

Introduction: About this book

Coverage

Geographical coverage. There is no agreed definition of the geographical area called West Asia, which includes or excludes the countries of the southern Caucasus, Iran, Israel, Türkiye, Egypt, and a few others. For this book, we follow a partly biogeographical and partly practical approach. West Asia, as covered in this book, includes all of Anatolia (the Asian part of Türkiye), Cyprus, the countries of the Caucasus south of its main rim (Armenia, Azerbaijan, Georgia, parts of Russia), Iran, Iraq, Syria, and the nations of the Levant (Lebanon, Israel, Jordan, Palestine), the Arabian Peninsula (Bahrain, Kuwait, Oman, Qatar, Saudi Arabia, United Arab Emirates, Yemen), including the coastal islands and the Socotra archipelago. In the Caucasus, the Greater Caucasus is considered to be the boundary that begins (approximately) at the Black Sea in the west, near the Russian city of Novorossiysk. Then, it runs along the entire Caucasus divide to Baku (Azerbaijan) on the Caspian Sea. The upper reaches of the Terek in Georgia are

excluded as they are part of Europe, as are Türkiye north of the Bosphorus and Azerbaijan north of Baku. In the Aegean, the boundary follows the political border between Greece and Türkiye. However, islands such as Lesbos and Rhodes were part of the Anatolian mainland during the last Ice Age. The entire territory of Iran is covered in this book, including the Sistan and Mashkid basins and the lower parts of the Helmand and Hari rivers. The middle and upper parts of these rivers in Pakistan, Turkmenistan, and Afghanistan are excluded. Strictly speaking, the Helmand (and others in the Sistan basin) and Hari are Central Asian rivers.

Toponymy (names of places, regions, rivers, etc.) follows the spelling in local languages or transcriptions as used in local maps. For features that extend across areas where different languages are spoken, the English name of the feature (if any) is used. Many of these names have several different spellings when transcribed from Arabic, Farsi, or other languages. We have tried to find a corrected and widely accepted transcription, but this has yet to be largely successful, as the names are strictly different in different languages and would always be translated differently. We use English instead of local names for



Figure 1. This book covers all freshwater fishes of West Asia known by early 2025 within the boundaries shown here.

countries, regions, large islands, major cities, and other well-known places.

Species coverage. All native freshwater fish species recorded in West Asia are included in the following accounts, including primary, secondary, diadromous, and sporadic species (see below for definitions). Accidental and vagrant species are excluded because many coastal species are occasionally found above the brackish water line. For the above purposes, records of occurrence have only been accepted if they are associated with reliable locality data and identification. No clear boundary exists between freshwater and marine/brackish water species. Particularly in the Persian Gulf basin, many marine fishes occur surprisingly high up in brackish rivers. Some species included in this book (such as some *Alosa*, *Chelon*, *Platichthys*, *Ponticola*, *Mesogobius*, and others) may only occur locally or rarely in freshwater. The reader of this

book should be aware that most fish caught in brackish or coastal waters may not be covered. We often mention (some) species known from brackish waters in the family chapters and may include them in identification keys. Non-native species are only included if they have established self-sustaining populations or are stocked so regularly that there is a realistic chance of finding them. Species such as *Atractosteus spatula*, *Pangasianodon hypophthalmus*, and several others have been released from aquaria and aquaculture. These non-native species have occasionally been recorded and included in regional or national lists, although their establishment has yet to be proven. Such species are excluded from the scope of this book. If the reader discovers a non-native fish not covered in this book, it is always worth consulting the aquarium literature. The order of the families follows Near & Thacker (2024).



Osteomugil speigleri; Oman, about 100 mm SL, an accidental species common in coastal waters in the Indo-West Pacific.

Freshwater fish

Ecologists classify freshwater fishes according to their tolerance to salt water.

Primary divisions are families whose members are strictly intolerant of salt water, both in the present and in their evolutionary past. Examples include all Cypriniform fishes, of which only some species may have become tolerant to elevated salinities but not salinities as high as in the sea.

