resistant to fishing pressure or have greater market value than fisheries for native species. In recreational fisheries new species are introduced to improve the variety available to anglers or promote a species of trophy or sporting value into an area, e.g. pikeperch and wels catfish. Stocking fish into newly created water bodies, e.g. reservoirs or redundant gravel pits also fall into this category.
- *Fill a vacant niche* where existing fish species do not fully utilize the trophic and spatial resources available. In some natural waters, evolutionary isolation has led to a limited number of native species, as seen in the United Kingdom of Great Britain and Northern Ireland and Ireland, where glaciation has extirpated many native faunas. More commonly, the need for species introductions arises from development activities. For instance, many newly created reservoirs lack native species capable of fully colonizing lentic environments. Additionally, in many river basins, the regulation of flow by dams has either eliminated or drastically reduced native rheophilic fish species, leaving these waters open to colonization by introduced species. The concern here is that introduce species naturally disperse and compete with native species, especially in degraded or altered habitats.

2.3. Stocking of fish into European inland waters

Stocking of fish is widely used across Europe and Central Asia. Most countries report stocking of freshwater and or marine fisheries as fish stocks and or aquatic biodiversity have declined because of environmental degradation or failure to control fisheries exploitation, or in attempts to increase fishery yield (Lorenzen, 2014). The scale of stocking in inland waters is extensive (Simicikas, 2019). Cowx and Godkin (1999) estimated that some 40 billion individuals are stocked annually in European fresh waters.

The objectives of stocking in European and Central Asian waters differ between species (**Table 2** and **Table 3**), but in general reflect a trend towards salmonids being stocked for mitigation, enhancement, put-and-take and repopulation. Cyprinids are generally used for maintenance of fisheries and catch- and-return, whilst other species are stocked for a variety of reasons, but especially to increase diversity of catch.

Table 2. Objectives for stocking across Europe – salmonid freshwater fishes. The larger the number of ‘Xs the greater the importance of these activities

Species	Compensation	Maintenance	Enhancement	Put-and-take	Put-grow-take	Repopulation	Increase diversitu	Fill vacant niche	Forage	Pest control	Environmental improvement	Conservation
SALMONIDS												
Atlantic salmon – *Salmo salar*												
- ova	XXX											
- fry	XXX		XXX			XXX	X	X			X	
- parr	XXX					XXX						X
- smolts	XX				XXX	XXX						
Trout – *Salmo trutta*												
- ova	X											
- fry	XXX	XXX	X	X	XXX	XXX	XX	XX	X		XX	X
- parr						XX						
- takeable size					XXX							
- smolts					X							
Adriatic trout – *Salmo obtusirostris*												
- ova	XXX											X
Rainbow trout – *Oncorhynchus mykiss*												
- adults	X	X	X	XXX	XXX				X			
Danube salmon – *Hucho hucho*												
- fingerlings		XXX										
Charr – *Salvelinus* species												
- fry	X		XX		XX		X					X
- adults			X	X	X							
White fishes – *Coregonus* species												
- fry	X		X	X		X	X		X		X	
Artic grayling – *Thymallus thymallus*												
- fry, age-0, age-1	XXX	XXX										X

Table 3. Objectives for stocking across Europe – non-salmonid freshwater fishes. The larger the number of Xs the greater the importance of these activities

Species	Compensation	Maintenance	Enhancement	Put-and-take	Put-grow-take	Repopulation	Increase	Fill vacant	Forage	Pest control	Environmental improvement	Conservation
CYPRINIDS												
Asp, *Leuciscus aspius*					X	X					XX	
Barbel, *Barbus barbus*	XX	X	X			XX		X				X
Bitterling, *Rhodeus sericeus amarus*												X
Bullhead, *Cottus gobio*												XX
Carp, *Cyprinus carpio*	XXX	XXX			XXX							
Chondrostoma polylepis/nasus	X		X		X	X						
Chub, *Leuciscus cephalus*		X			X							
Common bream, *Abramis brama*	X	X			X							
Crucian carp, *Carassius carassius*						X						
Dace, *Leuciscus leuciscus*		X										
Eurasian minnow, *Phoxinus phoxinus*												XX
Grass carp/*Silver carp*		X				X			X		XX	X
Gudgeon, Gobio *gobio*	X	X			X		X					
Ide, *Leuciscus idus*		X			X	X	X					
Roach, *Rutilus rutilus*	X	X	XX		X							
Rudd, *Scardinius erythrophthalmus*		X			X		X					
Tench, *Tinca tinca*	X	X	XX		X	XX	X	XX				
OTHER SPECIES\\												
Pike, *Esox lucius*			XXX					X		X	XX	
Micropterus salmoides	X	X	XX	X	XX							
Perch, *Perca fluviatilis*		XXX				X						
Pikeperch, *Sander lucioperca*		X			X			X			XX	
Eel, *Anguilla* species		X	X									X
Crayfish, *Astacus fluviatilis*						X					X	X

Except for salmon, few data are held on the size or life stages of fish stocked, although the general trend is that migratory anadromous fishes such as salmonids are usually stocked at an early life stage (fry) to acclimate to the natal river and to prepare for migration as their size increases. By contrast, cyprinids and other non-migratory species are generally stocked at larger sizes (fingerlings) as they are often supplementing a failure in natural recruitment. These fish are expected to grow on to a large size based on the natural productivity of the stocked water body.

Recreational fisheries tend to rely on stocking larger fish of specimen or takeable size and less on stocking smaller fish. Specialist recreational fisheries stock large-sized individuals to attract anglers, who are willing to pay high prices to capture specimen-sized fish, particularly carp. Rainbow trout put-and-take fisheries also stock with table-sized fish, as these individuals are given little opportunity to grow before being captured. It is estimated that more than 80 percent of captures occurs in the first 40 days after stocking and overwinter survival of stocked fish is low.

To address the gap of information about the scale and intensity of fish stocking across Europe and Central Asia, there is a need for more dedicated studies on stocking activities in each country to develop practical guidelines for stocking of the most appropriate species, selection of water body types for stocking and main stocking operations.

2.4. Legislation relating to stocking

Most governments rely on authorization systems (licenses, permits, consents) to regulate and control movements of fish for stocking. Licensing is the most widely used mechanism to exercise legal and administrative control over stocking: a governmental authority or agent authorizes a person/company to stock fish. Consequently, the holding of a license appears to be a prerequisite to move fish between water bodies, or between a fish farm and a water body, or import fish for stocking into open water bodies. This authorization is usually provided under fisheries legislation (Belgium, Denmark, France, Germany, Ireland, Sweden, United Kingdom of Great Britain and Northern Ireland) and/or under water management laws (Denmark, Germany, Portugal). In other countries (e.g. Greece) stocking does not warrant a specific set of rules and is subject to general environmental legislation.

All European Union countries have introduced legislation to comply with Council Directive 91/67/EEC and its amendment Council Directive 98/45/EC concerning the animal health conditions governing the placing on the market of aquaculture animals and products ("animal health directive") (EU, 1998). The main provisions are:

- a list of diseases and susceptible aquaculture species;
- a principle of freedom of trade between approved zones;
- the obligation to monitor zones and record species introduced;
- a possible protective clause; and
- equivalent rules for aquaculture animals or products imported from third countries to be introduced into Community waters.

Environmental considerations are provided under Directive 92/43/EEC (the Habitats Directive) concerning the conservation of natural habitats and of wild fauna and flora and the Invasive Alien Species Regulation (Regulation (EU) 1143/2014). The Habitats Directive prohibits the transport, from the wild, of specimens of a number of species considered to be in need of special protection (Article 12(2)). The Invasive Alien Species Regulation aims to prevent, minimise, and mitigate the adverse impacts of invasive alien species (IAS) on biodiversity, ecosystem services, and social and economic aspects and includes a list of Invasive Alien Species of Union concern, which was updated under Commission Implementing Regulation (EU) 2022/1203. Some restrictions are enabled in EU Member States through veterinary decrees or laws and the issue was partially resolved through changes to the EU Aquatic Animal Health (Amendment) Regulations 2022, but problems still persist.

Overall, fish stocking activities in Europe and Central Asia are subject to a range of legal frameworks enacted through national nature conservation and fisheries agencies aimed at ensuring sustainable fisheries management, protecting the environment, and conserving fish populations and habitats (Aas *et al.*, 2018).

3. HAZARDS AND RISKS FROM STOCKING

Stocking is a widespread practice that has been undertaken for many decades. Despite this, long-term impacts, both positive and negative, of stocking activities are not well understood (Cowx *et al.*, 2023; Claussen *et al.*, 2023). Nevertheless, evidence suggests that stocking can potentially affect the growth and survival of existing fish populations due to competition and predation, and there are substantial risks of introducing new pathogens and disrupting the genetic integrity of wild stocks (see **Figure 3**).

Hazards of stocking tend to be linked to interactions between five key elements (Figure 3):

- quality and condition of stocked fish;
- population dynamics of the resident wild fish in the recipient water body (specifically the natural production cycle);
- fish community dynamics of the recipient water body;
- environment and habitat quality of the recipient water body (carrying capacity for different species and size classes); and
- the existing fishery.

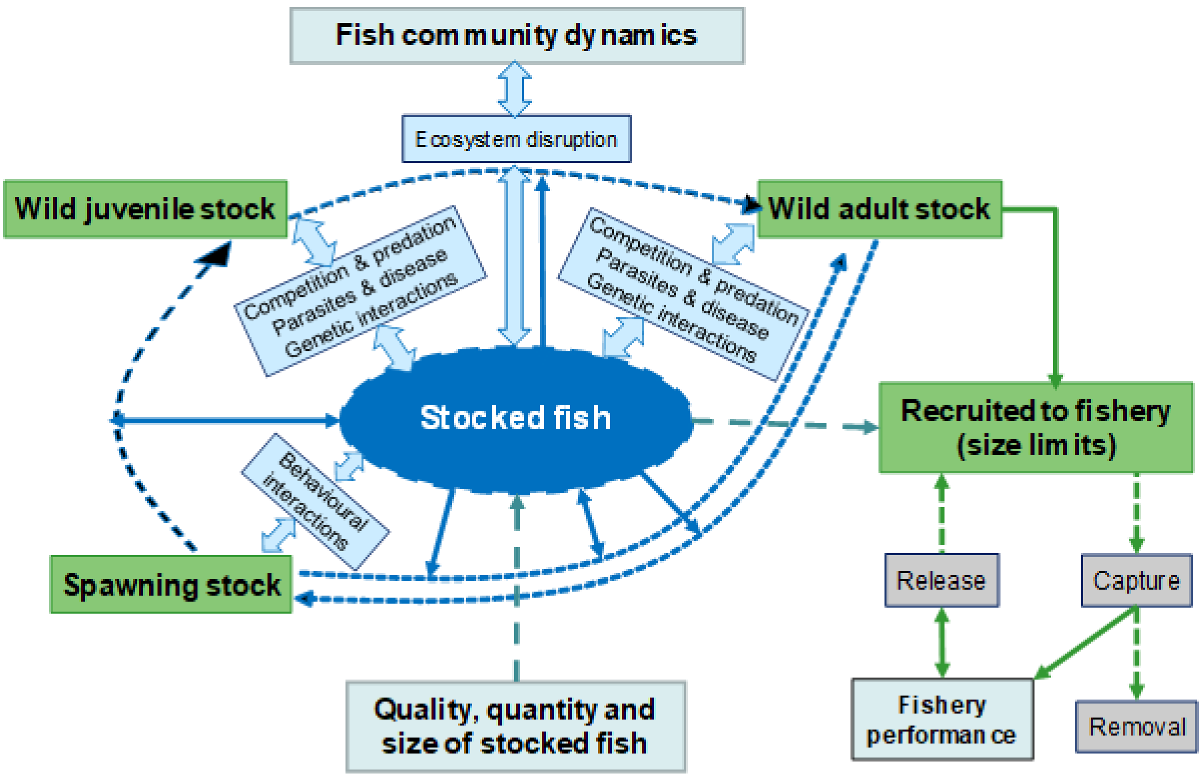

Figure 3. Schematic of interactions between stocked and wild fish indicating possible interactions with hazards to wild stocks. Potential interaction and hazards are identified by solid arrows.
Source: adapted from Cowx, I.G., Funge-Smith, S.F. & Lymer, D. 2015. Guidelines for fish stock enhancement practices in the Lower Mekong Basin. In: *Responsible stocking and enhancement of inland waters in Asia*. FAO Regional Office for Asia and the Pacific, Bangkok. RAP Publication 2015/11, pp. 5–84. http://www.fao.org/3/a-i5303e.pdf#

Assessing these potential hazards is fraught with uncertainty, primarily due to limited reporting on the long-term effects of stocking. Most records stem from scientific studies rather than dedicated monitoring by those conducting the stocking. It is potential interactions between these elements that may pose risks to the well-being of wild stocks. Interactions and potential hazards within this cycle are summarized below.

3.1. Disturbance of the local aquatic environment

There are numerous records of environmental disturbance from fish that have been stocked or escaped from aquaculture facilities on the physical habitat, water quality or biological resources required by other biota (e.g. Eby *et al.*, 2006; Kitada, 2018; Richardson *et al.,* 2019; Cucherousset & Olden, 2020; Skeate, *et al.*, 2020; Pearson *et al.*, 2021) provide evidence that stocking fish can lead to ecosystem change both directly and through disruption to the food web (Daupagne *et al.*, 2021).

One of the most cited examples is common carp *Cyprinus carpio*, which has been stocked globally, originally for cultivation as a food fish, but recently as an ornamental species for ponds and lakes, and to enhance recreational fisheries (Welcomme, 1988). Carp disturb the benthic sediments of lakes and slow-flowing rivers during feeding, disrupting the production of aquatic invertebrates (Moyle *et al.,* 1986) and damaging aquatic macrophytes (Crivelli, 1983; Fletcher *et al.,* 1985). The roiling behaviour of carp is believed to increase turbidity levels by re-suspending sediments (but see Fletcher *et al.,* 1985), and the fish excrete nutrients that may contribute to accelerated eutrophication and possibly cyanobacterial outbreaks. These effects are commonly observed where carp are heavily stocked in shallow lacustrine environments, but the impact is limited when carp are stocked at a biomass of <100 kg/ha (Vilizzi *et al.,* 2014, 2015).

Another example of potential disruption is related to the stocking of grass carp (*Ctenopharyngodon idella*), an herbivorous species, usually stocked to control excessive aquatic vegetation (Wells *et al.*, 2003). The species feeds selectivity on more palatable (soft-leaved) plant species, and may shift the plant communities towards tougher (ligneous) species that are more of a nuisance than the plants originally targeted for control. There is also concern that the removal of plant beds may eliminate the spawning habit of phytophilous species, the refugia of young fish and amphibians, and the feeding habitats of some water birds (Welcomme, 1988). Similarly, the consumption of macroalgae can lead to increased phytoplankton production because of exposure of the water column to more sunlight Vilizzi *et al.,* 2014, 2015).

