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Review

Ecology and Sustainable Conservation of the Nase, *Chondrostoma nasus*: A Literature Review

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Abstract: Cyprinid fish play a major role in riverine ecosystems because of their high abundance, variety of life-history patterns, and habitat requirements. The nase (*Chondrostoma nasus*) is an algivorous, rheophilic, lithophilic, and oxyphilic species and is very pollution-sensitive. Thus, it represents a good indicator for habitat quality in the lower rhithral and upper potamal zones of the European river system. Due to its high level of ecological requirements, the species is very sensitive to human disturbance, leading to habitat loss and river fragmentation, climatic disruption causing a modification of hydrological and thermal regimes, organic and inorganic chemical water pollution, as well as sediment deposition. Its populations are declining in most of its distribution areas. This paper aims to synthesise the scientific knowledge on the different aspects of the nase ecology thanks to consultation of the scientific literature by addressing the following themes: European repartition, morphology and identification, reproduction and life cycle, diet, movement dynamics of adults and juveniles, and the characteristics of spawning grounds and habitats of juveniles and adults. We also provide an overview of the impact of human activities and climate shifts on natural ecology and conservation and present restoration measures based on the results of some studies that have successfully improved their habitats and/or preserved their populations. A series of key research questions are identified that should stimulate new research on this species as well as conservation measures for sustainable conservation. This paper may be particularly of interest to researchers in aquatic and fisheries sciences, river managers, and environmental conservationists.

Keywords: biology; ecology; threats; sustainable conservation; protection measures; rheophilic cyprinids; nase

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1. Introduction—Generality

In European rivers, cyprinids play a major role in riverine ecosystems because of their high abundance [1,2]. Their variety of life-history patterns and habitat requirements make cyprinids good indicators of the ecological quality and the structural properties of river systems [3,4]. Among the Cyprinidae family, there are 11 species grouped within the genus *Chondrostoma* in Europe. Among these species, the nase *Chondrostoma nasus* is a potamodromous and exigent fish with highly specialised, ecologically and geographically distinct, ontogenetic trophic niches [5]. The nase is a shoal-forming species whose structure is linked to growth and age and performs seasonal migrations. It occupies medium and large watercourses with a preference for fast-flowing facies [6]. The species has no economic value and is poorly consumed.

The nase constituted one of the most common patrimonial fish species in European rivers. Its highly specialised and migratory nature promoted its decline due to habitat modifications and alterations because of human pressure and climate change [7]. It represents a good indicator for habitat quality in the lower rhithral and upper potamal zones of European river systems [6]. Among riverine species, the European nase is considered a target species of conservation [8], as its populations have severely declined in central

Europe [7,9–15]. A comprehensive analysis of >30 years of data on stream fish population trends and conservation status in Bavaria, Germany, showed that declines of nase and other gravel-spawning species of the hyporhitral and epipotamal in medium-sized and large rivers (grayling, *Thymallus thymallus*, Barbel, *Barbus barbus*) were mainly caused by habitat alterations through an increase in water temperature and fine sediment [16]. In the past, in Switzerland, spawning schools were often made up of several thousand individuals, sometimes more than 10,000. After 1993, a considerably smaller number of spawners was observed, often consisting of fewer than 50 individuals [17].

In the past, the nase was considered a harmful species for the spawning of certain native species in some countries, particularly the grayling. Destructive fishing was then authorised from 1901 to 1982 in France in the spawning sites common to both species, until their uselessness was demonstrated. The nase is not competitive with any species, not even for other native Chondrostomes in France, including the toxostome *Parachondrostoma toxostoma* [6]. In terms of official protection status, the nase only benefits from minor protection across Europe according to the IUCN and is protected in Europe and Belgium because it is listed in Appendix III of the 1979 Berne Convention, which aims to protect European wildlife and natural areas [18,19]. This is respected in most of the countries where the nase is present due to its patrimonial and exigent characteristics associated with habitats of high quality. Its presence in a river is a sign of good ecological quality. A review paper was already published by Penaz in 1996 [20], but it is outdated and was mainly focused on reproductive strategy and the cause of the decline of the species. The objective of this paper is to review and summarise the main knowledge of different aspects of the ecology of the nase and the threats to its populations in relation to human activities and climate change, and to propose guidelines for its conservation and a series of key research questions that should stimulate new research on this species.

2. Methodology and Worldwide Publication Trend on Nase

The methodological approaches used to reach the specific objectives of this work were focused exclusively on the published, peer-reviewed documents. These documents were obtained from a bibliographic search performed using three search engines: Google Scholar, the Web of Science, and Scopus. During this search, the following key words, such as "Chondrostoma and nasus" in the abstract title and keywords, were first used: Then more specific research was undertaken, with the items ""ecology", "conservation", "distribution range", "populations/stocks", "biology", "threats", "morphology and identification", "diet", "movement/migration", "habitat", "reproduction and life cycle" AND "1968–2023". In total, 236 publications were found worldwide (Figure 1). Among these 236 papers, many are not related to the ecology of the nase (biochemistry, medicine, immunology, veterinary, pharmacology, chemistry, neuroscience, computer science, energy, chemical engineering). For this review, we used 95 papers that are related to different aspects of nase ecology that we want to address and 1 bibliographic item that is not concerned with the nase but that is useful as a comparison.