Secondary division families are considered to be of marine origin but whose members are now found mainly, wholly or partly in freshwater environments. Some of the freshwater species are able, or their ancestors are thought to have once been able, to tolerate seawater, at least for short periods; others are euryhaline, e.g., able to live in fresh or salt water. Examples of secondary division families are the Cichlidae and the Aphaniidae. In addition to the above categories, which apply to whole families, many individual fish species occur in freshwater, although they belong predominantly to marine families. They are referred to as follows:

Diadromous species are those that migrate between freshwater and seawater at different stages of their lives, either to spawn in the sea (catadromous, such as the eel *Anguilla anguilla*) or in freshwater (anadromous, such as the shad *Alosa agone*). Individuals of both groups can be relatively flexible in their migratory patterns, with catadromous species often remaining in the sea. In contrast, anadromous species might complete their life cycle in freshwater, frequently becoming land-locked in lakes or reservoirs. Anadromous fishes all belong to freshwater families.

Sporadic species are those that usually occur in estuaries and appear to be indifferent to salinity (e.g., they are euryhaline). Examples include several species of the Mugilidae.

Accidental or vagrant species are marine fish occasionally caught in inland waters. Their occurrence is unpredictable, and there are usually only a few records of the species in freshwater, often just above the tidal zone or in remnant pools close to the coast.

How to use this book

Keys. Keys are provided for the identification of freshwater fish genera found in West Asia. Species-level keys are provided for genera with more than two species, based on characters that non-specialists can easily observe without dissection or sophisticated techniques; however, a hand lens or dissecting microscope may be required. No molecular methods are needed to use the keys. An identification key consists of a series of questions that enable the user to establish the identity of an individual fish and is made up of a series of couplets (numbered 1, 2, 3, etc.). Each pair contains two alternative descriptions (numbered 1a and 1b, 2a and 2b, etc.). Each description includes one or

more statements so that the two descriptions of the couplet always present alternative states of the same sign(s). To use a key, start with couplet 1. First, read sentence 1a and then 1b. If a sentence describes more than one character, read them all. Now, decide which phrase describes your fish. Each sentence concludes with a clue such as “go to 2” or “genus/species X.” If the sentence describing the fish you want to identify ends with “go to 2,” you should now read couplet 2 (both sentences again) and repeat the process until you have a correct name for your fish. In genus-level keys, if there is an exceptional species with respect to the character defined in a couplet, this species is indicated in parentheses in the sentence leading to the genus.

Characters, character states, and traits

A **character** is any morphological, colour (including pattern), ethological, molecular, or other characteristic that can diagnose a taxon (species, genus, family).

A **character state** is one of several alternative states that a given character may have. Character states are fixed for each species and, therefore, present in all individuals. For example, “interorbital pores present” is a character state of the character “presence or absence of interorbital pores” or “five” is a character state of the character “number of bars on flank.”

A **trait** is a genetically determined manifestation of a character (or other physical feature) that is not fixed in a species or population, e.g., one that cannot be described in terms of discrete alternative states (character “states” and therefore cannot be used directly to diagnose a taxon). Traits vary along a continuum so that different individuals of a given species or population may exhibit different traits of the same character. However, different traits of the same character may occur in varying combinations in different species or populations. For example, the presence, absence, width, shape, etc., of a vertical bar at the base of the tail may all be characteristics of the character “mark at the base of the tail.” In such a case, various combinations of the attributes of a given character may constitute different states of that character. For example, in species A, the bar may be absent, broad, or vertical in different individuals, whereas in species B, it may always be present, but either as a wide bar or as an oval spot.

Example. Let us take the following imaginary key:

1a - Two dorsal fins.

..... 2

1b - One dorsal fin.

..... 4

2a - Second dorsal fin with 7–8 rays.

..... Species Ab

2b - Second dorsal fin with 18–25 rays.