Summary of potential disturbance of the local aquatic environment

- Switch of trophic states through grazing pressure on zooplankton.
- Disruption of food chains/webs, e.g. by predation of native fishes or preferential feeding of stocked fish on certain taxa.
- Mobilization of nutrients and increased turbidity by carp, and to lesser extent other cyprinids, can cause eutrophication.
- Higher nutrient levels (especially phosphorus) due to an increased standing crop of fishes.

3.2. Predation

Predation on native species is probably the most widely documented impact of stocking, and can result in the complete elimination of indigenous species in parts of their range (Holcík, 1991; Cowx, 1997; Cambray, 2003; McDowall, 2006; Vera *et al.*, 2018; Gimenez and Cucherousset, 2024). Globally, introduced salmonids and piscivorous species, such as the largemouth bass (*Micropterus salmoides*) and trout (*Salmo* spp., *Oncorhynchus* spp.) have been implicated in the decline or local extinction of indigenous cyprinid species: e.g. the endangered Spanish minnow carp (*Anaecypris hispanica*) in Spain and Portugal (Collares-Pereira *et al.*, 1998). Stocking of pikeperch (*Sander lucioperca*), outside its natural range has also led to some controversy, especially in the United Kingdom (Smith *et al.,* 1998). It was implicated in the decline of the cyprinid fisheries in the east of England in the 1970s and early 1980s (Linfield 1984), although the evidence to support this is equivocal (Smith *et al.,* 1998).

In some situations, piscivory by stocked trout on native fishes may potentially be more significant because of the similarity in habitat occupied by wild trout, charr and whitefish, and the artificially high numbers of trout following stocking (Gimenez and Cucherousset, 2024). The degree of piscivory may depend upon the species of trout stocked, with brown trout seemingly more prone to display piscivory than rainbow trout (Phillips *et al.*, 1985).

Increased densities of fishes may encourage larger numbers of feeding cormorants (*Phalacrocorax carbo carbo*, *P. carbo sinesis*) (Ovegård *et al.,* 2021) and, in some places, other piscivorous birds such as goosander (*Mergus merganser*), red-breasted merganser (*Mergus serrator*) and grey heron (*Ardea cinerea*). It should be noted that increased densities of fishes could benefit other animals of conservation interest, such as otter (*Lutra lutra*) (Britton *et al.*, 2006).

Summary of potential risks to native fish populations - Predation

- Stocking of trout has been implicated in the decline or disappearance of many native fish species.
- Piscivory by stocked fish, which depends upon the species of trout stocked: brown trout more prone to exhibit piscivory than rainbow trout.
- Predation on eggs.
- Increased densities of fishes may encourage larger numbers of feeding piscivorous birds.

3.3. Competition

Competition is considered a major reason for decline in native fish species in areas where species have been stocked in large numbers. Stocked fish can compete with native species for critical resources such as food and habitat (Cowx, 1994; Araki and Schmid, 2010; Pinter *et al.,* 2019). This competition can lead to displacement of native species from their preferred habitats due to aggressive behaviour or increased energy expenditure in defending territories or competing for food.

These issues are important because hatchery-reared fish often display higher levels of aggression and faster growth rates compared to wild fish (Tatara and Berejikian, 2012). However, this doesn't necessarily translate into a competitive advantage for stocked fish due to inefficiencies in feeding, lower energetic efficiency, and inability to capitalize on aggressive interactions in natural conditions.

While there is evidence of competitive differences between hatchery-reared and wild fish, the ecological consequences of these differences are not universally quantified. Factors such as genetic background, environment, life stage, and size can influence competitive outcomes. Further, continuous stocking could also impact upon population productivity, disrupt local adaptations and reduce the genetic diversity of wild populations.

Competition from stocked fish for food resources and habitat can lead to reduced growth, survival, and reproductive potential of native fish populations. This can alter the characteristics and contribution of wild spawning stocks over time, affecting their overall size, age at maturity, and productivity.

If stocked fish occupy habitat and use resources that would otherwise be used by native fishes then, over time, the characteristics and contribution of the wild spawning stocks may change. This could potentially be realized in terms of overall size of the spawning stocks, or the size or age at maturity of the wild fish. The repeated injection of farmed fish into fisheries negates the effects of mortality (natural and fishery), and could potentially minimize the chances of wild fish maturing and occupying these niches. Ultimately, this has the potential to impact negatively on spawning stocks of native species such as trout, charr and whitefish.

Competition for food and space, both with conspecifics and other species, may be particularly strong when unnaturally high densities of fishes are released in restricted areas, potentially leading to stunting of stocked/introduced and/or wild fishes. Stunting results in rapid population expansion with individuals maturing and breeding at reduced sizes, diminishing their usefulness for angling or commercial purposes and exacerbating pressure on food resources. Unnaturally high densities of stocked fish in restricted areas can lead to stunting of both stocked and wild fish populations.

Summary of potential risks to native fish populations - Competition

- Displacement of native fishes through aggressive behaviour.
- Competition reduces energetic performance of native fishes.
- Competition for food resources and habitat with stocked fish may result in reduced growth, survival and reproductive potential of native fishes.
- Reduction in stocks of subordinate species or age groups.
- Stocked fish may compete with native fish for spawning habitat.
- Overstocking can lead to reduction in fishery performance through competitive bottlenecks.

3.4. Parasites and disease

One of the most persistent risks inherent with movements of living organisms is the spread of pathogens, parasites and disease associated with the stocked individuals to new hosts in the receiving area. Within Europe alone there is reference to over 100 new parasite species being introduced as a result of stocking (Cowx and Godkin, 1999).

The importation and movement of parasites, pathogens and diseases can be made via fish that have not been health checked or quarantined before release or through indiscriminate and planned stocking. For example, the cestodes *Khawia sinensis* and *Bothriocephalus acheilognathi*, parasites of common carp found in central Europe, have spread throughout Britain as a result of stocking activities, and this is despite strict health regulations on movements of fish.

Many diseases of salmonids that infect hatchery-reared fish, and now occur in the wild, have been imported. Rainbow trout from western North America carried Furunculosis to Europe and South America (Snieszko 1973) and spread rapidly. Similarly, wild Atlantic salmon populations in Norway have suffered massive mortalities and, in some areas, total eradication caused by the monogenean fluke *Gyrodactylus* sp., introduced from infected salmon hatcheries in Sweden (Munday *et al.,* 1992).

Although some parasites are host-specific, many are capable of infecting a wide range of host species. An example includes *Myxobolus* (syn. *Myxosoma*) *cerebralis*, the cause of whirling disease in rainbow trout, which is normally a harmless parasite of brown trout, but has been found to spread through intensely stocked environments. Thus, it is possible that stocking fishes could infect native fish species.

These examples illustrate the high risk associated with the introduction and dispersal of parasites and disease as a result of fish movements. The risks are dependent upon the relative disease status of the stocks and the condition of the fish farm or donor environment supplying the stocking material. It should also be recognized that the threat posed by infectious diseases has by no means reached its full manifestation in wild populations. Several diseases now being fought in fish farms, especially for salmonids, have yet to be discovered in the wild, or have only recently been registered in one or a few wild populations.

The potential spread of diseases associated with fish culture facilities and stocking indicate the potential dangers of transporting any biotic material over and within national borders. The spread of imported pathogens from their non-native hosts to indigenous species is of relevance to environmental protection and may have a high ecological and economic cost, although no information exists about the latter. The problem that faces the regulator is one of minimizing the spread of disease and parasites in natural systems, but this is fraught with problems. It is essential, therefore, that strict health-check regulations are enforced on stocking of fish to minimize any undue health risks to native fish populations.

Summary of potential risks to fish populations - Parasites and diseases

- High stocking densities in many aquaculture facilities may increase fish stress, potentially suppressing immunity and leading to outbreaks of disease, which may then become a source of transmission to wild stocks.

3.5. Genetic interactions

The application of population genetics techniques has revealed a diverse array of outcomes resulting from the stocking of fish transferred between water bodies or from cultured fish, sparking significant concern regarding repeated stocking events, especially involving strains not adapted to the local water body (Claussen *et al.*, 2023). Stocking environmentally or genetically altered fishes are considered to represent a serious threat to the genetic integrity of wild populations (Christie *et al.,* 2012, 2014; Karlsson *et al.,* 2016; Glover *et al.*, 2017; Hagen *et al.*, 2021; McMillan *et al.,* 2023), although there is debate about the intensity and long-term impacts of stocking hatchery reared fish or fish from different water bodies on genetic integrity (Näslund, 2021).

The fundamental issue is that genomes of wild fish might be negatively affected by introgression of hatchery genotypes through interbreeding of wild and stocked (Akari *et al.*, 2007, 2009; Garcia de Leaniz *et al.,* 2007; Christie *et al.*, 2013; Beulke *et al.*, 2023; McMillan *et al.,* 2023; Riddell *et al.,* 2024). Stocked fish often mate with their wild counterparts, potentially disrupting the genetic integrity of wild stocks (Taggart and Ferguson, 1986; Harada *et al.*, 1998; McGinnity *et al.*, 1997, 2003, 2004; Ayllon *et al.,* 2006; Janowitz-Koch *et al.*, 2019). For example, numerous traits in Atlantic salmon, such as growth rates, age at maturity, timing of smolting, egg sizes, sea migration patterns, and behaviour while at sea, are known to have a genetic basis that is heritable (Ford *et al.*, 2012; Gonzalez *et al.*, 2022; Horn and Narum, 2023; Koch *et al.*, 2023)

Stocked fish, including escapees from aquaculture facilities, may breed with wild populations, leading to intergression with conspecifics or closely related species (Munday *et al.*, 1992; Beveridge and Phillips, 1993; Glover *et al.*, 2017). Stocking has the potential to replace local, adapted stocks with more homogeneous stocks from hatcheries, thereby limiting the sustainability of the species in the wild (Waples and Drake, 2004; Hansen and Mensberg, 2009; Bingham *et al.*, 2014; Vøllestad and Primmer, 2019; Willoughby and Christie, 2019; Almodóvar *et al.,* 2020). The consequences of such interbreeding range from negligible impacts on the genetic structure of local stocks (Borgstrøm *et al.*, 2002) to the partial or complete displacement of genetically distinct indigenous populations by uniform hatchery fish (Munday *et al.*, 1992; Perrier *et al.*, 2013). This can lead to differences in timing of spawning, a trait with high heritability, between stocked and wild fish, especially in salmonids (Ferguson, 2007). The reproductive abilities of cultured fish often lag behind those of their wild counterparts (Jonsson *et al.*, 1991; Fleming and Gross, 1993; Chilcote *et al.*, 2011). Males, particularly from hatcheries, typically exhibit lower reproductive success compared to females from the same origin. Jonsson *et al.,* (1990, 1991) noted a higher proportion of unspawned individuals, particularly males, among ocean-ranched Atlantic salmon compared to wild fish. Leider *et al.,* (1990) reported that sea-ranched steelhead (anadromous rainbow trout) had only 11–13 percent of the lifetime reproductive success of wild fish. It is considered that brooders domesticated over numerous generations in the hatchery produce an F_1 generation that is relatively less fit than wild fish. Genetic introgression is particularly worrisome when fish stocks are geographically isolated and genetically distinct (Mills *et al.*, 1990; Maitland *et al.*, 2007).

However, studies have also shown that offspring of wild captured broodstock compare favorably with native fish (Araki *et al.,* 2007). For instance, Hansen (2002) found that the contribution of stocked brown trout to the gene pool of wild populations ranged from 5 percent to as high as 88 percent, and Ferguson (2007) suggested that stocking brown trout had little impact on genetic integrity of wild stocks. Similarly, Hess *et al.* (2012) and Janowitz-Koch *et al.* (2019) found supplemental stocking with 100 percent natural-origin broodstock provided a long-term demographic boost to the population and found no loss to genetic integrity. Moreover, Berejikian and Van Doornik (2018) and Dayan *et al.* (2023) found a single generation in the wild increased fitness for descendants of hatchery-origin Steelhaed trout and Chinook salmon, respectively, while Courter II *et al.*, (2022) found hatchery propagation did not reduce natural productivity of steelhead in a mid-Columbia River. Furthermore, the reproductive rates of escaped fish showed no apparent difference from those of wild individuals in either the River Oselven, Norway, or the River Polla, Scotland (Fleming, 1995), and Vøllestad and Primmer (2019) also found only small differences in grayling (*Thymallus thymallus*) populations isolated in stable conditions for 30 generations that might eventually evolve to be adaptive.

Welcomme (1988) suggested that the stresses associated with stocking may lead to a breakdown in normal behaviour and the formation of hybrids between species and even genera that do not normally hybridize in the wild. The potential for this could be further increased by degradation or loss of spawning areas. Habitat loss could reduce the areas suitable for spawning and induce a breakdown of normal reproductive isolating mechanisms. Irrespective, the problem is serious because of a potential loss of genetic fitness in wild populations (McDowell, 2002; McGinnity *et al.*, 2003). Repeated interactions between stocked and wild fishes result in lowered fitness, causing cumulative fitness depression and potentially an extinction vortex in vulnerable populations (McGinnity *et al.*, 2003). Hence, the threat of hybridization, whether intraspecific (between races, strains, or subspecies of a species), interspecific (between species), or intergeneric (between genera), to the genetic integrity of wild populations must be regarded as a major concern for some species, particularly salmonids and those of conservation importance.

The preservation of genetic variability within wild populations remains important for the maintenance of ecological fitness and function, and the ability to adapt to environmental changes (Jørstad *et al.*, 1999; Klütsch *et al.*, 2019), as the fitness and adaptability of organisms are largely determined by genetic factors (O'Connell and Wright, 1997; Taniguchi, 2003). The ever-expanding aquaculture industry is likely to lead to increases in the numbers of fishes released (Cowx *et al.*, 2008; Bostock *et al.*, 2010). Thus, the threat of hybridization and introgression with farmed fishes to the genetic integrity of wild populations is a concern. It follows, therefore, that programmes involving the release of fishes should aim to minimize any genetic changes and conserve genetic resources (Carvalho, 1993; Grant *et al.*, 2017; Tsuboi *et al.*, 2019).