If we considered the 206 bibliographic items related to *Chondrostoma* and *nasus*, Austria had the most published papers with 53, followed by the Czech Republic, Germany, France, Poland, Hungary, Serbia, Belgium, Switzerland, and Romania as the 10 countries with the most papers. These 10 countries represent more than 75% of the published papers among a total of 36 countries (Figure 1a). Concerning the 95 bibliographic items with the search selection "ecology", "conservation", "distribution range", "populations/stocks", "biology", "threats", "morphology and identification", "diet", "movement/migration", "habitat", "reproduction and life cycle", the number of countries concerned decreased from 37 to 13. The top five countries are Austria, Germany, Belgium, France, and Switzerland, which represent 76% of the published papers (Figure 1b).

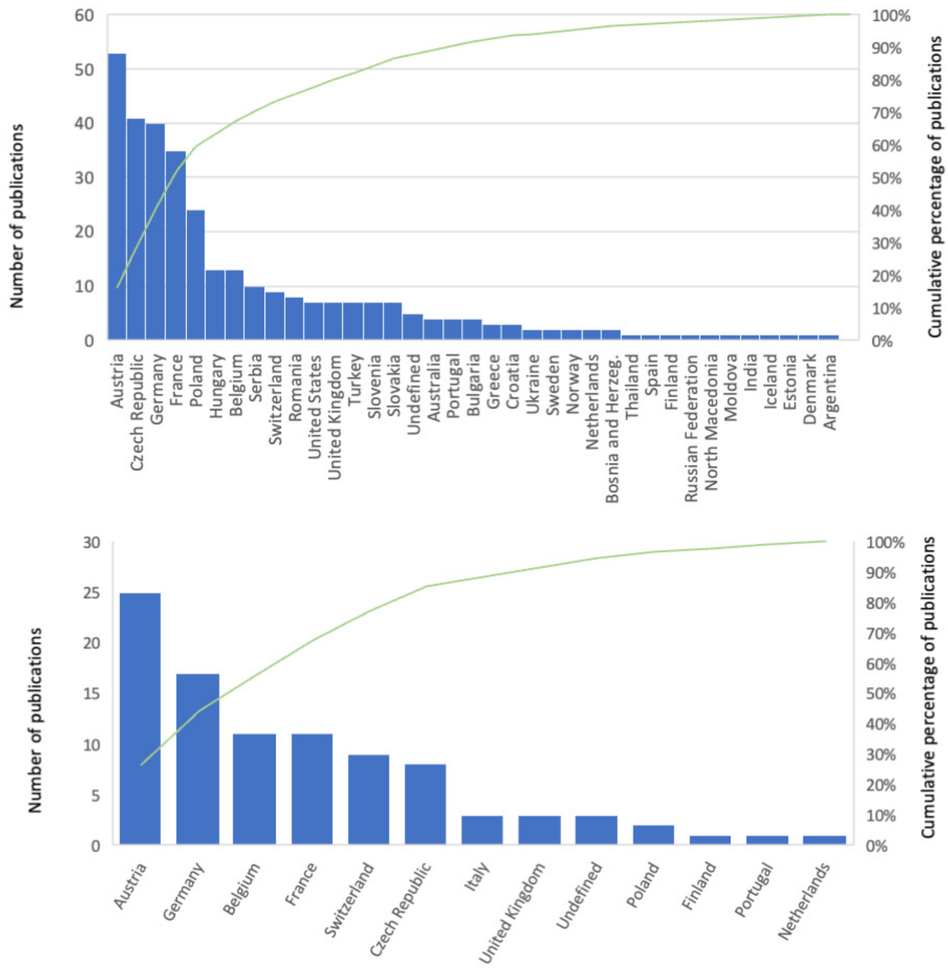

Figure 1. (**a**) Repartition of the published papers according to country with the search items *Chondrostoma* and *nasus* in the title, abstract, and keywords. (**b**) Repartition of the published papers according to country with the additional items "ecology", "conservation", "distribution range", "populations/stocks", "biology", "threats", "morphology and identification", "diet", "movement/migration", "habitat", "reproduction and life cycle". The green line represents the cumulative curve.

3. European Repartition

The geographic range of the nase covers Western Europe, from the Atlantic to the Black Sea. The species is naturally absent from the United Kingdom, Scandinavia, the Iberian Peninsula, most of Italy, and the Southern Balkans [21]. The species is exotic in the Rhône basin in France, where the toxostome *Parachondrostoma toxostoma* is native [6,22]. Introductions of the species were reported in France in 1853 from Central Europe [23] and in Italy in 1991 from restocking of nases carried out in Slovenia [24–27]. Given its ecological requirements, the species does not have the profile to become invasive.