..... 3

First, read couplet 1 (both sentences 1a and 1b). Look at your fish. How many dorsal fins does it have, 1 or 2? If it has one dorsal fin, go to couplet 4. If it has two dorsal fins, go to couplet 2. Now read the two sentences in couplet 2. The second dorsal fin has a number of rays. Count them. If your fish has, for example, 20 rays in the second dorsal fin, go to couplet 3. If, for example, your fish has eight rays

in the second dorsal fin, the key indicates that it belongs to species Ab. When running a key, a given species may fulfil the conditions of both sets of a couplet, or it may appear twice in the key. Suppose you come up with the following couplet:

6a - Caudal peduncle depth 20–26 % HL (head length).

..... 7

6b - Caudal peduncle depth 25–44 % HL (head length).

..... 10

Imagine that the material in front of you has a caudal peduncle depth of 21–28 % HL. On closer analysis, it may turn out that very few individuals have a caudal peduncle depth less than 25 % HL; if so, go to pair 10. However, if individuals with a caudal peduncle depth less than 25 % HL are common or represent most of the population, then both couplets 7 and 10 should be tested.

The key does not work! Why not? There are times when a key does not work. For example, it may lead you to a species completely different from the one you are trying to identify (of course, you started by looking at the picture), or it may ask questions that do not apply to your fish (e.g., the number of scales, when your fish has no scales). There are several possible explanations for this:

1. You may have an aberrant (malformed or deformed) individual; some characters may have been lost due to damage or injury; or your fish may be a senescent individual with an abnormal shape or a juvenile that has not yet developed the diagnostic characters. Try to check these characters on another individual.
2. You may be trying to identify a species not described in this book. The fish fauna of West Asia is still being catalogued; indeed, there are species unknown to the authors at the time of writing. Alternatively, your species may be a marine species found accidentally in freshwater, an introduced species, or a species that has escaped from an aquaculture facility or aquarium. In such situations, try to consult a specialist.
3. The key may be incorrect. If this is the case, please accept our apologies. For some species, we have only been able to examine a small number of individuals, or we have taken characters from published species descriptions. The key and diagnosis may not reflect the full variability of character states in a species for various reasons. In this case, we encourage the reader to publish the information and/or suggest a better key to improve our knowledge for future generations of ichthyologists.

A word of caution. Today, fish are usually sequenced for their mitochondrial DNA first and then compared with the sequence of other species. If both are different, morphological characters are examined to see if the molecular groups can also be distinguished externally. This morphological description is sometimes based on a very limited number of individuals and populations, usually because there were simply no more fish available to study. While almost all authors do their best to study enough individuals, there are some “black sheep” in fish taxonomy. Because it is easier to find morphological differences when only a few individuals, ideally from a single population, are examined, some authors intentionally limit their material, often ignoring published data. As species based solely on mtDNA distances are poorly defined and often not accepted by the scientific community, careless handling of morphological data discredits the science of taxonomy and should be avoided.

For example, a new species was described based on seven individuals from one locality. The original description

distinguished it from just five individuals of another species that is widespread in the same area. A large previous study published morphological data from 65 individuals from this species. The new species (7 individuals) differs from the known species (5 individuals) in having a shorter head (20–24 % vs. 24–30 % SL; in the 65 individuals: 21–27 % SL), a shorter pectoral fin (10–15 % vs. 16–19 % SL; in the 65 individuals: 15–21 % SL), and 25–29 circumpeduncular scales (vs. 23–24; in the 65 individuals: 23–28, usually 24 or 26). The length of the pectoral fin seems to distinguish the two species, but the other characters do not when a more extensive series is examined.

This example shows why a key may not work. We often need to learn more about the variability of morphological characters in many species, and some character states published may no longer distinguish species when they are better studied.

Species description. The following headings explain the nature of the information provided in each species account.