Considering the current debate on selective significance of specific genes or gene combinations in natural populations, stocking practices must be essentially non-specific, although with an emphasis on maximizing allelic diversity and the associated variance in ecologically significant traits (Grant *et al.*, 2017). Busack and Currens (1995) emphasized that although genotypic traits that do not closely relate to obvious fitness characters (i.e. molecular variation) can be measured with relative ease, it is much more difficult to assess genetic differences within or among populations in terms of quantitative traits (Neff *et al.*, 2011). It is the latter, however, that determines fitness variation in physiological, morphological or behavioural characters, but understanding their control typically requires elaborate breeding experiments in controlled environments. Indeed, it is the poor understanding of the link between molecular variation and fitness parameters that is the obstacle in assessing genetic risks in stocking and introduction practices. Fish farmers now generally select broodstock to minimize genetic 'pollution' of wild stocks (Doyle *et al.*, 2001; Willliams and Hoffman, 2009). The use of all-female, triploid fish has also been proposed as a potential solution (Noble *et al.*, 2004; Budy *et al.*, 2012), as they are considered infertile, although the methods used to induce triploidy may not be entirely effective (Pawson, 2003; Pease *et al.*, 2023).

Summary of potential risks to fish populations – Genetic issues

- Stocks exhibit genetic variation that is manifest as differences in growth potential, age at maturity, fecundity, and can have implications for coevolution and adaptation processes.
- Stocks exhibit adaptation towards particular environments and stocking could lead to loss of.
- Stocking may result in genetic drift and dilution of gene pool; loss of genetic diversity; and hybridisation.

4. FACTORS AFFECTING STOCK ENHANCEMENT SUCCESS

Stocking is a prominent management strategy employed in modern fisheries (Cowx, 1998; Molony *et al.*, 2005; Baer *et al.*, 2007; Lorenzen, 2014; Harrison *et al.*, 2018; Simickas, 2019), with billions of individuals introduced annually into European and Central Asian freshwater bodies. Despite many years of operation, many stocking programmes have failed to achieve their objectives or meet project expectations (see Svåsand *et al.*, 2000; Lorenzen, 2014; Cowx *et al.*, 2023). Several factors contribute to this perceived lack of success, which can be categorized into five primary areas: size and density of fish stocked; suitability and condition of stocked material, effectiveness of release strategies, inadequate project planning, and failure to consider external factors, including potential governance and social issues (Camp *et al.*, 2013, 2017; Arlinghaus *et al.*, 2022).

4.1. Poor project planning

Failure to define objectives

Many past stocking programmes operated under the assumption that releasing fish into the wild would boost stock abundance and consequently increase harvest levels (Winton and Hilborn, 1994; Simcikas, 2019). However, many of these programmes lacked clear objectives (Cowx, 1994, 1999; 2015; Camp *et al.*, 2014). Unfortunately, this trend persists today (Svåsand, *et al.*, 2000; Simcikas, 2019), and when objectives are specified, they are often challenging or impossible to evaluate: for instance, "The main goal was to investigate the possibility of enhancing an oceanic cod stock" (Fjallstein and Jákupsstovu, 1999), or "... whether captive-bred fish could survive in the wild, grow to a size suitable for recreational fishing, and be caught by recreational anglers" (Lenanton *et al.*, 1999). Stocking projects with well-defined objectives aimed at population recovery generally have a higher likelihood of success (Heppell and Crowder, 1998; Taylor *et al.,* 2017; Cowx *et al.*, 2015, 2023).

Similarly, a lack of well-defined endpoints poses challenges for stocking programmes (e.g., Svåsand, 1998; Svåsand *et al.*, 2000), leading to pressure to perpetuate stocking activities indefinitely, even if the project proves ineffective or unnecessary (Svåsand *et al.*, 2000; Aprahamium *et al.*, 2003; Salveit, 2006; Kitada, 2018). Without established endpoints, there is no benchmark to gauge project success, increasing the risk of adverse outcomes as programmes continue indefinitely. Consequently, poorly planned and underperforming stocking activities often persist, despite their ineffectiveness and high costs (Svåsand *et al.*, 2000; Salveit, 2006). Proposals for stocking should align with national policy objectives to improve the status of the fisheries, especially where they have been compromised by degradation of the environment or overexploited, address concerns of species of conservation value, and provide social and economic benefits to communities

Improper planning and evaluation

While most stocking initiatives align with the overarching objectives discussed in Section 2.2, their potential for success is often hindered by lack of appraisal of specific objectives, available resources, and the ability of stocking to address underlying issues. Many projects are improperly conceived and fail to fully tackle the core challenges that impact fishery improvement (Cowx *et al*., 20015; 2023). Moreover, they frequently overlook broader cross-sectoral and environmental considerations, particularly regarding long-term impacts (Arlinghaus *et al.*, 2022).

The root of the problem lies in deficient planning and evaluation of proposed stocking activities. Before investing resources, a thorough pre-feasibility study should be conducted, linking the stocking programme to sectoral objectives beyond fishery goals. From a sectoral perspective, stocking objectives should balance conservation, ecosystem protection, economic returns, and food security or employment. However, a fundamental question often remains unanswered before embarking on a stocking programme: "Why does the fish stock require enhancement?" This question is typically overlooked due to poor management of the environment or fish stocks themselves.

Stocking is often deemed necessary due to overexploitation or environmental disturbances in the fishery. In many cases, the focus should be on addressing constraints affecting the fishery and on enhancing natural production. Yet, even when fishing pressure is identified as the main cause of stock decline, exploitation reduction may not be implemented alongside stocking, limiting its potential success. Sometimes, stocking is chosen simply as an alternative to inaction or as a superficial solution to declining fishery resources.

Inappropriate promotion of stocking as a panacea for declining resources, without addressing underlying causes such as habitat loss or overfishing or bottlenecks to fish recruitment, can lead to limited success (Arlinghaus *et al.*, 2022). Under these circumstances, stocking must be complemented by other fisheries management tools to mitigate underlying causes effectively (Camp *et al.*, 2017; Radinger *et al.*, 2023). Projects planned in conjunction with other management tools demonstrate a deeper understanding of ecosystems and stock decline causes, offering better chances of success (Arlinghaus *et al.*, 2016; Camp *et al.*, 2017). This is particularly evident when declines result from man-made interruptions to riverine passage, which stocking cannot rectify. While stocking may seem cost-effective initially, recurrent costs and changing financial and political conditions can pose challenges in the long term, without addressing the root cause of the fishery decline.

Cost benefit analysis

Stocking is widely recognized as an effective management tool, particularly in intensively managed fisheries within lakes and reservoirs. However, its effectiveness in running waters, especially large river systems, and the best life history stage for stocking remain subjects of debate. Despite this, evaluations of stocking programmes in inland waters are primarily drawn from systems with significant commercial or recreational fishing activities (Hunt *et al.*, 2017; Kitada, 2018). Few studies from European countries exist (Radtke and Davis, 2000), and those that do primarily focus on biological parameters and constraints, with limited economic evaluation.

Economic analyses of stocking programmes reveal mixed results, with many projects found to be economically unviable or inconclusive (Hunt *et al.*, 2017). Several studies suggest that the highest cost benefits are achieved when no stocking occurs (Camp *et al.*, 2017; Radinger *et al.*, 2023), but see Baer *et al.* (2007) and Baer and Brinker (2010). This is mainly due to the relatively high costs associated with stocking, especially in the initial stages, including hatchery costs.

To be successful, stocking programmes must justify the costs of rearing fish before release by considering their value in terms of returns from the fishery or benefits from improved ecosystem services delivery. Economic tools such as cost-benefit analyses and bio-economic modelling are available to determine the most cost-effective strategies for stocking (Camp *et al.*, 2017). However, economic evaluation is often overlooked in decision-making processes compared to biological and environmental considerations.

4.2. Technical issues

Poor understanding of fisheries and ecosystem dynamics

Aquatic ecosystems are characterized by complex interrelationships between society and the environment (Welcomme *et al.*, 2010; Funge-Smith and Bennett, 2019) Moreover, different fish species exhibit distinct habitat requirements that must be satisfied by the receiving environment for stock enhancement programmes to succeed (Brannon, 1993). For instance, most fish species undergo complex life-history migrations, possess specific habitat preferences, and, in certain cases, exhibit local adaptations to particular sections of rivers (Heggberget *et al.*, 1993; Wiley, 1995). Failing to recognize the importance of aligning fish population ecology and dynamics with ecosystem functioning is likely to lead to diminished stocking success or outright failure (Jonhston *et al.*, 2018; Arlinghaus *et al.*, 2022). This could involve underestimation of crucial variables such as natural mortality (Lorenzen, 2000; Lorenzen and Camp, 2019) or constraints of carrying capacity and productivity (Wiley, 1995; Lorenzen, 2005).

Source of fishes

Information on quantities and value of fish stocked into inland waters is sparse and rarely held in central databases. This is partly because material for stocking comes from five main sources.

- Government hatcheries operated exclusively for production of stocking material.
- Private hatcheries and farms which supply fish for stocking and for consumption. Here it is difficult to separate the output for each sector and they are recorded together, usually as consumption. Also, many farms that supply material for stocking do not provide data to central statistical units, because it is not necessarily considered an aquaculture output.
- Dedicated hatcheries/farms built to produce stocking material to compensate for human interference with the natural fish production.
- Transfer of stock cropped from one water body to another. This source of fish is usually from water bodies which have an excessive stock produced deliberately or naturally and cropped as a management intervention. Some fishes come from dewaterings, fish rescues, change in the status of the fishery, maintenance of specialist fisheries or general movement of fish as commercial ventures.
- A final source of stocking material is imports. There is a significant market for the import of specimen-sized fish to support specialist fisheries. This mode of supply is one of the root causes of the spread of parasites and disease in fisheries. Although the fish should be certified disease-free, veterinary inspection is weak and several potentially lethal pathogens have been introduced via this route.

Suitability of stocking material – acclimatization

Fish reared in a hatchery environment tend not to be exposed to the diversity of environmental conditions they will experience when released to the wild (Lorenzen *et al.*, 2012). The hatchery lacks both the structural complexity and wider variation in environmental characteristics (e.g. temperature, flow velocity, salinity) typically found in natural habitats. Consequently, fish are less tolerant of the physical conditions they will experience in the wild. Brief exposure to such conditions prior to release can improve post-stocking survival (Jonsson *et al.*, 2011; Johnsson *et al.,* 2014; Clark *et al.*, 2016; Naslund, 2021). In these situations, fish are not only exposed to natural temperature and light regimes and more complex habitat structure, they are also exposed to limited supplies of live prey and avian predation pressure. Simple measures like increasing flow rates within raceways to match natural conditions, providing dark backgrounds, semi-natural streambeds, submerged structure and overhead cover can improve survival rates upon release (see Maynard *et al.,* 1995 for a review; Johnsson *et al.,* 2014; Roberts *et al.,* 2014; Clark *et al.*, 2016; Naslund, 2021). Exposure to natural conditions not only increases the fitness of individual fish, but provides submerged structure creates visual isolation amongst potential competitors, allowing the establishment of territories through improved visual references, leading to lower levels of aggression and improved growth rates (Jonsson *et al.*, 2011; Clark *et al.*, 2016; Naslund, 2021).

This process of acclimation and conditioning is referred to as ‘soft release’ in conservation management, and broadly refers to the provision of any kind of training or preparation for release (pre- or post-release conditioning: Clark *et al.*, 2016). Soft release enables fish to become accustomed to the prevailing environmental conditions (temperature and chemical composition of the water, for instance), familiarize themselves with local landmarks for orientation and navigation, recover from transportation, and develop cohesive social bonds wherever appropriate (Brown and Day, 2002). Allowing an acclimatization period prior to liberation should, therefore, result in substantial reductions in post-release mortality. The exact period of acclimatization required to maximize survival is likely to be species- or case-specific, but several studies suggest that holding fish in cages or enclosures for 1–7 days prior to liberation substantially increases survival rate, increases growth rates and improves recapture rates (e.g. Jonssonn *et al.*, 1999; Clark *et al.*, 2016), all desirable attributes of successful stocking. Holding the fish prior to release will also help alleviate the stress caused during transportation of hatchery reared fish to the release site.

Suitability of stocking material – life skills

Hatchery-rearing techniques have undergone significant advancements in recent years, yet the survival rates of stocked fish originating from captivity remain notably low (Coleman *et al.*, 1998; Blaxter, 2000; Christie *et al.*, 2012). Despite being reared in captivity for prolonged periods, their survival relative to wild stocks, particularly in terms of age-specific mortality, is markedly poor. The majority of mortality tends to occur in the first few days following release (Howell, 1994; Blaxter, 2000), primarily due to predator-mediated mortality (McDonald *et al.*, 1998). However, if hatchery- reared fish manage to survive their initial weeks in the wild, their prospects for long-term survival significantly improves (Brown and Smith, 1998; Deverill *et al.*, 2005).

The relatively low success rate of stocking in wild fisheries, coupled with various other issues such as the potential loss of genetic integrity in wild stocks (discussed in Section 3), raise questions about the efficacy of hatchery supplementation programmes (see Winton and Hilborn, 1994; Riddell *et al.*, 2024 for further discussion). To address this issue, modern hatcheries now place greater emphasis on carefully selecting brood stock to prevent genetic contamination of resident wild stocks (Doyle *et al.*, 2001; Lorenzen *et al.*, 2012), ideally sourcing many mature individuals from the target population and reducing the density of fish in captivity prior to stocking (Larsen *et al.*, 2016).

Arguably, the two primary factors contributing to poor survival rates are compromised ability to feed on natural food sources and vulnerability to predation. Other factors such as social interaction with conspecifics, tolerance to environmental conditions (as discussed in the previous section), and navigation in complex environments are also significant. Many of these behaviours necessitate learning, which can only be acquired through repeated exposure to appropriate stimuli (McLean, 1997). Hatchery-reared fish are typically fed a diet of manufactured, pelleted foods, limiting their exposure to a natural range of foraging behaviours due to the consistent timing, location, abundance, and type of food available. Consequently, they often rely on learning from prior experience or contemporaries to improve prey recognition, attack skills, and handling efficiency (Paszkowski and Olla, 1985; Stradmeyer and Thorpe, 1987; Reiriz *et al.*, 1998; Costas *et al.*, 2012), crucial for survival in the wild where prey distribution, abundance, and trophic value vary. Stocked fish demonstrate limited prey choice, consume fewer items, and exhibit slower prey type switching compared to wild counterparts (Ersbak and Haase, 1983), depriving them of essential nutrition necessary for survival (Paszkowski and Olla, 1985). Additionally, stocked fish often fail to disperse, display reduced aggression, and are frequently found in higher densities, leading to competition for limited resources (Olla *et al.*, 1998).