4. Morphology and Identification

The nase is a rheophilic cyprinid fish that can reach about 60 cm [28] and has a maximum lifespan of 25 years [29]. Adult individuals generally measure around 40 cm [28]. The term "Chondrostoma" etymologically comes from the Greek words "Chondros" which means cartilage, and "stoma" which means mouth, in allusion to the prominent snout of this fish. The term "nasus" is a Latin word that designates the nose [28,30]. The nase has a slender, shiny body. The head is small with large eyes and a lower mouth with a transverse slit provided with a thick, horny, sharp lower lip perfectly suited to scraping the bottom substratum Figure 2 [28,30]. The teeth are all similar and oriented in the same direction, and they have thin and very elongated crowns without grooves. They are arranged in a single row (dental formula 6/6) on the pharyngeal bones, including its two branches of almost equal and parallel length, which form a U [31]. The dorsal fin is inserted directly above the pelvic fins and has 3–4 spiny rays as well as 7–9 soft rays. The anal fin has 3 spiny rays and 9–11 soft rays. The pelvic fin has 2 spiny rays and 8–9 soft rays. There are 1 spiny ray and 14–17 soft rays on the pectoral fin. The caudal fin is deeply indented. The species has 52–67 scales on the lateral line and 27–36 gill rakers on the gill arches. The nase has a grey-blue to grey-green back; the sides are silver; and the ventral side is white-yellowish. The pectoral, pelvic, anal, and caudal fins are reddish grey to orange-red. The dorsal fin is grey. During the breeding season, the spawners display brighter colours. Males develop spawning tubercles, and the first ray of the pectoral fin is broad [32]. Spawning tubercles provide protection against mechanical injury and a means of conspecific recognition [33]. Wetjene et al. [7] analysed nine microsatellite markers and mtDNA cytochrome b sequences to assess the distribution of genetic diversity and structure of this species in the Rhine River system. *Chondrostoma nasus* exhibited high gene flow within the Rhine system and, therefore, limited geographical genetic differences between populations where migration is not prevented by human intervention.

Figure 2. Morphological characteristics of the nase. General morphology, spawning tubercles; lower mouth with a transverse slit and prominent snout.

5. Reproduction and Life Cycle

The species generally reproduces at the age of 4–5 years (30 cm) for males and 7–8 years (34 cm) for females [29,34]. Reproduction can take place between late March and late May [4,29,35–39]. Reproduction is preceded by movements that can reach several kilometres towards the spawning grounds where the males gather (see Movement Dynamics of Adults section). The nase is a litophilic species. During the spawning season, shoals of males appear at the spawning area, often before females; they occupy deep pools near the spawning area [40]. Females generally arrive later and take positions upstream and downstream of the males, and during reproduction, they swim rapidly into the shoals of the males [40]. For 3–4 days, the female puts up to 100,000 eggs (synchronous oogenesis) that are 1.7–2.9 mm in diameter on pebbles and stones stuck to the substrate in small fractions [29,41]. The nase does not practice parental care and does not hide its eggs [42]. The eggs of a female are fertilised by several males [43]. Incubation lasts 10–30 days, or 100–250 degree days. Hatched larvae measure approximately 8.2 mm [44]. The greater fertility of the nase compared to other rheophilic cyprinids, chub *Squalius cephalus*, dace

Leuciscus, leuciscus and barbel *Barbus barbus* [39], compensates for very high initial mortality in a variable and unpredictable environment [6].

After emergence, nase larvae can drift downstream (see Movement Dynamics section for more details) [45]. Viable hybrid nase larvae have been reported between congeneric species (nase *C. nasus* × toxostome *C. toxostoma*: [46–48] and even intergeneric species (roach *Rutilus rutilus* × nase *C. nasus*: [49]). The main characteristics of nase life cycle are presented in Figure 3.

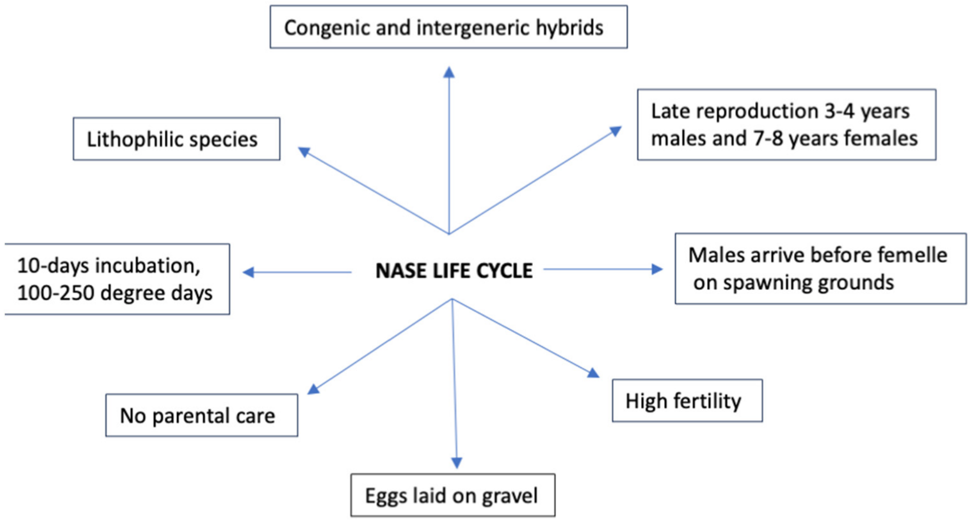

Figure 3. Mean characteristics of the nase life cycle.