Species names. According to the International Code of Zoological Nomenclature, all names used for the listed species are valid scientific names. A few species, such as some *Atherina*, *Oxynoemacheilus*, *Paraphanius*, *Ponticola*, and others, still need to have scientific names. This is because they have only recently been discovered by science, and the formal process of describing the species and assigning a valid name is time-consuming and requires the resolution of very complex nomenclatural and systematic issues. Common names also present a variety of problems. Many species do not have a species-specific common name (by which we mean a real one, in local lay use, not one coined by scientists, especially for a technical glossary). They are only referred to by a collective name, such as the different species of *Garra*. Of course, names mentioned in the scientific literature or official documents may be completely unknown to the general public. We have tried to give a single common name for each species. Where an English language name is commonly used, we have listed this as the vernacular name. As specific names based on local languages are rarely available, introducing English names as preferred vernacular names is beneficial. We have, therefore, tried to assign such names to all species based on their character states or geographic range. We have usually used names suggested by previous authors, but we have not hesitated to create new names where we felt that the earlier names could have been more satisfactory. We have never used personal names as part of a common name (e.g., *Garra gallagheri* is the Black garra, not Gallagher’s garra).

Diagnosis. A diagnosis is a summary of characters applied to identify and distinguish a species from other similar species. There are usually many more characters that

distinguish species than those listed in our diagnoses, but we focus on those that are the easiest or most reliable to use. In some cases, a single character may be sufficient to identify a species, but a combination of characters is required in many cases. If a fish exhibits some of the character states listed in a diagnosis but not others, it should be concluded that the individual does not belong to the diagnosed species. Very often, it is possible to identify species at a glance based on general appearance, but general appearance is often very difficult to describe in words. Increasingly, the artificial intelligence of citizen science platforms, largely based on general appearance, is making it easier to identify fish from images. Each diagnosis starts with an explicit statement that the species in question is distinguished from another species or a group of other species (the **reference group**) by the characters to be described. The size of the reference group varies according to the context, as does the usefulness of the characters and character states.

For example, suppose the reference group is “all species of the genus known from the Aegean basin.” In that case, this means that the diagnosis can be used to reliably identify a fish from within the Aegean basin (e.g., the Anatolian Aegean basin) but not from outside the area covered by this book. Some additional species may occur outside Türkiye and/or outside the Aegean basin, and these may share the same character states but may be distinguished by additional characters not listed here. However, whenever possible, without including too many technical details and without writing long and cumbersome diagnoses, the reference group has been extended as far as possible. In the diagnoses, the different characters and character states are separated by slashes (/) and each character is preceded by a symbol indicating the “efficiency” of the character in identifying a species within the reference group. **The symbol “●” means that this character state is not observed in any other member of the reference group and that its presence alone allows identification of the species; whereas “○” means that this character state is shared with some (not all) species of the reference group, but its presence alone does not allow identification of an individual fish.** Therefore, it is the combination of all the characters given that distinguishes the species.

A word of caution. Where there is doubt as to whether a particular character state is unique to the diagnosed species, we have listed the character as “○” rather than “●.” For example, we have generally not included fin ray counts, scale counts, and morphometric characters as “●” unless they are clearly distinctive because they are often close to or overlap with those of other species. Ambiguities are possible due to slightly different approaches to counting and measuring. Sizes are usually given as standard length (SL)

(see Morphological features) and correspond to the largest size recorded based on literature or personal observation. However, this information must be treated with caution, as the true maximum size of some large or rare species may be considerably larger than that reported in the literature. Some sizes are given as total length (TL). Bilaterally symmetrical structures are written in the singular (e.g., “the eye is large,” not “the eyes are large”) unless syntax or common sense requires the plural. In keys and diagnosis, male and female are used in the singular.

Distribution. First, an overview of the native and non-native distribution in West Asia is given, followed by a summary of the global distribution. Including an area or country in the distribution is for general information only and does not imply that a species is evenly distributed within that area. Of course, the distribution of many species still needs to be better understood.