Similarly, hatchery-reared fish tend to have poorly developed anti-predator skills due to limited exposure to predators prior to release (Kieffer and Colglan, 1992; Olla *et al.*, 1994, 1998; Dellefors and Johnsson, 1995; Deverill *et al.*, 2005), increasing their susceptibility to predation (Berejikian et al 1999; Dellefors and Johnsson, 1995; Shively *et al.*, 1996), which is the primary cause of mortality among released hatchery fish (Howell, 1994). For example, hatchery-reared fish tend to exhibit more risk-taking behaviours (Dellefors and Johnsson, 1995; Johnsson *et al.*, 2014), have poorer predator recognition skills (Berejikian *et al.*, 2003; Hawkins *et al.*, 2004), and weaker anti-predator responses (Järvi and Uglem, 1993; Alvarez and Nicieza, 2003) than wild-reared fish.

Olla *et al.* (1994) and Lorenzen *et al.* (2012) emphasized the need to develop methodologies for hatcheries to improve post- release behavioural performance. Captive-rearing programmes could address this need by providing some form of experience to the captive animal to stimulate the acquisition of foraging or anti-predator skills (Berejikian *et al.*, 1999, 2003; Griffin *et al.*, 2000; Roberts *et al.*, 2011), a concept termed life skills training (Brown and Laland, 2001; Johnsson *et al.*, 2014). Foraging and predator avoidance training regimes can easily be implemented at scale in hatcheries as learning in pre-release training occurs relatively quickly. Even a single exposure to predators may make a substantial difference to the behaviour of prey on subsequent exposures (Olla *et al.*, 1994, 1998).

4.3. Effectiveness of release strategy

Timing and nature of release

There is increasing evidence highlighting the critical role of timing and method of release of stocked fish on their survival. It is crucial to stock fish at a time when they can swiftly adapt to the new environment and start foraging on natural foods. This requires abundant food resources being available upon release. However, many fish are stocked based on hatchery availability, often at the end of growing seasons when natural food resources are declining. Consequently, these fish not only compete with and encounter aggression from wild counterparts but also struggle to survive on depleted nutritional reserves. Low reserves diminish their chances of survival. Therefore, optimal stocking periods should coincide with abundant natural food resources, typically found during spring in Europe and Central Asia as temperatures rise.

As mentioned earlier, acclimatization is crucial to help fish adjust to their new surroundings. However, this process should be paired with release strategies that minimize stress on the stocked fish. Releasing large numbers of fish at a single location not only triggers aggression among individuals but also intensifies competition for food resources in the immediate vicinity until the fish disperse. Hence, survival is influenced by whether the fish are stocked in one concentrated area, dispersed across the water body, or gradually released in various locations over time.

Release site characteristics

The significance of selecting the appropriate location and time of year for releasing captive-reared fish is widely acknowledged, particularly concerning factors such as flow rates, habitat quality (including stream-bed structure), prey and predator abundance, and competition (Leber *et al.*, 1996; Jokikokko, 1999; Cowx, 1998; Arlinghaus, 2017; Camp *et al.*, 2017). However, many stocking programmes overlook these considerations, releasing fish either based on availability or convenient access to the water body, without considering potential impacts on survival. Additionally, there is often a lack of consideration for existing stocks in the receiving water and the potential for competition, predation, or social interaction between stocked and wild fish (Welcomme and Bartley, 1998; Deverill *et al.*, 1999; Lorenzen, 2014; Arlinghaus, 2017; Camp *et al.*, 2017).

Part of this challenge stems from the difficulty in assessing the carrying capacity of receiving waters or the size of existing stocks. Consequently, fish are stocked at predetermined densities based on available resources. However, evidence suggests that lower stocking densities can yield higher-quality fish and improve survival rates. Introducing habitat enrichment during hatchery rearing may hold the key to fostering more natural social behaviours in hatchery fish, potentially mitigating some of the social challenges they face. Conversely, low abundance or absence of existing fish populations may signal an unsuitable stocking location due to environmental degradation or excessive fishing pressure. In such cases, addressing habitat limitations before stocking may enhance the success of stocking efforts.

Stocking density

One of the greatest concerns with stocking is that the capacity of the recipient system to support enhanced stocks is not considered (Hühn *et al.*, 2023). If too many fishes are present, increased mortality rates, through predation and starvation, reduced growth rates and increased dispersion, generally follow. Thus, whilst stocking increases the number of fish present at certain times or in localized areas, no more fish will survive than the resources allow, and abundance of fish will eventually decline to levels that can be supported by the water body, often resulting in the demand to restock to maintain the fishery (Baer *et al.*, 2007; Riepe *et al.*, 2017). In worst-case scenarios, overstocking can lead to reductions in the performance of fisheries, below that prior to the introductions. For fisheries already subjected to stocking activities, reducing stocking densities should reduce the potential for competitive interactions between wild and stocked fishes, as pressure for finite resources is reduced. Reducing stocking densities could also minimize any detrimental impacts on the ecosystem as a whole.

Determination of optimal stocking densities should be based on assessment of the carrying capacity of the receiving water body, and be commensurate with the risk and scale of the stocking programme. For lakes, the optimal density can be determined from relationships between environmental parameters such as shore-line development and water depth and fish biomass (Welcomme and Bartley, 1998a). This has been further developed for other types of water bodies by Lorenzen (2005), Johnston *et al.* (2018) and Camp *et al.* (2017) to estimate optimal size-specific stocking densities for fisheries.

Size at release

While Cowx (1998) provided a theoretical framework outlining the implications of stocking different sizes of individuals, empirical studies on this topic remain scarce (Johnston *et al.,* 2018, Camp *et al.*, 2017). However, there is a general consensus that survival rates are higher for fish stocked at larger sizes (e.g., Tsukamoto *et al.*, 1989; Svasånd *et al.*, 2000; Branigan *et al.*, 2021; Barrow *et al.,* 2022; Huhn *et al.*, 2023). Consequently, hatcheries often rear fish intended for stocking for extended periods before release to capitalise on this size-related mortality advantage. However, economic and spatial constraints typically limit the extent to which fish can be grown to very large sizes in captivity before release, as prolonged captivity increases feeding and husbandry costs and requires more space (Branigan *et al.*, 2021). Moreover, these extended grow-out periods can negatively impact fish behaviour (as discussed above) and prolonged captivity also increases habituation.

Thus, there is a need to balance the benefits of prolonged captivity to reduce mortality, the drawbacks of behavioural deficiencies and the cost-effectiveness of stocking numerous small fish versus fewer larger individuals, factors that have been modelled by Lorenzen (2005) and Camp *et al.* (2017). Pre- release conditioning may offer a potential solution to this dilemma (as discussed above).

4.4. External issues

Institutional weaknesses

Many stocking strategies primarily focus on fishery-related factors such as fish size, density, or biomass (refer to Cowx, 1994 for more details). However, the effectiveness of stocking activities, especially in fisheries reliant on regular stocking like commercial put-and-take, catch-and-release, or culture-based fisheries, depends on addressing broader issues and constraints. These can be categorized into two main aspects: provision of stocking material and management of the fisheries.

One common challenge in maintaining fish stocks at desirable levels is the availability of suitable stocking material. Often, failure to meet stocking targets stems from the unavailability of fish at the right time or in sufficient quantities. This issue often originates from sources of seed or fish used in stocking. Fisheries relying on wild seed (e.g. eel), face challenges due to natural fluctuations in availability, which can impact stocking programmes. Similarly, obtaining stocking material from fish farms or hatcheries presents its own set of challenges. Many of these facilities have limited capacity, and the increasing demand for stocking material can surpass their supply capabilities. Additionally, logistical challenges arise from the central locations of hatcheries and farms, especially in countries with poor transport networks, making access to the fishery difficult and complicating transportation logistics.

Ownership

Another significant issue pertains to ownership rights. In water bodies with clearly defined boundaries, such as put-and-take and still water fisheries, ownership is straightforward. However, in open systems like large rivers, lakes, or coastal regions, ownership is less clearly delineated. In these cases, stocking resembles ranching, and the dispersion of stocked fish beyond the jurisdictional boundaries raises questions about ownership and exploitation rights.

Often, stocked fish in such open systems become a common property resource, subject to external exploitation. This complicates the sustainability of stocking programmes, as return on investment may not directly benefit the primary owner. Consequently, many ranching programmes struggle to succeed solely on financial grounds, as returns are dispersed among various stakeholders rather than accruing to the primary owner.

To address this challenge, programmes typically need to be managed by a central institution. If the objective is to establish an economically viable fishery, stakeholders exploiting the fishery may be required to pay a levy or license fee to cover programme costs. Community-based management or licensing systems, emerge as promising strategies for implementing regulatory control in such scenarios. These approaches help ensure sustainable management of the fishery while fairly distributing benefits and costs among stakeholders.

Ignorance of social and economic considerations to set reference points

Stocking programmes often face challenges, and may even fail, due to overlooking the broader political, social and economic aspects of fisheries management. In Western Europe stocking strategies typically aim to achieve ecological objectives, such as mitigating for habitat degradation, enhancing recreational fisheries and conserving species diversity, whereas in Eastern Europe and Central Asia, the primary focus is on economic goals, specifically food security and income generation. These contrasting priorities lead to distinct issues and constraints in fisheries enhancement activities in the different regions. As a result, strategies tailored to the specific circumstances of an individual country are necessary to address the challenges effectively.

Failure to evaluate stock enhancement programme

Many stocking programmes suffer from a fundamental weakness: inadequate evaluation of their outcomes. Numerous studies have pointed out this weakness, highlighting the importance of thorough evaluation to determine the success or failure of such projects. However, in many cases, evaluations are incomplete, short-term, or solely focused on the number of fish released and caught. Furthermore, if hatcheries supporting stocking are in place it is unlikely that any alternative solution will be sought (Arlinghaus *et al.*, 2022).

It is essential that evaluations continue until released animals begin to contribute to the fishery, which may take several years depending on the species' life history characteristics. Some evaluations may even need to extend further to assess impacts on reproductive biomass, genetic diversity and ecosystem dynamics. Without such long-term assessments, the true benefits or drawbacks of stocking may remain hidden. Moreover, evaluation should not be limited to quantifying recapture rates but should also consider broader impacts on ecosystem functioning, population dynamics and genetic integrity. These complex impacts require comprehensive evaluation methods to ensure a thorough understanding of the programme's outcomes.

4.5. Summary

Whilst the stocking of fish has had obvious positive benefits, they are not without cost, and the whole issue of stocking fish species is highly controversial. Most stock enhancement activities, both deliberate and accidental, have had negative effects on indigenous fish communities and other fauna through predation, competition, introduction of pathogens and invasive species, and change in ecosystem dynamics. The effects of hybridisation, loss of genetic integrity and reduction in biodiversity are also issues that must be considered. These issues are discussed in the literature, but it is worthy of highlighting the reasons why stocking remains prevalent. These include stocking being short-term fixes for depleted stocks or those lost through pollution or habitat alteration, pressure from fishers and the public to recover stocks and to support conservation efforts.

In view of the many concerns that exist about stocking, a responsible attitude towards the activity is essential. Mechanisms must be put in place to minimize the prospects of any degradation of fish communities and ecosystems as a result of stocking. It should perhaps be stated that if the need to stock fish species into natural systems arises, existing management has probably failed. Consequently, before stocking is considered, alternative strategies for rehabilitating the fisheries (see Cowx and Welcomme 1998) should be evaluated. Such strategies include use of indigenous fish, improved water resource management (quality and quantity), habitat protection and rehabilitation, and use of sterile fishes.

5. STRATEGIES TO MINIMISE RISKS AND IMPROVE STOCKING SUCCESS

5.1. Introduction

Despite considerable investment in stocking activities, there are significant concerns about the potential risks associated with stocking fish. These risks include impacts on ecosystem functioning, alterations in community structure, disease transmission, and disruption of genetic integrity (Cowx *et al.*, 2023; Claussen *et al.*, 2023). While stocking can provide benefits such as improved catches and the conservation of threatened species, it is not without costs.

A major reason for controversy around stocking programmes is the inadequate evaluation of their outcomes. Success is often claimed based on short-term assessments or simply the number of fish stocked, rather than on rigorous, long-term evaluations. Comprehensive post-stocking evaluations are rare, and even fewer studies determine the long-term cost-benefit of stocking. To assess the success or failure of stocking projects accurately, evaluations must continue until the released fish begin to contribute to the fishery, which may take several years depending on the species' life history traits. Long-term assessments are crucial, especially when evaluating reproductive biomass, genetic risks, or ecosystem effects, as some projects initially deemed successful may show no long-term benefits upon reassessment.

These issues are well-documented in the literature (see Sections 3 and 4), but it is important to highlight the reasons for differing opinions on the impacts and benefits of stocking activities:

- **Primary reasons for stocking**: The main goals of deliberate stocking are to enhance yield and output in both controlled (aquaculture) and natural (commercial and recreational fisheries) systems. The benefits are typically measured in economic terms for the fisheries, often neglecting cross-sectoral impacts, such as conservation status and the social and cultural aspects of fishing communities, which are difficult to quantify.
- **Short-term benefits vs long-term harm:** Beneficial effects of stocking are usually immediate and short-lived, while harmful effects are often delayed. Managers frequently face political and economic pressure to prioritize short-term gains over the long-term health of an ecosystem.
- **Lack of baseline information and monitoring**: The absence of comprehensive baseline data on fish communities and ecosystem dynamics prior to stocking, coupled with inadequate long- term monitoring, means the success or failure of stocking activities is not accurately measured. This gap makes it difficult to determine whether the desired objectives have been achieved.
- **Ecosystem degradation**: Many recipient ecosystems are already degraded, and stocking is often viewed as a short-term solution to increase fish production. This makes it challenging to isolate the effects of stocking from other anthropogenic activities, such as habitat degradation.
- **Defining success**: There is a lack of precise definitions for the success of stocking activities, hindering the proper evaluation of their positive impacts.

Given these concerns, adopting a responsible approach to stocking is crucial. Mechanisms must be established to minimize or mitigate any potential impact of stocking operations on fish communities and ecosystems, which can. The following sections review the major issues and outline mechanisms to achieve this need and ultimately provide the scientific, technological and logistical basis to develop guidelines for carrying out fish stocking in fresh waters in Europe and Central Asia in an environmentally friendly, socially acceptable and economically justified manner.

5.2. Review the need for fish stocking

The first step when considering any stock improvement must be to ensure proper clarification of the management policy and objectives, and establish whether the stock is below optimum productivity s or if the quality of the stock (e.g. in terms of age or size distribution) can be improved (**Figure 4**). This requires not only an assessment of the existing stock status but also an appraisal of the water body condition, including natural factors and anthropogenic stressors that may limit production. Identifying and resolving constraints on the fishery is crucial before any stocking is carried out.