6. Diet

The nase has an original oral adaptation. Its diet is very specialised, benthophagous-phytophagous, inherent to a particular adaptation and oral morphology. The species scrapes algae (especially diatoms, chlorophyceae, cyanophyceae, and dinophyceae) on stony bottoms with the lower lip, making frequent rotations on the side. Digestion of algae is facilitated by the length of the digestive tract and the presence of enzymes. Nelva [6] describes the nase diet as consisting mainly of algae (>90% of stomach contents) and very few microorganisms associated with these algae (<10%). This particularity allows the species to play the role of purifier of the river ecosystem by reducing eutrophication. The nase incidentally consumes microorganisms associated with these algae (protozoa, rotifers, nematodes, oligochaetes, aquatic insects), plant debris, and mineral debris mixed with the algae and fish eggs. Predation of nase eggs by barbels and burbots *Lota lota* and piscivorous birds have been reported [3].

Two size-specific diet shifts occur during the young stage of ontogeny. The first one occurs at about 14 mm in total length (TL), when nase switch from rotifers of the genera *Brachionus* and *Keratella* to drifting invertebrates, especially chironomids and terrestrial insects. The second occurs between 40 and 60 mm TL, when the drift-oriented feeding mode is replaced by a benthic-oriented feeding mode in which nase feed exclusively on benthic algae [50]. According to Nelva [6], the young stages of nase feed on small planktonic and nektonic invertebrates. The phytophagous diet begins at 5–7 months [6]. The trophic activity of the nase is essentially diurnal [39]. Sysa et al. [51] analysed the digestive tract during nase larval development using a histological method. Protein digestion and absorption by enterocytes was observed on the sixth day, while lipid digestion and absorption began on the ninth day of larval development. Intestinal mucous cells developed and became active by the fourth day [51].

7. Movement Dynamics of Adult and Young Stages

7.1. Adult

Biotelemetry studies showed the important mobility of the nase. A home range of 12 km has been reported for a nase of 41–52 cm length in a river in Switzerland. In a 58 km-long section of the Austrian Danube, nase had an average home range of 22 km, with some individuals exploiting more than 30–40 km of river. Frequent homing behaviour was observed from a tributary to the main river [52]. A total distance travelled of 15.6 km has been reported over 2 months [4] and 186.7 km in 12 months [53] in Belgian rivers. Other significant movements of the species upstream (>25 km: [54]; up to 140 km: [55]) as well as downstream (up to 440 km: [55]) have also been reported. The home-range size is larger in the warmer season than during the winter [4,56,57].

Spawning migrations are stimulated by decreasing flow when the water temperature increases considerably, ranging from 7.5 to 12.5 °C [4,39]. An optimal stimulus for the spawning migration in nase is a combination of variables. As suggested by Ovidio et al. [58], reliance on combined stimuli is apparently a more efficient strategy than responding to a single cue. Such single cues can occur on several occasions outside the breeding season, potentially reducing the fish's fitness. In the warmest years in a medium-sized upland river in Belgium, nase may be present in spawning areas in late March and in early May in the coldest year, suggesting an adaptation to environmental conditions. Studies using RFID (Radio Frequency Identification) monitoring technology in fish-passes of the bream zone (canalised River Meuse, Belgium) demonstrated that adult nase migrate during the four phases of the diel period (day, night, dusk, dawn), principally from early March to early May [59,60]. Juveniles also realise upstream movement through fish passes, but from late June to early November, with peaks in late June and early July [61]. Even if they use fish-passes, adult nase followed by radiotelemetry did not show any motivation to overcome physical obstacles, even under optimal flow conditions [4]. Although spawning migrations are usually upstream, the presence of physical obstacles may provoke downstream movements to search for spawning areas [4].

Intensive tracking clearly demonstrated that adult nase move in shoals over long distances [4,57,62]. Huber and Kirchhofer [57] suggested that outside the spawning season, nase are non-territorial and aggregate at the most favourable habitats within the river.

Post-spawning activity of tagged nase is characterised by a clear tendency to move several kilometres downstream, frequently exceeding the starting point of the upstream migration [4]. Similar observations were made in the River Aare in Switzerland, where nase dispersed over a greater area after spawning [57]. This behaviour may be associated with a sort of space-use strategy on the part of the species, but it can also simply correspond to the free-flowing movements of weakened individuals after exhausting spawning events. Nase obviously invests a great deal of energy into reproduction and suffers a higher mortality rate afterwards [11].

7.2. Young Stages

Baras and Nindaba [63] studied the seasonal and diel movements of nase larvae through electric fishing. In July, larvae of both species consistently used calm, shallow inshore bays throughout the day. In August and early September, larvae moved into bays at dawn, reached maximum densities at mid-day when the bay was warmest compared to the stream, then moved into neighbouring shallow riffles in the late afternoon. By early autumn, most nase larvae had left the bay but occasionally returned at night. While overwintering, nase occupied shelters in bays all day and showed no diel movements [63].