Habitat. The habitat types given are those in which the species has been found. This does not mean a given species could not colonise other habitats if they become available. Also, habitats can change significantly over a year, as floods and droughts can change the water table. For this reason, habitat descriptions are usually brief and general. West Asia is made up of a wide variety of freshwater ecosystems. These include waters in warm, wet, and humid forests, such as along the northern Black Sea and southern Caspian coasts; wadis in full deserts, typical of the Arabian Peninsula; high mountain lakes, such as in the Caucasus; and places remarkably below sea level, such as in the Dead Sea basin. Most areas are strongly influenced by seasonal rainfall patterns, with little or no rain in summer and more rain in winter. As a result, many areas in Anatolia and the Levant are classified as having a Mediterranean flow regime, with streams flowing from autumn to early summer, often with high flash floods in winter. In summer, surface water frequently stops flowing, leaving only pools of stagnant water. However, this type of flow regime is extreme in the arid areas of the Arabian Peninsula, where streams receive only infrequent rainfall, usually in winter, often associated with very high floods. During the dry season, groundwater continues to flow below the surface in the alluvial gravel that fills the channels and locally emerges as springs. In the arid and semi-arid landscapes of Arabia, Mesopotamia, Central Anatolia, and the Levant, streams are often spring-fed, and permanent water may be seasonally limited to the springs.

Biology. For most freshwater fish species in West Asia, even the most basic biological data still need to be included. Adequate biological information is generally available for species outside West Asia, particularly in Europe. Much of the available biological data are derived from observations outside West Asia, so it may only partially represent the

region's fishes. Our descriptions of the biology of individual species usually begin with reproductive biology, including data on age at first spawn, frequency of females spawning in each season, and longevity, in addition to basic data on the spawning season, timing, and behaviour. In freshwater species, water temperature and day length often trigger spawning. The biology section usually ends with the type of food consumed. Even where data are available, it is impossible to give quantitative or detailed qualitative data on the food consumed. More data are needed for most species to correlate the type of food consumed with the prey available, and most species appear to prey indifferently on invertebrates of appropriate size. However, there is a strong correlation between (i) observed and available prey (common prey is usually consumed), (ii) prey size and the size of the fish (fish usually prefer large prey), and (iii) the prey chosen and the differences in predation risk that foraging fish select when searching for different types of prey (fish prefer to feed in safe places).

Conservation status. The global IUCN Red List status is given, followed by a brief description of the main threats to the species, if any, and related comments. The status of species endemic to West Asia is based on the results of the IUCN 2024 Assessment of the Status and Distribution of Freshwater Biodiversity in the region. Details of the categories and criteria and the assessment methodology are available in the IUCN Red List of Threatened Species database (<http://www.iucnredlist.org>). It is also important to note that the IUCN Red List is a tool for assessing extinction risk rather than determining conservation needs or prioritising conservation actions. During an assessment, the Red List category assigned to a species is not unchallengeable and may change over the years. Status is influenced by the recognition of new or previously unknown threats or opportunities that have been identified and are causing a visible decline or increase in the number of individuals of a species or are likely to cause a future decline or increase. Therefore, the conservation statuses given in this book may need to be updated in the coming years.

Remarks. Other information that is of potential interest, including open questions and research needs.

Further reading. References are given to provide published sources where more detailed accounts of a species can be found, and notes indicating what information is emphasised in each source where appropriate. The reader will find the full reference list in the bibliography section at the end of the book. Readers should be aware, however, that for many species, much of the information presented is based on field experience and laboratory research by the authors, some of which are presented here for the first time. The species bibliographies still need to be completed. The sources listed

are the most relevant, contain important information, or provide references to additional publications or critical compilations, etc. In some cases, there may be only a single reference, which may only sometimes be fully authoritative.

Figures. Each species is illustrated with a figure in the left lateral view, as is standard in fish taxonomy. Only sometimes, the left side was unsuitable, then the image was rotated, and the right side of the body was shown. Species known to be highly variable are often illustrated with several figures. The origin and size of the individuals depicted are given where known. **Identification should be made only based on the characters presented in the diagnoses and not by comparing an individual with the pictures.** The general appearance of fish may vary seasonally (spawning, feeding), or by size and age, or environmental parameters (e.g., pattern and colour are more contrasting in individuals living in clear water than in turbid water). There is also variation between individuals and between sexes. The light conditions during photography and the condition of the individual fish (alive or dead, fresh or preserved, in or out of water, etc.) significantly influence appearance. It is impossible to illustrate every species under all these conditions, so we have chosen figures that will best facilitate the diagnosis of the species. While freshly preserved specimens are the best for comparison purposes, the colours of some fish fade or change as soon as they die, sometimes as soon as they are out of the water or under stress. We have tried not to make this a “book of dead fish” but to show living individuals whenever possible. However, there are a few species for which no live photographs are available, usually because the species is extinct.