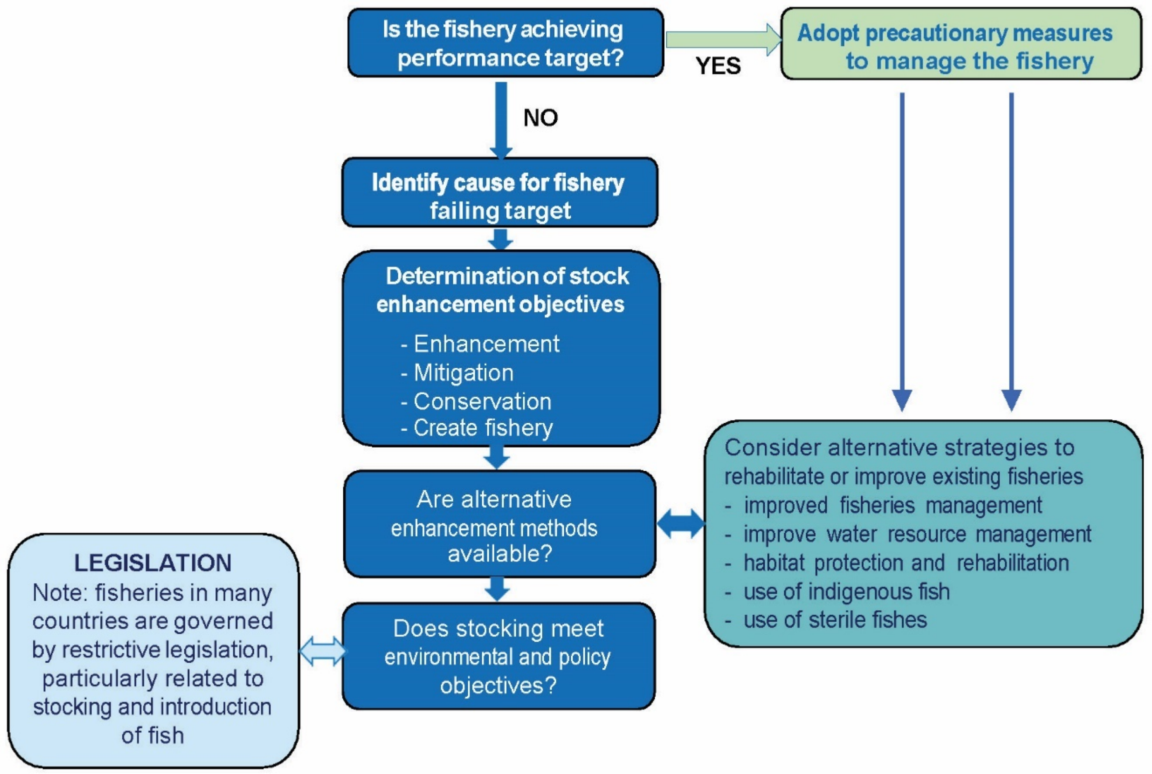

Figure 4. Defining performance objectives and potential alternative solutions.
Source: Authors' own elaboration.

If no apparent cause for stock decline can be identified, enhancement stocking might be considered. However, stocking should be rejected if the water body cannot support a sustainable population. In such cases, alternative improvement strategies should be explored, or resources should be redirected to rivers or lakes that can be improved (Figure 4). This does not include put-and-take fisheries, which are stocked to provide catchable-sized fish for rapid exploitation by anglers without considering sustainability through natural recruitment.

It is needed to determine whether existing stocking programmes are both necessary and effective and whether alternative approaches should be adopted. This arises because stocking programmes are frequently driven by political or public pressure to improve fishery catches or meet conservation targets. However, the viability and tangible benefits of these programmes are now in question. Therefore, there is a need to reassess ongoing stocking activities to determine if they are viable, cost- effective, or sustainable in the long term. Additionally, **it is important to consider whether alternative fishery improvement measures could achieve the same goals in a more sustainable and cost-effective manner** (Cowx *et al.,* 2023; Radinger *et al.,* 2023**).** These strategies include the use of legislative and fiscal measures to address harvest constraints (Jonhston *et al.*, 2018), improved water resource management and habitat protection and rehabilitation where the ecosystem has been degraded (Cowx and Welcomme, 1998; Angelopoulos *et al.*, 2017) and control of predators where they are having a serious impact (Ovegård *et al.*, 2021).

Legislative and fiscal measures: within each country there are measures in place to regulate the exploitation of fisheries. These generally relate to catch limits, closed periods, legal size limits and type of gear that can be used and are often controlled locally under fishery-specific bye-laws. These measures can be upscaled to stem any decline in the fisheries, especially closed seasons and closed waters to control fishing pressure.

Habitat management: fisheries managers use habitat management techniques to improve access to, and quality of, fishing, improve degraded habitats and increase the production potential of the fishery. Restoring the water body to improve levels of reproduction, shelter, food resources and vital habitat is a tool that deserves more attention. At present habitat improvement and restoration schemes suffer from the fact that few cost benefit analyses have been undertaken (Angelopoulos *et al.*, 2017).

Predator control: Predator control is perhaps one of the most controversial methods of fishery management. It involves regulating the numbers of predators, usually fish, otters or birds, foraging on the water body, to reduce predation pressure. Of particular concern at present, is the control of fish- eating birds which have increased dramatically in numbers around inland waters in Europe in recent years and are perceived to cause considerable damage to fish stocks (Ovegård *et al.*, 2021).

5.3. Technical and logistical requirements for stocking

Stocking is a widely used tool to enhance the status of fish populations and fisheries, but many programmes have not met their objectives or achieved expectations, despite some projects operating for many years. The fundamental reasons for the lack of success are:

- stocking too many or too few fish;
- stocking poor quality, unconditioned or unfit fish;
- inappropriate or stressful release strategy;
- poor cost-benefit analysis resulting in low economic returns; and
- failure to take into account potential governance and social issues.

There is, therefore, a need to identify technical and logistical requirements and methods to ensure successful stocking (**Table 4** and **Figure 5**).

Resourcing

As outlined in Section 4, a range of resourcing and logistic issues need to be addressed (**Table 4**), including:

- Sourcing of fish of appropriate size and numbers available to achieve goals.
- Control of quality of stocking material and disease status.
- Mechanisms and timing of release.
- Pre-conditioning and acclimatization.
- Handling and transportation.

The issues also need to be addressed in a systematic, logical order (**Figure 5**).

Table 4. Criteria for sourcing, handling, transportation and release of fish for stocking

Source of fish	Fish are well fed and have energy reserves
	Fish are in good physical shape and condition, there is no fin damage or scale loss
	Fish show active swimming behaviour (not upside down or dying fish at the bottom of the tank)
	Fish are free of parasites and major non-specific diseases of nutrition and water quality or pathogens specific to the species – valid health certificate of veterinary inspected.
	Source fish from same waterbody or first generation hatchery reared stock to minimise genetic disruption
Preconditioning and acclimation	Where feasible fish should be preconditioned to improve survival
	Acclimation (temperature, pH, feed changes) should be commenced several days prior to transportation
Handling and transportation	Fish are starved before transport to reduce pollution of transport bags and reduce oxygen consumption
	Packing for transportation should take place early in the morning, ideally at dawn
	Fish are packed at the correct density for their size – small fingerlings can be packed more densely. For long journeys or for larger fish the densities should be reduced
	Transportation containers are aerated or have oxygen added (in the case of bags).
	The volume of water in the transport container should be sufficient for the fingerlings to be transported (see above) – Plastic bags: 1/3 water 2/3 oxygen (not compressed air)
	– Plastic bags are kept in Styrofoam boxes during transportation
	Transportation should start as early in the morning as possible so as to take advantage of cool conditions
Release	Fish are acclimated to temperature and water quality of receiving waters
	Release strategy and location follows decisions made in Section 4.2
	Fish are nursed/acclimated in floating cages or other ponds before release to main waterbody

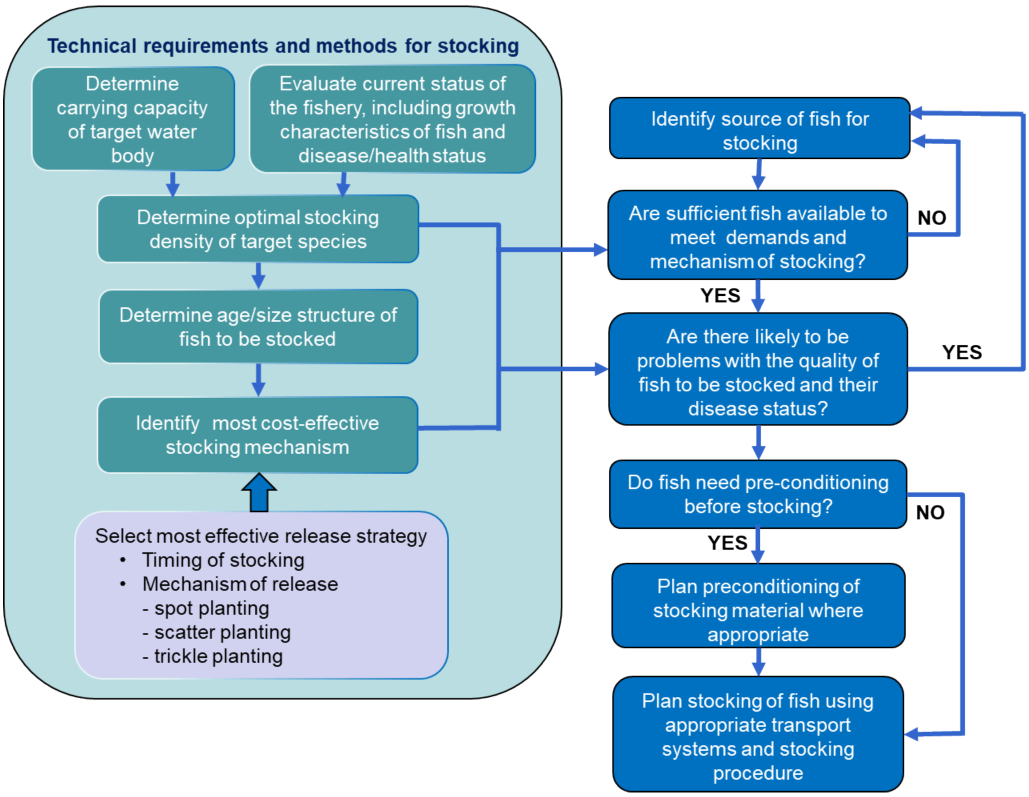

Figure 5. Flow chart illustrating considerations to be addressed when planning fish stocking
Source: Authors' own elaboration.

Determine the appropriate size of fish for release

Selecting the size of fish for stocking needs an understanding their potential impacts on native fish and the broader ecosystem, along with conducting a cost-benefit analysis. The significance of the size or age of the released fish is particularly apparent for species that undergo size-related or ontogenetic shifts in feeding behaviour or habitat use. For example, many fish species start as planktivores and shift to piscivory or benthivory as they develop. The size or age of the fish released determines their position in the food web and, consequently, their effects on ecosystem functioning and trophic status. Many piscivorous species consume zooplankton and benthic macroinvertebrates when young but become increasingly piscivorous as they grow, impacting ecosystem functioning. Releasing fish at smaller sizes can reduce incidences of piscivory and aggressive behaviour towards wild fish.

Optimal size determination: In principle, the size that maximizes yield from stocking (benefits) relative to cost should be preferred. The optimal size to maximize benefit should be determined for all stocking programmes. In well-managed fisheries, where fish are allowed to grow to a reasonable size before exploitation, the optimal stocking size is likely the early juvenile period. However, in poorly managed fisheries with intense exploitation of young fish, the optimal size may be the larval period due to lower production costs.

Cost-benefit analysis: Two main factors influence the size chosen for stocking material: cost and survival. Releasing fish at smaller sizes carries higher mortality risks, but the cost of stocking material increases exponentially with fish size, especially in slow-growing species. Fewer larger fish are needed to achieve the desired additional catch from stocking. However, this must be balanced against the decreasing uncertainty in fishery and economic yield from stocking as fish size increases. There is generally a transition size (juvenile bottleneck) where the yield from stocking becomes predictable, reducing uncertainty. The chosen size depends on an empirically determined balance between these factors unless a biological characteristic of the species dictates the necessary stocking size (Johnston *et al.,* 2018; Camp *et al.*, 2017).

Due to size-related mortality, hatcheries typically grow fish for extended periods before release. However, economic constraints often prevent fish from being raised to very large sizes in captivity, as prolonged grow-out periods significantly increase feeding and husbandry costs. These extended grow-out periods also negatively impact the behaviour of the fish. Therefore, it is crucial to strike a balance between the benefits of reduced mortality from longer captivity, the behavioural disadvantages, and the cost-benefits of stocking many small fish versus fewer larger individuals.

General trends: Migratory and anadromous fish are typically stocked at young life stages (fry) to allow them to acclimate to their natal river and prepare for migration as they grow. Cyprinids and other non-migratory species are generally stocked at larger sizes (fingerlings ≈12 cm) to supplement natural recruitment failures. These fish are expected to grow to a large size based on the natural productivity of the stocked waterbody.

Identify the best source of fish for stocking

There is growing awareness of the importance of maintaining the genetic integrity of fish stocks. Therefore, it is crucial to minimize the dilution of genetic variation through indiscriminate stocking policies with fish of unknown origin. Before implementing a stocking programme, several options regarding the source of fish should be considered:

i. ***Dedicated hatcheries/farms*** built to produce stocking material to compensate for human interference with the natural fishing production.
ii. ***Local hatchery production:*** Build up stock through hatchery production based entirely on local stock, returning brood stock to their home system.

iii. ***Redistribution within catchment:*** Redistribute adults cropped from other parts of the catchment, although this may not be suitable for movement to areas with different prevailing conditions.
iv. ***Donor stock with similar biological characteristics:*** Choose donor stock that shares the same biological characteristics as those in the recipient system.
v. ***Environmentally similar source:*** Select stock from a lake or part of a river with a similar environment, considering factors like stream size, gradient, water temperature, flow regime, altitude, and profile.
vi. ***Genetic diversity maximization:*** If genetic differences are presumed to have little adaptive significance, obtain stock from various sources where they are readily available to maximize the range of genetic material.

Stocked fish should not have been reared in captivity for more than one generation to limit the possible effects of selection within the hatchery. Particular care must be taken when obtaining fish from hatcheries to ensure this criterion is met.

Stocking sterile fish (e.g. triploids) has the potential to avoid inter-breeding between stocked and wild fishes, although it should be recognized that inducing triploidy is not 100 percent effective so some genetic introgression can potentially occur. This is of particular importance for water bodies that support unique strains of species. In addition, despite being mostly sterile, triploids may interfere with the post-spawning recovery of wild fishes.