They also reported that the young of the year occupy shallow bays in summer and move towards deeper habitats rich in macrophytes in autumn to protect themselves against predators, floods, and frost during the winter [63].

Nagel et al. [64] characterised spatio-temporal drift patterns of fish larvae in the heavily regulated large alpine River Inn and within a constructed nature-like fish bypass. They observed that nase larvae realise downstream drift from mid-April to late June, with a peak in late April and early May, and can take place at every period of the diel cycle. Nase drift can occur in the five developmental stages of free embryos: young larvae, intermediate larvae, older larvae, and young juveniles, but was mainly observed in young larvae (>70%) in nase [64]. A synthetic view of the main characteristics of nase movements is presented in Table 1.

Table 1. Mean characteristics of nase movements in riverine ecosystems.

Adult Movements	Young Stage Movements
Home ranges up to tens of Km.	Seasonal active movements of young stages between shallow habitats in summer and deeper habitats in winter.
Frequent high mobility within the home range.	Downstream drift is from mid-April to late June, with a peak in late April and early May.
Spawning migrations are stimulated by decreasing flow and increasing water temperature within 7.5–12 °C.	Drift in every period of the diel cycle.
Spawning migration occurred between late March and early May.	Drift occurs in free embryos, young larvae, intermediate larvae, older larvae, and young juveniles.
Spawning movements usually occur upstream unless obstacles are present that may provoke downstream migration.	Drift has a strong active component.
Migration occurs during the four phases of the diel period (day, night, dusk, and dawn).	Juveniles realise upstream movement through fish passes from late June to early November, with peaks in late June and early July.
Frequent movements in shoals.	
Frequent important post-spawning downstream movements.	

The dispersal of fish larvae in lotic environments (streams, rivers, estuaries, and marine habitats) was often assumed to be a primary consequence of water movement [65]. For nase larvae, dispersal is not solely a passive process but has a strong active component [66–68].

8. Characteristics of Spawning Areas and Habitats of Juvenile and Adult

8.1. Spawning Area

The spawning grounds of nase are located in shallow habitats (15–50 cm water depth) made up of substrate from 2.7 to 10 cm in diameter, generally with no vegetation and fine sediments, and in running water from 0.7 to 1.1 m/s, with a cover structure characterised by overhanging riparian vegetation and broken water surfaces [39,69,70]. Nase larvae require a permeable and well-oxygenated hyporheic zone for successful development [3,71–73]. The importance of spawning ground management in impacted river systems for lithophilic cyprinid species must be considered a priority for managing and enhancing nase populations [71].

8.2. Juvenile Habitats

Juveniles live in tight shoals in open spaces without shade or shelter, which are located on narrow, shallow, and slow-flowing reaches [63]. All class sizes of larvae densities were greater in water velocities of <10 cms^{-1} and in deep water [63]. Large juveniles (>30 mm) were associated with gravel banks with coarse substrate and higher velocities, but they prefer water currents <10 cms^{-1} [73]. Keckeis et al. [74] observed that 0^+ nase selected sites with low water currents, which was the overwhelming controlling factor for the distribution and occurrence of this species, with 70% of the total catch being in the velocity range between 1 and 10 cms^{-1}. *Rutilus rutilus*, *Leuciscus leuciscus*, and *Chondrostoma nasus* used different microhabitats as larvae, but their microhabitats overlapped notably during 0^+ juvenile development. Overlap in microhabitat use by 0^+ juveniles increased notably during a period of reduced discharge, when the amount of available vegetal and ligneous structures decreased, while most species exploited the increased area of shallow waters [75].

8.3. Adult Habitats

Adult nase favour large and medium-sized watercourses (rheophilic species) with gravelly and stony bottom substrates (lithophilic species). They are mainly found in the barbel and grayling zones [39]. Due to their rheophilic character, they tend to rise to the upper shaded area. They are sometimes still present in the bream zone [60,61]. The species is absent in brackish waters (oligostenohaline species). A radio telemetry study showed adult habitat preference for run facies, water velocity from 0.5 to >1 ms^{-1}, cobble and pebble substrate, and depth > 2 m [57]. In the Danube River, another telemetry study showed that nase were located in areas from 1 to 9 m with a mean of 4.2 m [52]. In the Belgian Meuse basin, the optimal habitat with which the maximum biomasses were associated had the following range of ecological values: width 5–55 m, slope 3.2–0.8‰, pH 6.6–7.9, dissolved oxygen 10.2–12.2, N-NH4 < 450 mg/L [29]. The optimal temperature for nase is around 15 °C, and the thermal tolerance threshold extends from 4 °C to 24 °C [26,76]. A synthetic view of the main characteristics of nase habitat preferences is presented in Table 2.

Table 2. Mean characteristics of nase habitat preferences.