Maps. Each species chapter consists of a distribution map with dots and hydrobasin layers as well as the species' latest IUCN categories. The dots indicate site-scale records for a species, e.g., where the species has been found at least once. This does not mean the species is still found there, especially as many records are decades old. In other cases, the species may have been found elsewhere, but the record(s) have yet to be published or sourced by the authors. Accurate mapping of freshwater fish species is challenging but essential for future conservation planning and research. The maps presented in this book are based on publicly available data downloaded from GBIF (www.gbif.org), additional published records, museum records, authors' field records and the individuals whom they have examined, as well as information provided by colleagues. The background of the points is layers of hydrobasins. These show the distribution of the species according to the published knowledge and experience of the authors and experts consulted. For some species, there are few or many hydrobasins without

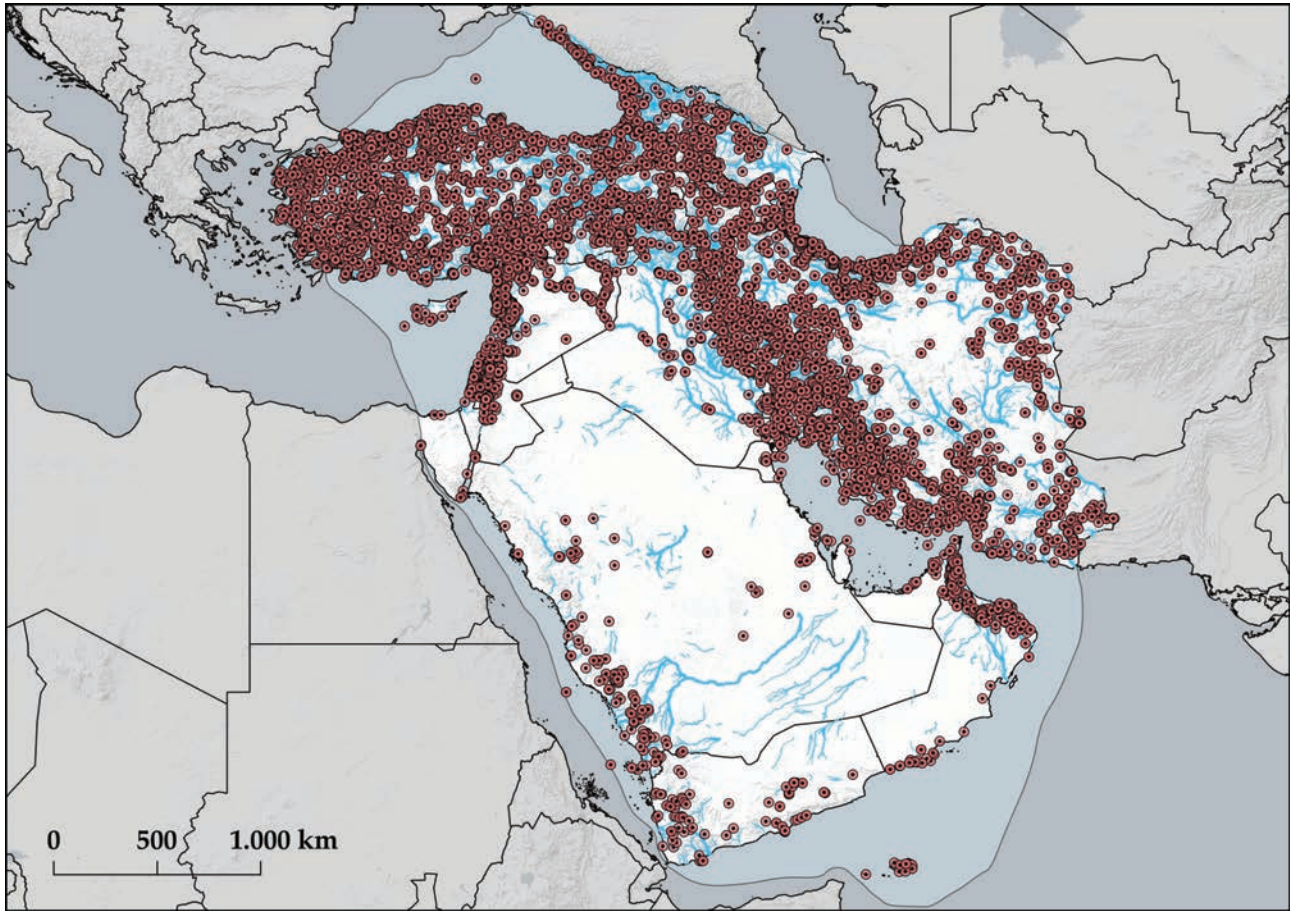


Figure 2. Precisely 26,003 site-scale records of freshwater fishes were used to map the species for this book. This map also shows areas without permanent waters and areas with very little research efforts (e.g., lower and middle Euphrates).

site-scale records, which simply shows how poorly the distribution of these species is documented.

On the other hand, hydrobasins without site-scale records also indicate that the species may have a much smaller range than previously thought. For example, several species known to be widespread in the northern Black Sea basin rivers were also considered widespread in