Improving the survival of fish to be stocked – pre-conditioning and acclimatization

Despite advancements in hatchery-rearing techniques, fish reared in captivity for extended periods experience much higher age-specific mortality than wild stocks. This can result from:

- Compromised feeding abilities on natural food sources.
- Increased vulnerability to predation.
- Inadequate social interaction skills.
- Reduced ability to tolerate and navigate the receiving environment.

In hatcheries, fish are typically raised on a diet of manufactured, pelleted foods, limiting their exposure to the natural range of foraging behaviours. With little variation in the timing, location, abundance or type of food provided, the fish do not develop natural foraging skills. Stocked fish generally exhibit limited prey choice, capture fewer items, and are slow to switch between prey types compared to wild fish. This limited foraging ability deprives them of essential nutrition needed for survival. Additionally, stocked fish often fail to disperse, are less aggressive, and are frequently found in higher densities, leading to competition for limited resources.

Fish reared in hatcheries often lack exposure to the diverse environmental conditions they will encounter in the wild. Hatcheries typically do not replicate the structural complexity or the environmental variations (such as temperature, flow velocity, and salinity) found in natural habitats. As a result, hatchery fish are less tolerant of the physical conditions they will face upon release

Hatchery-reared fish also tend to have poorly developed anti-predator skills due to limited interaction with predators before release, making them more susceptible to predation. Fish are more likely to engage in risk-taking behaviours, have poorer predator recognition, and weaker anti-predator responses compared to wild fish.

To address these deficiencies, it is critical to develop methodologies that enhance the post-release behavioural performance of hatchery-reared fish. Pre-conditioning and acclimating fish to the conditions of the receiving waterbody can significantly improve their survival rates.

These conditions can be provided in the hatchery for 3–5 days prior to the stocking. Measures like increasing flow rates in hatchery raceways to match natural conditions, providing dark backgrounds, semi-natural streambeds, submerged structures, and overhead cover can improve survival rates post- release. Exposure to natural conditions not only increases the fitness of individual fish, but providing submerged structures creates visual isolation among potential competitors, allowing for the establishment of territories through improved visual references, leading to lower levels of aggression and better growth rates. Exposing fish to running waters exercises their red-muscle tissue, enhancing their ability for sustained swimming, and even brief exposure to such conditions before release can improve post-stocking survival. Further, introducing diverse and natural prey types into the hatchery environment in the days prior to stocking can also to stimulate the development of natural foraging behaviours and overcome reliance of artificial feeds during their rearing.

Providing an acclimatization period before release should result in substantial reductions in post- release mortality. While the exact period required to maximize survival varies by species or case specific, holding fish in cages or enclosures for one to seven days before release can substantially increase survival rates, growth rates, and recapture rates—key indicators of successful stocking. However, it is recognized that pre-conditioning and acclimatization may not always be possible but holding fish in cages in the water body prior to release can help alleviate the stress caused during transportation from the hatchery to the release site.

Preparing receiving water body for fish stocking

Prior to stocking, efforts should be made to ensure the receiving water body is suitable for stocking. A number of actions should be carried out prior to stocking to ensure the receiving water body is suitable for the fish being release.

- Ensure water quality in receiving water body is optimal by checking pH, dissolved oxygen, ammonia and conductivity or salinity are appropriate for the species to be stocked.
- Do not stock fish when water temperatures are high (18°C) or rivers are in flood.
- Undertake habitat improvement measures to ensure the receiving water body has suitable habitat for the species being stocked to ensure survival and good growing conditions. This includes placement of artificial reefs, reinstatement of spawning substrate, planting of aquatic macrophytes and regulating flows to benefit species habitat needs. Measures should address the bottleneck in the receiving water body that underlies the reason why stocking is needed.
- Additional measures include suspending fishing activities for several days after the stocking event to allow stocked fish to disperse from the stocking point and acclimate to the receiving water body.

Select the most effective release strategy

The timing and nature of release are critical to the survival of stocked fish. It is important that fish are stocked at a time when they will be able to adjust to the new environment quickly and thus learn to forage on natural foods with minimal delay. It is important therefore that abundant food resources are available.

Unfortunately, many fish are stocked when the fish are available from the hatchery, often at the end of the growing seasons when food resources in the wild are declining or depleted. Consequently, the fish not only have to survive the rigors of competition and aggression from wild fishes, but they also have to survive on their body’s nutritional reserves (e.g. lipids and fats). If the reserves are low, chances of survival are equally low. Thus, the preferred period of stocking should match an abundance of natural food resources, such as that typically found in the spring as temperatures are warming up.

Pre-conditioning and acclimatization are crucial for fish to adapt to their new surroundings. However, this must be accompanied by a release strategy that minimizes stress on the stocked fish. There are three mechanisms for releasing fishes:

- spot planting - releasing all the fish in a single batch;
- scatter planting - simultaneously releasing batches of fish at several locations; and
- trickle planting - releasing batches of fish over an extended period.

Releasing large numbers of fish at a single spot not only leads to aggression between the individuals, but also to competition for food resources in the immediate vicinity of the stocking point until the fish have dispersed. Scatter planting minimizes the potential for competitive interactions by reducing over- dispersion of released fishes. Similarly, trickle planting minimizes the potential for competition, but is often constrained by lack of manpower, finance and available stock periodically over an extended period.

Evidence suggests that, in terms of stocking success, scatter and trickle planting should be preferred over spot planting. However, these mechanisms are constrained by fish not being available at the ideal time or in the numbers required.

Handling and transportation of stock

Handling and transportation induce stress and potential harm to fish, which can subsequently impact their post-release survival. Hence, protocols that minimize handling duration or frequency should be implemented from the moment donor fish are captured until they are introduced into the recipient system. These practices should be consistently applied whenever fish are relocated, particularly over extended distances and durations. Stocking fish in poor condition or health serves no purpose, as it undermines the success of the intervention.

Preferred techniques for capturing fish initially, such as seine netting and "controlled" electric fishing, should inflict minimal damage. During collection and transportation, handling should be minimized whenever practical. Fish should be kept at low density and provided with ample oxygen.

All fish should undergo a minimum 24–hour fasting period before transportation to reduce oxygen demand, prompted by heightened respiration rates during digestion, and to minimize ammonia production. For long-distance transport, measures should be taken to mitigate the effective toxicity of unionized ammonia by adjusting temperature and pH.

Using appropriate anesthetics should be considered to decrease physical activity, thereby reducing the risk of injury and respiration rate. Tertiary amyl alcohol (180–900 mg/L) and benzocaine (10-40 mg/L) are recommended as the most suitable agents.

5.4. Risk management framework

To evaluate the potential risks of any stock enhancement programme amid considerable uncertainty, conducting a risk assessment is crucial. This should be integrated into the overall evaluation of the project and address significant biological, environmental and economic aspects (**Table 5**). The assessment process should establish a standardized method for gauging genetic and ecological risks, including the possibility of introducing unintended species, especially pathogens and non-target organisms, which might impact on the native flora and fauna of the receiving waterbody.

Table 5. Precautionary considerations prior to stocking

Considerations	Actions
Whenever stocking of fishes is being considered, the aims and specific objectives of the exercise must be clearly defined and adhered to	The potential economic and environmental advantages should be demonstrated, although it is recognised that in some situations (e.g. stocking for conservation purposes) there may be no economic imperative. These should be matched against the disadvantages or problems that may ensue.
Before stocking programmes are undertaken a thorough evaluation of the reasons for the action should be examined	Alternative approaches to stocking should be considered/discounted (e.g. habitat improvements or better fisheries management). The wider issues and constraints that are likely to affect the long-term success of stocking programmes should be reviewed and considered in the design of stocking projects.
If it is possible to remove or minimise the causes of declines in fisheries, this course of action should be taken, such that the fishery may then recover without stocking	Habitat improvement is the most desirable alternative because it should lead to long-term sustainable improvements with minimal deleterious ecological impacts.
When evaluating stocking as a possible management tool, the relative benefits and costs of all options should be considered	The "do nothing" option should not be disregarded but considered as fully as any of the other options under discussion, despite possible external pressure to stock
Regulatory bodies must consider the potential long-term implications of stocking on the ecosystem, and should not be guided solely by short-term economic gains	The entire catchment and any adjacent waterbodies must be taken into account when considering the proposals. Stocking activities should be considered mainly for systems that have been altered by human activity.
The potential adverse impacts of stocking in terms of environmental, genetic and ecological interactions should be considered fully	The precautionary principle should be adopted where foreseen adverse impacts cannot be mitigated, particularly in the case of designated natural heritage sites. Species that might be sensitive to the proposed introductions should be identified in the receiving waterbody. Special consideration should be given to rare species or those most ecologically similar to the species proposed for introduction.
Significant new stockings should be evaluated by an independent review	Ideally, this is a panel of scientists familiar with ecological principles and aquatic systems. It is important not to be hasty with introductions, as most effects are irreversible.

A risk management framework involves several steps:

1. ***Establishing the context****:* Define the specific stocking event.
2. ***Identifying risks***: Determine the likelihood and consequences of potential risks.
3. ***Assessing risks:*** Evaluate the identified risks by relating the probability of an event occurring with its potential consequences based on the species' ecology and the release environment.
4. ***Treating or mitigating risks:*** Implement measures to address identified risks.

The magnitude of potential risk is a measure of the probability (*likelihood*) of the impact (*consequence*) occurring if a species is stocked in a waterbody. Consequences are gauged by the potential impacts informed by ecological interactions between the stocked species and the recipient water's ecosystem. Ideally, these ratings are based on scientific evidence; otherwise, expert judgment is necessary, introducing a degree of uncertainty into the assessment process.

Certainty is a measure of the wider scientific understanding or experience of an impact occurring. Therefore, an additional layer in the matrix should account for uncertainty in knowledge or natural processes. A risk matrix can be used to determine the risk level, correlating the probability of impact with potential consequences. Where knowledge is deficient or uncertainty is high, a precautionary approach should guide decision-making to mitigate unforeseen impacts.

Acknowledging the risks associated with stocking in critical and by thoroughly evaluating these risks and incorporating precautionary measures, stocking programmes can be designed to minimize potential negative impacts and ensure the long-term sustainability of fish populations and ecosystems. Mitigation measures such as quarantine procedures or stocking with reproductively sterile fishes (e.g. triploids) should be incorporated into the overall assessment to manage the risks where appropriate. Where no such mitigation is considered viable it is recommended a precautionary approach to stocking or continuing to stock is adopted.

This recommendation draws the attention of fishery managers, owners and practitioners to the many problems that must be resolved within a wider fisheries sector context before stocking programmes are likely to achieve their objectives from ecological, economic and social perspectives. As part of this approach, a number of aspects should be considered at an early stage (**Table 5**).

Minimizing ecological impacts.

In cases where negative impacts on ecological diversity emerge, such as high mortality of stocked fish due to natural predators, or from stocked fish predating on other wild fish, resulting in reduced yields, the stocking strategy should be modified. While this scenario is relatively uncommon where stocking is predominantly of omnivorous or herbivorous, issues may still arise with predation on eggs and larvae of other wild species, impacting ecological diversity. Changing the species being stocked may alleviate negative impacts on habitats or mitigate interactions with wild species**. If significant impacts become apparent and cannot be managed, the stocking should be abandoned.**

Minimizing genetic impacts

The genetic interactions, such as hybridization, inbreeding, and the erosion of genetic integrity, can impede the success of stocking initiatives. Stocking, particularly with farm-reared fish, poses a threat to the genetic purity of wild populations due to reproductive interactions. Wild stocks exhibit genetic variation that is manifest as differences in growth potential, age at maturity, fecundity, and can have implications for coevolution and adaptation processes. In particular wild fish exhibit adaptation towards particular environments and stocking could lead to loss of fitness. Thus, releasing fish should prioritize the mitigation of genetically-driven alterations and the preservation of genetic diversity.

There are several potential mechanisms to reduce the genetic effects of stocking cultured fish or transferring fish of different strains on the wild stocks of the recipient water body. It should be noted that these largely mitigate the effects but do not necessarily eliminate genetic effects. The intention can only be to minimize genetic differences between released fish and recipient wild populations. Such measures in relation to hatchery practice and fish releases, include:

- Using fish from elsewhere in the same catchment.
- Using broodstock from the same water body but breeding for no more than one generation in the hatchery.
- Using sterile fish, e.g. triploids: This is an easily induced way of avoiding direct genetic effects.
- Locating fish farms far away from wild populations, and choosing locations for ranching that minimise straying, and may reduce gene flow in wild populations.
- Restricting spread of exotic genes and diseases by restricting transport of live fish and eggs.
- Gene banks: extinction of local populations can be counteracted by the establishment of gene banks.

If any potential for inbreeding, hybridization, or compromising genetic integrity exists, the programme should either be rejected outright or employ measures, such as stocking with triploids, to mitigate the risk.

Preventing the spread of diseases and parasites

There is considerable concern about the spread of diseases and parasites through stocking, highlighting the necessity to shield natural environments from unwanted pathogens. Consequently, stocking materials must be free from diseases and parasites. The process of stocking can involve the transfer of pathogens and heighten the risk of fish diseases. It is crucial to assess the likelihood of transfer of diseases and pathogens from the fish being stocked as well as the potential for stocked fish being infected by diseases prevalent in fish stocks in the receiving water.

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Preventing the inadvertent introduction or transfer of parasites and diseases is an important consideration associated with any movement of fish. Three possible strategies exist:

- improved control over fish movements through legislation;
- veterinary inspections; and
- quarantining.

The improved control over fish movements is essential to stem the continuing dispersion of pathogens and the accidental introduction of alien fish in consignments of a target species. This can only be achieved by improving the understanding and consequences of introducing and transferring fish and other aquatic organisms. The European Union and national agencies can play an active role by reassessing their legislation over the free movement of fish species linked to conservation and environment regulations.

Preferably, all stocking materials should originate from certified disease-free sources, although achieving disease-free status may be challenging. Nevertheless, fishes intended for stocking into open waters should undergo thorough checks for various parasites and clinical disease symptoms. These should be carried out by certified veterinary services in the country of origin and an appropriate certificate should be provided before the stocking takes place. Where no certificate is provided the stocked fish should be tested locally prior to stocking again using a certified veterinary service. The presence of any major pathogen or substantial evidence of clinical disease warrants rejecting or cancelling a proposed stocking operation.

Where there is any uncertainty about the disease status of the fish to be stocked, they should be held in quarantine in an isolated pond or tank or preferably in an indoor recirculating system (i.e. no direct hydrological links to any local water body) and tested periodically for pathogens before stocking.