Spawning Habitats	Juvenile Habitats	Adult Habitats
Shallow habitats (15–50 cm).	Narrow, shallow, and slow-flowing reaches.	Medium-sized watercourses with gravelly and stony bottom substrates.
2.7–10 cm diameter substrate.	Large juveniles (>30 mm) are associated with gravel banks with coarse substrate and higher velocities.	Barbel zone and grayling zone preferred, but presence in bream zone.
0.7–1.1 m/s water velocities.	Larvae in water have velocities ranging from 0.01 to 0.1 ms^{-1}.	0.5 to >1 m/s water velocities.
Overhanging riparian vegetation.	Overlap of habitats with other cyprinid species.	Deep water (up to 9 m).
Permeable and well-oxygenated hyporheic zones.		Optimal temperature around 15 °C, tolerance 4–24 °C.
		Preference for slope 3.2–0.8‰, pH 6.6–7.9, dissolved oxygen 10.2–12.2, and N-NH4 < 450 mg/L.

9. Impact of Anthropogenic Pressures, Environmental Disruptions, and Restoration Measures

9.1. Water Pollution

This algivorous, rheophilic, lithophilic, and oxyphilic species is very sensitive to pollutants (water quality indicator: [6]). Chemical pollutants and micropollutants cause significant mortality, and its great longevity exposes this fish to PCB and associated contaminants for longer. Exposure of embryos to a strongly reduced oxygen content enhances mortality and depresses hatching success [3]. The species reproduces in cold or fresh water, and therefore thermal pollution (discharge of cooling water from thermal and nuclear power plants; heatwave drought under the effect of warming and climate change) is also detrimental for the nase in terms of the periodicity of premature development of eggs, migration, and/or spawning activity [77].

The nase is also sensitive to eutrophication, which seriously threatens the ecological quality of their habitats. In nutrient-enriched streams and shallow rivers, eutrophication leads to excessive periphyton growth and, in turn, biological clogging, oxygen depletion in the hyporheic zone, and finally a reduction in hyporheic habitat quality [78]. A four-year study in a medium-size eutrophic river demonstrated that the presence of nase and chub mitigates the effect of eutrophication by increasing oxygen availability and the vertical exchange flux of water in the upper layer of the hyporheic zone. The presence of chub and nase also increased the concentration of oxygen in the studied rivers [78]. Nase (and chub) can reduce eutrophication effects in the hyporheic zone of running waters;

their protection will contribute to restoring this zone in efforts to preserve biodiversity in eutrophic rivers [79].

The restoration of the good quality of the aquatic environment by eliminating all forms of organic and inorganic chemical pollution (sewage, industrial discharges, eutrophication) affecting water bodies is essential to preserving their populations due to their high sensitivity to pollution.

9.2. Loss of Habitat and Hydromorphological Perturbations

The nase is very sensitive to physical alterations of their habitat (spawning grounds, nurseries, residences). All types of development and hydraulic exploitation works that affect the flow (disappearance of fast currents and shoals during the channelling of rivers and large rivers), the diversity of microhabitats (adults: deep zones with slow current; young stages: shallow areas with fast current), mortality (entrainment of fish into water intakes), and the availability of stony-gravelly bottom substrate (withdrawal of sand and gravel) are the main factors in the degradation of water used by the species [80]. Rehabilitation works, including habitat diversity and quality, demonstrated a new colonisation of a side channel by the nase [81]. A river restoration programme with riverbed embankment and the creation of a new meander by constructing a side channel and allowing self-developing side erosion showed a strong influence of riverbed dynamics on habitat quality and quantity for the juvenile age classes (0^+, 1^+, 2^+) of nase (*Chondrostoma nasus*) [13]. In the river Danube, restoration measures (Groyneflied adaptations, bank re-naturalisation, and side-arm reconnection) increased the abundance of nase and barbel and provided suitable conditions for young-of-the-year fish. The bank re-naturalisation significantly increased the abundance and ratio of rheophilic fish [14]. In an Alpine River, Pander et al. [82] demonstrated that bank restoration with improvement of the lateral connectivity that results in shallow water zones and areas of lower current speed provides refuge and facilitates the development of species like nase, barbel, and grayling. During habitat restoration in highly modified man-made rivers, experiments demonstrated that life stage requirements of highly specialised target species like nase for their reproduction, juvenile growth, or feeding habitats cannot solely be provided in deep, slow-flowing habitats of the main channel but rather need a combination of different habitat restoration measures that are placed in appropriate local and interconnected arrangements [83].

The nase is very demanding for a qualitative spawning substrate (lithophilic species). Sufficient availability of high-quality spawning grounds (stony-gravelly bottoms) must be ensured in watercourses used by nase. When restoring spawning grounds, long-term morphological development is an important issue. The functionality of a restored spawning area must be maintained for future generations of nase, which might carry out homing migrations to their place of birth [84]. Successful egg development is a key factor in sustaining nase recruitment. The presence of fine particles must be minimised to avoid egg death due to a lack of oxygen. Consequently, the designation of protected zones during the spawning and egg incubation periods would be a useful measure at sites with high water quality and functionally intact streambed conditions [15]. A study in a large outdoor mesocosm facility demonstrated that among the three major stressors (warming, fine sediment, and low flow), fine sediment had the most significant single negative effect on both hatching rates and embryonic development, with 50% in nase; warming and low flow can exacerbate the fine sediment response [85]. The negative effects of fine sediments on hatching rates were also observed by Duerreger et al. [71]. Tests with an incubation system on spawning grounds indicated that a permeable, well-oxygenated stream interstitial at spawning grounds can greatly enhance hatching rates and the successful development of nase [71]. Nagel et al. [64] demonstrated that a loose and porous stream bed can positively contribute to the development success of eggs and larvae and thereby potentially improve the recruitment of nase populations. Emergence is excellent (98%) in the absence of fine sediment and decreases to 55% with the addition of 20% of fine sediment [72]. Free-nase embryos use the shelter of the interstitial zone for early ontogeny, suggesting the importance of the substrate and interstitial conditions for juvenile development [72].

Improving the quality of the spawning area is a possible management objective. Nagel et al. [72] observed that substrate cleaning (the substrate was loosened and cleaned down to a depth of 50 cm by an excavator) resulted in an immediate reduction of 70% of fine sediment; nase spawners preferentially used the restored areas with a significantly greater number of eggs laid. These results clearly indicate that gravel cleaning is a successful short-term restoration tool for nase spawning grounds.

9.3. Disruption of Hydrological Regimes—Hydropeaking

The presence of hydroelectric power stations and the associated utilisation of river flow are detrimental to nase. Hydropeaking during the spawning season may affect the survival of the eggs, which can be taken away [77]. Insufficient minimum flow conditions may also affect the river conditions; high temperatures and high concentrations of $N\text{-}NO_3$ and $P\text{-}PO_4$ promote the growth of luxuriant green algae, which comes at the expense of the diatoms constituting the main food of nase [77]. Zingraff-Hamed et al. [86] demonstrated by habitat modelling that an increase in minimum flow conditions in the Isar River (Germany) increases the habitat quality for all life stages of nase as well as for grayling and adult Salmon *Salmo salar*. This suggests that good management of hydrological regimes may have positively influenced nase and other exigent fish species.

Mesocosm experiments under semi-natural conditions, simulating hydropeaking, revealed that bank dewatering due to artificial flow reduction causes larval nase to strand. The results showed that bank slope is a major determinant for the stranding risk of nase, with more stranding being documented on lower-sloped banks. In general, more fish became stranded during the night than during the day, particularly during earlier life cycle stages [87]. Another hydropeaking study in a mesocosm showed that nase larvae's downstream displacement and stranding rates were higher at the sill and ditch than at the flat gravel bar riverbanks. In addition, the effects of down-ramping were more visible at night than during the day [88]. Studies in an experimental outdoor channel showed that nase drift increased during peak flow in the cold thermopeaking treatment compared to hydropeaking in normal temperature conditions. Higher drift rates were also negatively associated with pronounced water temperature drops during peak flow conditions [89].

These studies underline the necessity of reflexive and restrictive politics of hydropeaking in rivers where nase and other lithophilic species are present, especially before and after their reproduction period. As nase eggs are laid in the substrate, they are particularly sensitive to being carried away by the sudden rise in water level.

9.4. Obstruction of Movements

Nase are affected by various anthropic developments (dams, hydraulic exploitation, navigation) that degrade or cause their habitats to disappear (spawning grounds, nurseries, residences) through the modification of flow, a drop in the water level [77], and the deposition of fine sediments on the stony bed (clogging) in aquatic environments [6,42].

Spawner individuals show great mobility during the breeding season. The free movement of the species must be ensured in watercourses to allow spawners to access their spawning grounds in time [4]. A lack of access to spawning grounds due to the presence of impassable obstacles erected on watercourses is an important factor in the extinction, decline, and/or change in the abundances of species [90–92]. According to Le Pichon et al. [93], management policies for rheophilic cyprinids like barbel and nase should focus on the restoration of environmental conditions for local populations that provide feeding, resting, and spawning habitats, separated by distances consistent with the dispersal capacities of the fish.

A focus should also be placed on the restoration of free movements using, for example, different fish pass models [52,83]. When such devices are installed and monitored, nases have demonstrated their ability to use them.

In the River Meuse, Belgium, among adults and juveniles of over 35 different fish species, nases were frequently captured in a cage of a vertical slot fish pass, or their passages were detected by RFID-Technology [60,61]. In the Danube, the construction of a nature-like by-pass allowed the capture of 17,000 individual fish of 43 species over three years, including nase, which was highly represented and successfully undertook movements to spawn [94]. In the river Drau (Carinthia), Zitek et al. [95] showed that passage efficiency was good for nase in a vertical slot fish pass, but attraction efficiency must be improved as it is not well positioned in relation to turbines. In the Danube River, the upstream migration of European nase fish species through fish bypass channels has been studied daily with fish counting pools over three years. Many nases entered the fish-bypass channel to spawn and exited instantly after spawning downstream [96]. These studies also demonstrated that when longitudinal connectivity is restored with fish-passes, the nase take advantage of them to pass through and exploit new available habitats.

A preliminary test using radiotelemetry with nase translocated in a fragmented river stretch where the species is historically absent demonstrated reproductive success in the newly exploited habitat by the translocated individuals. Genetic parental assignment demonstrated that recaptured juveniles correspond to the progeny of translocated adults [53]. This suggests that in highly fragmented rivers, with no fish-pass installation, translocation of individuals may be a way to enhance populations if the quality of the habitat in the newly occupied zone is sufficient for reproduction and development [53].