Quarantine is usually defined as the placing of organisms under observation in isolation, whereby their disease and/or parasite status can be assessed and controlled prior to release. Quarantine procedures should be applied if, and when, there is a risk of introducing or transferring exotic diseases and/or parasites, whether identifiable or not, together with the organisms in question. The actual procedures recommended depend very much on the disease history of the stocks in question, the expertise available at the point of origin of the stocks, the degree of confidence in the abilities of the exporting agency and expertise, and facilities, available at the place of arrival of the stock to be moved. The safest quarantine strategy is not to move any organisms at all, anything else involves risk.

It should be noted that some diseases and parasites may only become evident post stocking so continuous monitoring of the disease status of the stocked and wild fish in the receiving waterbody should from part of the post-stocking assessment.

It should be noted these health inspections and quarantining should also help prevent the introduction of alien fish that piggy-back in consignments of fish to be stocked, including cryptic species such as *Psuedorasbora parva* that can be transferred in the buccal cavity of carps.

5.5. Social and economic considerations

Undertake a cost benefit analysis

In any proposal, the overall costs and benefits of stocking should be evaluated to ensure that the outcomes are justified in terms of social and economic benefits to the locality or region (**Table 6**) and balanced against with the risks to the environment. Costs relate to producing/obtaining the desired life-stage of the fish and capital costs until fish are released. Typical economic costs incurred are listed in **Table 7**.

Table 6. Table of typical quantitative and qualitative benefits to be taken into account relating to the outcomes of stocking events

Prior to stocking	Before stocking baseline production revenues
	Opportunity for employment
	Improved fishery productivity
Post stocking	Harvested yields
	Increased revenues
	Employment
Secondary impacts	Support to the fish farms producing stocking material
	Change of fishery status, e.g. supporting recreational and commercial fisheries
	Recreational benefit for people (income, employment).
	Benefit to conserve endangered species.
	Benefits to society by allowing alternate uses of water and managing water resource use

Table 7. Typical economic costs for stocking to be reviewed for inclusion in cost-benefit analysis

Fixed costs	Lease value
	Costs of physically modifying the environment (e.g. creation of bunds, embankments, creation of spawning and shelter habitats, construction of artificial reefs, fencing)
	Cost of physically intervening to maintain the environmental quality (e.g. draining reservoir, dredging,)
	Labour involved in management
	Costs for water abstraction and discharge licenses
	Taxes and insurance
Preparation	Fertiliser, weed removal, liming, cost of removal of unwanted species
Stocking	Stocking materials (this often amounts to between 40 and 70% of total costs)
	Costs of genetic manipulation and genetic resource management will increase cost of stocking material (e.g., selective breeding, hybridisation, polyploidisation, gene transfer, or sex manipulation)
Production and management	Feeding and fertilization costs
	Patrolling and enforcement
	Energy costs
	Draining down water body
	Predator control costs
	Costs of harvesting

Analysis of this type is critical because the cost of stocking may not result in the benefits expected, and in some cases lead to deterioration in the fishery, e.g., when the fishery is overstocked, growth rates and survival of stocked material are compromised. Calculating the costs of stocking different life stages should include identification of stocking location, and specialist equipment and transport. Eggs and larvae are the least expensive option, but there are doubts about cost-effectiveness due to relatively high levels of mortality during these early life stages. Growth and mortality are key issues in estimating economic returns. A simple assessment of this nature should also flag up if stocking has little tangible benefit and reduce the number of unnecessary stocking events.

Governance and social issues

Most stocking strategies generally concentrate on fishery-related aspects such as size of fish, density or biomass of fish to be stocked. However, there are many wider issues and constraints that need to be overcome before a stocking activity should take place or will be effective, particularly where fisheries are maintained by regular stocking, i.e. commercial put-and-take, catch-and-release or culture-based fisheries. These can be broken down into institution weaknesses, fishery and stock ownership, fishery management interventions and legal/ regulatory requirements.

In many cases, failure to maintain fish stocks at adequate levels arises because of weaknesses in fisheries management, and heavy fishing pressure. Actions need to be taken before any stocking takes place, otherwise the fishery just becomes a put-and-take operation with little distribution of the equity to society or the institution undertaking the stocking.

This raises the question of ownership of the stocked fish. Ownership is rarely a problem in waterbodies where the boundaries are well-defined (e.g. put-and-take and still-water fisheries), but in open systems, such as large rivers, lakes or coastal regions, ownership is less well defined. In these systems stocking is more akin to ranching and the dispersion of stocked fish outside the area of jurisdiction raises questions on ownership and exploitation rights. In many instances the stocked fish become a common property resource, and any stocking programme will probably have to sustain any external exploitation. This is the reason many ranching programmes do not succeed on a strictly financial basis because the return on investment is dissipated and not accrued by the primary owner.

Finally, for any stocking programme to be legitimate, they should comply with national and regional legal/regulatory requirements. Most governments have statutory authorization systems (e.g. licenses, permits, consents) to regulate and control movements of fish for stocking (see Section 2.4) and the European Union has a number of Directives to protect animal health (Council Directive 98/45/EC and European Union Aquatic Animal Health (Amendment) Regulations 2022) and offer environmental protection of natural habitats (Directive 92/43/EEC [Habitats Directive]) and regulate movements of non-native species (Invasive Alien Species Regulation – Regulation (EU) 1143/2016). It is therefore essential that all stocking complies with these regulations and legislation to avoid problems arising from stocking and transfer of fish.

5.6. Post-stocking monitoring to measure impacts and outcomes

One of the major weaknesses with stocking programmes is post-monitoring of outcomes. Management agencies should ensure robust post-monitoring not only for financial assessment, thus determining cost-effectiveness, but also for evaluating whether desired outcomes or unintended consequences have transpired.

Comprehensive monitoring should encompass all aspects of stocking, spanning ecological, genetic, socioeconomic, and disease-related outcomes. It is essential that monitoring is carried out prior to the stocking to determine pre-stocking status of fish populations, communities and associated fisheries and act as a baseline to assess changes in target fish stocks, fisheries and waterbodies against management objectives.

Post-stocking monitoring should cover an extended timeframe, as outcomes of stocking often manifest gradually, sometimes several years later. These outcomes can vary; for instance, in commercial fisheries where success may be gauged by improved economic value of catches. In sport fisheries outcomes expected may relate to angler satisfaction, which is a more intangible measure and requires dedicated angler surveys.

To ensure that monitoring and evaluation of stocking is conducted holistically, there is a need for defined criteria and indicators against which to measure performance. Such criteria and indicators must be based on the stocking objectives. These are summarized in **Table 8**.

Table 8. Holistic criteria for evaluation of stocking

Biological and environmental	Technical/biological effectiveness.	Impacts on survival, production/yields.
	Environmental impacts and/or benefits.	Ecological effects Impacts on habitats, invasive species, disease. Environmental externalities. Impacts on target and non-target species.
Social and economic	Economic effectiveness and efficiency.	Cost recovery. Financial sustainability. Cost-benefit.
	Social and livelihoods benefits and/or impacts.	Impact on fisher incomes and livelihoods. Influence on social cohesion.
Governance	Rights and equity.	Impacts on access to fishery, tenurial aspects. Creation or resolution of conflicts.
	Institutional sustainability/effectiveness.	Sustainability of (institutional) arrangements. Enforcement and compliance with harvest/management measures.

Source: Authors' own elaboration.

Ideally, the criteria used seek to evaluate stocking across the range of issues that influence the stocking outcomes. Using a broad range of criteria also provides greater scope for the development of management solutions to problems and can assist in the development of mitigating actions or trade- offs when there is no direct solution.

More detailed evaluation criteria are elaborated in **Table 9**, which also provides suggestions for the type of indicator that could be used to evaluate performance under each of the criteria.

Table 9. Criteria and associated indicators recommended for the holistic evaluation of outcomes of existing stocking programmes

Biological and environmental criteria	Criteria	Indicator(s)
Technological effectiveness/ efficiency	Efficient use of natural productivity.	Fish yield, fish size at harvest, recapture rate.
	Minimised mortality at stocking.	Post-release survival.
	No significant genetic or health impacts.	Genetic quality and health status of seed.
Environmental impacts and/or benefits	Ecosystem services within target area maintained (e.g., food, water, energy) according to objectives.	Provisioning, regulating, supporting and cultural ecosystem services indicators through measurement of changes to: – physical habitat; – water quality; – trophic structure; – biodiversity;
	Biodiversity not impacted negatively Surrounding ecosystem (external to target area) and watersheds not adversely impacted.	Abundance of key species and habitat Habitat disturbance. Presence of undesirable species.
Economics and economic efficiency	Increased revenue from production, processing or distribution of target species (or from the whole fishery).	Improvement of household incomes;* related businesses/services; total value of the fishery.
	Economic/financial sustainability and reduced dependence on external financial support.**	Income or revenues meet the costs of stocking and are sufficient to sustain the stocking activity. Change in level/regularity of financial support.
	Positive economic impact within the broader community directly resulting from the fishery and related activities.	Community infrastructure built by fishery or taxes or license fees collected from fishery. Human development index in community.
	Economic opportunities from existing ecosystem services are sustained or compensated.	Value of appropriate ecosystem services.
Social and livelihoods benefits and/ or impacts	Livelihoods of people in the community improved as a result of the stocking and related activities.	Income from fishing activities. Employment from fishing activities.
	Livelihood options increased in target area. Nutritional and food security increased in community. Community development and social cohesion increased. Women and marginalised and vulnerable groups engaged in stocking and related activities.	Time allotted to fishing and other activities (i.e., changes in labour patterns). Fish consumption and nutritional status (e.g., stunting, growth rate). Development of social activities and community infrastructure. Migration to/from community. Community groups and fishing associations. Participation in stakeholder consultations and in production, harvest, processing, distribution and marketing activities.
Rights and equity	The distribution of benefits from the intervention are equitable considering multiple objectives.	Benefits for individual/household for specified stakeholders and target beneficiaries Impacts on non-target beneficiaries.***
	Appropriate tenure/access ensured for resources (water, land etc.).****	Access to resources (water, land etc.) for stakeholders. Tenure arrangements, consideration of the impact of external factors.
	Mechanism in place to reduce and resolve arising conflicts.	Incidence/severity of conflicts Policy and legal frameworks for conflict resolution.
	Recognition and respect of users' rights and rights of traditional users.	Incidence of rights violations.

Biological and environmental criteria	Criteria	Indicator(s)
Institutional sustainability	Coordinated institutional mechanism(s) between water management environment agency and government arrangements/agencies responsible for assigning rights facilitates the establishment of responsible stocking initiatives.	Institutional mechanism(s) or lack of legitimate stocking initiatives.
	Fishery stakeholders empowered to lead management, monitoring and decision-making processes, leading to community management or co-management and consequent reliance on government institutional support for this.	Fishery management groups. Fishery co-management arrangements capable of developing regulations and implementing monitoring, control and surveillance (MCS).
	Effective enforcement and compliance with regulations.	Incidence of non-compliance. Effective management action taken in the case of non-compliance.
	Stocking initiative is effectively or integrated into the existing wider fishery and does not compromise effective fishery management and/or maintenance of habitat integrity.	Impacts or conflicts in the wider fishery environment resulting from the stocking activity. Fishery management plan in place, with considerations for stocked fish.

* Improvement in incomes assumes equitably is distributed and not subject to elite capture by a limited group.
** Note that economic sustainability and cost recovery may not be an objective in a rural development or livelihood support programme. Equally, a conservation objective may not have an economic objective as it is a public good. Sustained resourcing or financing may be secured via government support.
*** Benefits may be defined according to the system and context: quantitative (food, catch, financial, income, savings) or qualitative (livelihood opportunities, social capital).
**** Including women, and marginalised and vulnerable groups.
Source: adapted from Cowx, I.G., Funge-Smith, S.F. & Lymer, D. 2015. Guidelines for fish stock enhancement practices in the Lower Mekong Basin. In: *Responsible stocking and enhancement of inland waters in Asia*. FAO Regional Office for Asia and the Pacific, Bangkok. RAP Publication 2015/11, pp. 5–84. http://www.fao.org/3/a-i5303e.pdf#

As different stocking programmes may have multiple objectives, performance may have to be evaluated according to multiple and varying criteria to determine success or failure. A "success/failure matrix" such as provided in **Table 10**, provides a mechanism to align these multiple objectives with the goals of the stocking initiative, typically outlined in a fishery management plan.

Table 10. Success/failure matrix for evaluating stocking activities with multiple objectives

	Performance according to evaluation criteria				
Objective	**Economics**	**Institutional sustainability**	**Livelihoods**	**Environment**	**Technological effectiveness – efficiency**
Enhance food/fish production	+	+	=	=	+
Enhance/diversify livelihoods	-	=	-	=	+
Rehabilitate degraded systems	=	=	+	-	=
Conserve species or environment	-	=	+	=	-
Increase recreational opportunities	+	=	+	+	+

Legend: +: a positive impact/benefit is expected or necessary to achieve the primary objective; = no change/effect is expected; -: a negative impact/benefit is expected (a negative rating in any criteria requires corrective action or mitigation).

This evaluation approach aids decision-making for present and future stocking by pinpointing areas of weakness concerning priority management goals. It also highlights secondary issues related to additional benefits or threats. Success is determined by a positive outcome under the main criteria aligned with the primary objective. Ideally, all other criteria remain unaffected or may also exhibit positive impacts, signaling even greater success. A negative impact on any criterion suggests a problem requiring correction. A negative rating for a criterion expected to be positive indicates significant issues or failure to meet the primary objective.

Negative impacts on other criteria may signal serious problems or necessitate corrective measures. In scenarios where several evaluation criteria suggest failure and/or the cost of improving failed criteria is prohibitive or unrealistic, the recommended management action would be to phase out the stocking intervention and devise an alternative strategy aimed at achieving similar outcomes (e.g., alternative fishery management actions, habitat modification or restoration to a natural state).

Following implementation and 2-3 years of monitoring, a thorough re-evaluation of the stocking considering ecological, economic, genetic, disease spread, and social aspects is essential. This should be linked to a comprehensive long-term evaluation plan, integrating insights from technical, ecological, genetic, social and other relevant disciplines, and assess ongoing stocking programmes and ensure they are both effective and meet their targets.

The long-term holistic approach will assist in identifying and resolving:

- impact on habitat (e.g. loss of aquatic vegetation, change in the composition of aquatic vegetation, increase in dissolved solids and turbidity) of the recipient ecosystem;
- impact on trophic dynamics of the recipient ecosystem (e.g. change in the quality and quantity of plankton communities, increase in a single age group of a particular fish species, change in the quality and quantity of benthic organisms);
- change in the genetic integrity of stocked/ resident fish species (e.g., presence of hybrids, fish with deformed bodies, fish maturing earlier or later than the same species in other similar natural waterbodies, egg quality, and survival of hatchlings and fingerlings);
- latent disease and parasites, which were not detected during quarantine;
- change in the species and catch composition;
- growth performance of both stocked / resident fish species;
- production trends of both stocked / resident fish species; and
- change in the socioeconomic conditions of people related to the fishery.

This post-stocking appraisal should include a mechanism for disseminating the outcomes to highlight best practice stocking activities and the risks of any unforeseen adverse impacts in similar exercises.

It is recommended that existing and proposed stocking programmes should be independently assessed to ensure that the wider environmental, ecological and socioeconomic issues have been thoroughly reviewed.

5.7. Strategic approach to fish stocking

As outlined above, a number of issues arise that need to be addressed if stocking is to be carried out in an ecologically acceptable, socially responsible, technically feasible and cost-effective manner. In particular, the threats posed by fish stocking are especially problematic because few management measures exist to overcome any adverse effects. Furthermore, many stocking programmes appear to have been unsuccessful because of poor project planning and poorly defined objectives (Cowx 1994, 1999; Cowx *et al.,* 2015, 2023). Consequently, there is a need to adopt a strategic approach to fish stocking to both improve overall success and minimize impacts on the ecological functioning of recipient water bodies.

A number of global normative and technical documents that cover movements, introductions, assessment methods and codes of practice are available to inform the development of these guidelines (Tables 11 and 12)

Table 11. Global and regional codes of practices, guidelines and regulations for fish stocking

Codes of practice and guidelines	
Precautionary approach to the introduction and transfer of aquatic species	Bartley and Minchin (1996)
Guidelines for environmentally sound practices for introductions and translocations in aquaculture (IMPASSE)	Cowx *et al.,* (2009)
Codes of practice and manual of procedures for consideration of introductions and transfers of marine and freshwater organisms.	EIFAC (1988)
Code of conduct for responsible fisheries (CCRF)	FAO (1995)
Code of Practice for Introductions and Transfers of Marine Organisms	ICES (1988, 2005)
Code for alien species in aquaculture	IUCN (2006)
Guidelines for Reintroductions and Other Conservation Translocations	IUCN (2013)
Guidelines for Stocking Atlantic Salmon	NASCO (2022)
Regulations and resolutions	
Council Regulation on Setting rules governing the use of alien species in aquaculture	EU (2011)
Guidelines on aquaculture restocking and stock enhancement	FAO (2023)
Resolution by the Parties to the Convention for the Conservation of Salmon in the North Atlantic Ocean to Minimise Impacts from Aquaculture, Introductions and Transfers, and Transgenics on the Wild Salmon Stocks	NASCO (2003)

Source: Authors' own elaboration.

These codes of practice and technical guidelines are mostly voluntary in nature and generally focus on the risks associated with stocking and introductions.

In addition, there are many global and regional technical reviews, as well as a number of regional technical workshops specific to Europe and Central Asia, that review the various aspects of stocking, introductions and movements and have developed best practices for stocking.

Table 12. Global and regional technical reviews of fish stocking

Global technical reviews	
Review of existing guidelines: advantages and constraints. IMPASSE Report to EC	Angelopoulos *et al.,* (2008)
A responsible approach to marine stocking	Blankenship and Leber (1995)
Stocking strategies	Cowx (1994)
An appraisal of stocking strategies in the light of developing country constraints	Cowx (1999)
Guidelines for fish stock enhancement practices in the Lower Mekong Basin	Cowx *et al.,* (2015)
A review of stock enhancement practices in the inland water fisheries of Asia.	De Silva and Funge- Smith (2005)
General aspects of stock enhancement in fisheries developments	Ingram and De Silva (2015)
Economic, Ecological and Genetic Impacts of Marine Stock Enhancement and Sea Ranching: A Systematic Review	Kitada (2018)
Responsible approach to marine stocking: an update	Lorenzen *et al.,* (2012)
Developing and integrating enhancement strategies to improve and restore fisheries	Lorenzen *et al.,* (2021)
Stocking as a fisheries management tool.	Molony *et al.,* 2005)
Inland fishery enhancement	Petr (1998)
International measures for the control of introductions of aquatic organisms	Welcomme (1986)

Technical workshops and reviews specific to Europe and Central Asia	
Angling club guide to stocking fish.	Angling Trust (2020)
Hand in Hand für eine nachhaltige Angelfischerei: Ergebnisse und Empfehlungen aus fünf Jahren praxisorientierter Forschung zu Fischbesatz und seinen Alternativen	Arlinghaus *et al.,* (2015)
Gute fachliche Praxis fischereilicher Besatzmaßnahmen	Baer *et al.,* (2007)
Analysis of the environmental and economic impact of operations to reinforce the aquatic fauna of fresh waters for fishery purposes	Cowx and Godkin (1999)
Fish Stocking Technical Manual, Environment Agency	Cowx *et al.,* (2007)
Non-native fish species in Central Asia and the Caucasus: environmentally sound practices for introductions and translocations FAO Regional study on fish introductions in Central Asia and the Caucasus	Cowx *et al.,* (2012)
Guidelines for stocking coregonids	EIFAC (1994)
Asia regional technical guidelines on health management for the responsible movement of live aquatic animals and the Beijing consensus and implementation strategy	FAO/NACA (2000)
Manual of procedures for the implementation of the Asia regional technical guidelines on health management for the responsible movement of live aquatic animals	FAO/NACA (2001)
Guidelines and regulations on andromous salmonid stocking from the Norwegian Environment Agency.	Norwegian Environment Agency (2014)

Source: Authors' own elaboration.

The underlying framework of the various guidelines presents a systematic review and decision process for the holistic evaluation of stocking and introductions, integrating risk analysis and factors affecting successful outcomes, through to its final implementation. The structure of these guidelines is typically broken down into a number of key components, summarized in **Figure 6**, but organized into three phases:

- **What** to consider before attempting stocking (define whether restocking or stock enhancement).
- **How** to ensure optimal stocking programmes.
- **What** to assess, evaluate to monitor/optimise the stocking.

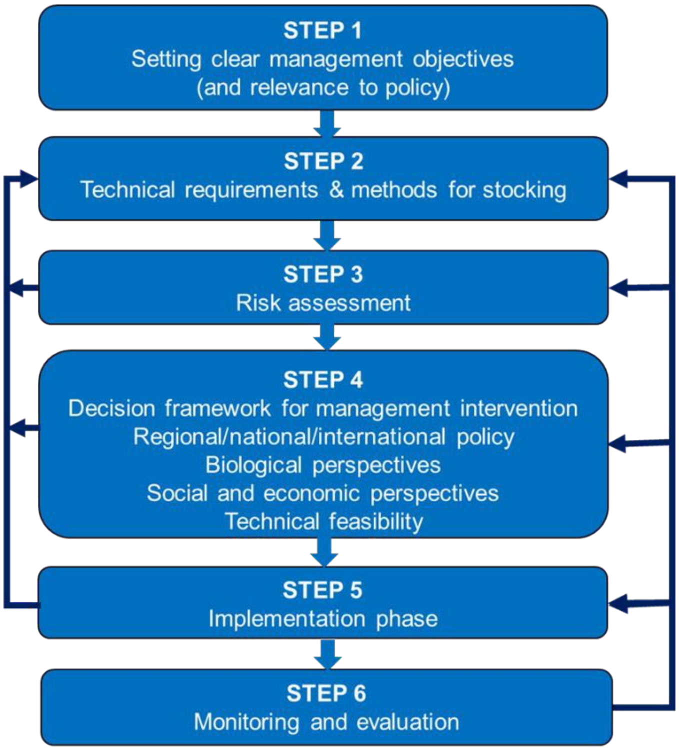

Figure 6. Framework for responsible stocking of aquatic organisms

Source: adapted from Cowx, I.G., Funge-Smith, S.F. & Lymer, D. 2015. Guidelines for fish stock enhancement practices in the Lower Mekong Basin. In: *Responsible stocking and enhancement of inland waters in Asia*. FAO Regional Office for Asia and the Pacific, Bangkok. RAP Publication 2015/11, pp. 5–84. http://www.fao.org/3/a-i5303e.pdf#.

The existing guidelines are voluntary and predominantly focused on the risks associated with stocking (see EIFAC 1988; ICES 2005 and IUCN 2013, for examples). These recommendations often offer broad advice that lacks the necessary detail to support fishery managers adequately. They typically lack guidance on assessing consequences and fail to provide sufficient information on the ecological, genetic and pathological impacts of stocking, as well as economic and social perspectives, crucial for informed decision-making. This limitation stems from existing guidelines primarily targeting fish introductions rather than stocking explicitly. Consequently, a precautionary approach to stocking aquatic organisms is often necessary due to the lack of sufficient information to make well-informed decisions.

In this context, it would be valuable to assess the relative merits and cost-effectiveness of stocking with different life stages and at various times of the year to determine whether stocking contributes to improving stock status (Aprahamian *et al.*, 2003). Any decision-support tool should incorporate protocols that ensure stocking is carried out effectively to maximize success.

To address these limitations, a comprehensive framework is needed that covers the six key steps identified in **Figure 6**, namely: identifying the objectives of the stocking programme, including understanding any factors underlying the need for stocking (Step 1); formulation and evaluation of technical requirements and methods for stocking including management options (Step 2); assessment of potential sort and long-term ecological, pathological, genetic and environmental risks (Step 3); evaluation and selection of management options (Steps 4); and implementation and monitoring of activities (Steps 5 and 6). Such a framework provides a logical review and decision process for the holistic evaluation of stocking activities, integrating ecological, fishery, socioeconomic, and implementation considerations, as well as determining whether alternative strategies should be implemented to achieve the same objective. The option to revise or reject the stocking at any stage is inherent within this framework.

The underlying principle for stocking management should dictate that once the objectives are established through a thorough assessment of the fishery status and limitations, a specific stocking strategy must be developed to achieve those objectives. This is akin to identifying the bottlenecks that limit the fishery potential performance.

After confirming the need for stocking, scenario analyses should assess critical bottlenecks to fish population productivity or fishery performance to determine if stocking is a viable option for enhancement. This evaluation should consider ecological and environmental risk criteria and include a cost-benefit analysis. Ultimately, the overall feasibility of the action should be assessed in terms of environmental and ecological risk, bio-economic and social gain, and practicality. If at any stage of these assessments the risks, costs, feasibility, or potential benefits are deemed unacceptable, the programme should be rejected, and alternative strategies be considered.

It is recommended that the information provided in this overview of the state of knowledge on fish stocking in Europe and Central Asia, the potential impacts of stocking and reasons why fish stocking programmes do not achieve their desired objectives, is used to develop stocking guidelines for Europe and Central Asia that addresses the negative impacts and maximizes the benefits of fish stocking activities.

6. CONCLUSIONS AND RECOMMENDATIONS

Stocking is a vital component of fisheries management, serving commercial, recreational, and conservation purposes. However, there are ongoing concerns about the benefits and successes associated with stocking fishes in Europe and Central Asia, as well as the potential risks, particularly with respect to ecological impacts from stocking from competition and predation, changes in ecosystem functioning, changes in community structure, disease transmission and losses of genetic integrity. Consequently, there is a need to review the factors that drive successes and failures of stocking programmes so enhancement programmes are carried out in the most effective way. It is recommended to adopt a precautionary approach towards fish stocking, along with strategic planning aligned with established guidelines, taking account of the risks and procedures presented here.

This review underscores the need for fishery managers and owners to address various challenges within the broader fisheries sector before stocking programmes can effectively meet their objectives. Key considerations include:

- Clearly define the aims and specific objectives of stocking programmes and demonstrate potential economic and environmental benefits. It is important to weigh these against potential drawbacks or challenges.
- Prior to planning stocking, conduct a thorough evaluation of the rationale behind the action and explore alternative enhancement approaches such as habitat improvements or better fisheries management. Address any underlying causes for the underperformance of the fisheries before resorting to stocking. Prioritizing habitat improvement can offer sustainable, long-term gains with minimal ecological impacts.
- Review and address broader issues and constraints likely to impact on the long-term success of stocking programmes during project design and implementation. Stocking should primarily be considered for waterbodies heavily impacted by human activities, where natural fish populations are disrupted or eliminated, for example after a fish kill, or where habitat restoration is not feasible.
- When assessing stocking as a management tool, the pros and cons of all options should be evaluated, including the "do nothing" approach. Despite potential pressure for stocking from the public, all options should receive consideration. Regulators must evaluate long-term ecological implications of stocking beyond short-term economic or public gains, and consider the entire watershed and adjacent water bodies.
- Risk assessment protocols should evaluate the potential for stocking to introduce new parasites or diseases into recipient systems. Full consideration of potential adverse impacts on the environment, genetics of native stocks and ecological interactions is necessary. The precautionary approach should guide decisions, especially in areas of high conservation value, with special attention given to species sensitive to stocking.
- It is advisable that all stocking initiatives undergo thorough formulation and planning to prevent haphazard and often ineffective stocking efforts. The anticipated results of specific stocking endeavours should align with broader objectives within the fisheries sector, while acknowledging constraints that may hinder success.
- Species-specific guidelines should be developed, outlining effective protocols for deciding on stocking, implementation methods, and potential impacts. Tailoring the stocking strategy to suit the ecological requirements of the species involved is crucial for maximizing success. Appropriate monitoring should be implemented for all stocking activities to assess progress and outcomes, and reduce risks of unforeseen adverse effects in future endeavours.
- When assessing the viability of stocking programmes an evaluation of the most cost-effective options in relation to expected benefits should be undertaken. All too often, the strategy is to make do with existing circumstances, yet some forward planning could significantly enhance outcomes.

It is recommended that all stocking programmes are properly formulated and planned before being carried out to avoid indiscriminate and often futile stocking activities. The expected outcome for particular stocking exercises should be compared with wider fisheries sector objectives, and constraints that are likely to prevent a successful outcome should be considered in all appraisals. To this end, practical guidelines for stocking various fish species in a range of water-body types to meet specific objectives should be made available through government agencies and international advisory bodies. Finally, it is recommended that stocking programmes, existing as well as proposed activities, should be independently assessed to ensure that the wider environmental, ecological and socio- economic issues have been thoroughly reviewed.

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Fish stock enhancement through formal stocking programmes was long recognized as an important tool to compensate the loss of productivity and diversity. Fish stocking is widely implemented across Europe and Central Asia to increase or maintain fish productivity. However, there are concerns about the benefits and successes associated with stocking fishes, as well as the potential risks, particularly with respect to ecological impacts from stocking, competition and predation, changes in ecosystem functioning, changes in community structure, disease transmission and losses of genetic integrity. Consequently, there is a need to review the factors that drive successes and failures of fish stocking programmes and the risks from stocking, so stock enhancement programmes are carried out in the most effective way.
This report summarizes the main conclusions of a review of the benefits and impacts of fish stocking. It provides a framework to mitigate the negative impacts and maximize the benefits of fish stocking activities.

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