9.5. Mean Threats, Guidelines for Conservation, and Key Research Questions for the Future

Based on our knowledge of the species, a synthesis of the main threats to nase populations is presented in Table 3, and we propose guidelines for its conservation in Table 4. These guidelines summarise management actions applicable to ecosystems, which act directly on the improvement of altered physical habitat as well as the improvement of declining populations.

Table 3. A synthesis of the main threats to nase populations. Threats under climate perturbations (thermal pollution, flow shifts: floods, droughts, and lack of oxygen) and human activities (habitat alterations, obstacles to movements, eutrophisation, hydropeaking, and chemical pollution).

Mean Threats to Nase Populations	
Thermal Pollution	Lack of oxygen
Channelling	Eutrophication
River flow perturbations	Chemical pollutants and micropollutants
Hydropeaking during the spawning season	Poor diversity in microhabitats
Insufficient minimum flow conditions	Sedimentation and the presence of fin particles
Obstacles to upstream movement	Poor availability of spawning substrate
Obstacles to downstream movement	Poor availability of stony-gravelly bottom substrate

Table 4. Main guidelines for nase conservation based on current knowledge.

Guidelines for Nase Conservation
Restore the good quality of the aquatic environment by eliminating all forms of inorganic and organic chemical pollution.
Ensure sufficient availability and quality of habitats for reproduction, nurseries, and residence.
Guarantee the availability and stability of spawning substrates, at least for the duration of incubation.
Prohibit all types of hydraulic exploitation works that lead to significant variations in flow, water level, temperature, and turbidity and that degrade spawning grounds (stony bottoms), nurseries, and residences.
Determining a suitable catch size for recreational fishing.

Table 4. *Cont.*

Guidelines for Nase Conservation
Avoid the reduction in large areas of potential habitat by canalization of watercourses (incompatible with the microhabitats of juveniles), dredging and cleaning (destruction of gravelly and stony beds essential for reproduction), catchment water leading to a permanent reduction in water height, water intakes from hydroelectric power stations causing a sudden variation in flow (hydropeaking), and direct discharge for cooling water.
Guarantee free movement throughout the life cycle (river annexes, tributaries) by equipping with effective fish-passes (or other devices) to ensure the rise of nase and the continued recolonization of upstream sectors.
Limit development work (cleaning, reprofiling, channelling, and backfilling of banks) as much as possible.
Choose suitable times of the year (outside the breeding season) to carry out certain essential work.
Develop new spawning grounds and nurseries in the most altered waterways according to ecological principles.
When the construction of a fish-pass is not possible, carry out intra- and inter-river translocations of non-introgressed wild spawners to initiate or support the reconstitution of stable self-reproducing populations.
Restore and protect all potential spawning grounds and nurseries habitats.

The species is globally well-known, but additional research may be needed to reduce the gaps in different aspects of its ecology and the impact of anthropogenic pressures and climate change on its populations. We propose in Table 5 key research questions for the future.

Table 5. Key research questions for future research on nase.

Subject Area	**Research Questions**
European repartition	– Clarify and update the European repartition. – Compare the distribution with that of the toxostome.
Morphology and identification	– Highlight the possibilities of hybridization with congeneric and intergeneric species. – Describe the hybrids morphologically to improve their recognition.
Reproduction and life cycle	– Evaluate the possibilities and success of reproduction in alternative habitats in anthropized watercourses.
Diet	– Understand diet adaptation (food items) of this very specialised benthophagous-phytophagous species in response to habitat and climate disruption conditions.
Movement dynamics in adult and young stages	– Analyse the movement of adult and young stage in a larger diversity of typology of rivers. – Initiate studies on the movements of the sub-adult stage.
Characteristics of the spawning area and habitats of juveniles and adults	– Analyse the habitat preference in a larger diversity of typology of rivers during the four periods of the 24 h cycle (dawn, day, disk, night) using telemetry.
Impact of anthropogenic pressures and restoration measures	– Evaluate the capacity of the species to clear physical obstacles and to use different typology of fishways. – Analyse the effect of river restoration (water quality, hydro-morphology, and longitudinal connectivity) on nase population. – Determine the ecological flows adapted for the realisation of the entire life cycle (reproduction, activity, and resting).

10. Conclusions and Perspectives

This literature review on nase is the only one proposed since the paper published by Penaz in 1996 [20]. It highlights that there is an urgent need to protect nase populations in their entire natural distribution area to avoid additional declines or even their extinction in some countries where the species is already endangered. This need is further exaggerated by the current negative influence of human activities and global warming/climate change on the quality of living environments at each ontogenetic developmental stage of the species and their population structure. The presence of this patrimonial species in a river is a sign of good biodiversity and the quality of habitats with water of good physico-chemical quality. The present paper may help to set up protective measures for the nase that will also produce positive effects on the sustainability of this species as well as that of other patrimonial species such as grayling, barbel, dace, and trout *Salmo trutta* and to slow down the decline of their populations, and try to reverse this situation. Some of the protective measures presented in this paper have already demonstrated their positive impacts on the nase population.

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