the southern Black Sea basin (e.g., *Abramis brama*, *Leuciscus aspius*, *Rutilus lacustris*). However, many empty hydrobasins have been investigated, and these species have a very limited distribution in the southern Black Sea basin. All maps have been checked by the authors and regional experts.

The maps are produced using QGIS 3.28.15-Firenze version software. The distribution of each species was mapped to river and lake sub-basins as defined by the HydroBASINS framework, which consists of a series of vector-based polygon layers delimiting sub-basin boundaries at a global scale. HydroBASINS provides these delineations at 12 different levels of resolution and incorporates key

details of hydrological connectivity. While IUCN Red List assessments typically map species distributions at HydroBASINS level 08, our methodology used a more detailed approach by using HydroBASINS up to level 12, which represents finer sub-basins, to achieve greater spatial precision in species distribution mapping. This increased resolution was applied in two scenarios: (1) when highly detailed spatial data were available and (2) for narrowly distributed endemic species, allowing for a more accurate representation of their geographic ranges. The maps show the distribution of all species native to West Asia, distinguishing the current native range (green), areas where they have been non-native (purple), and areas where they are extirpated (red). For species that also occur outside West Asia, only the West Asian range is shown. A simplified approach we have taken to mapping such species is illustrated in Figure 3.

Literature cited. The bibliography section lists only published references mentioned in the text.

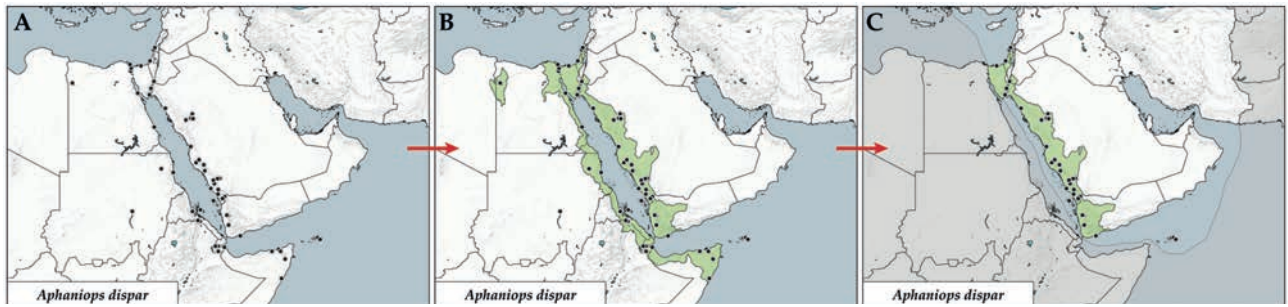


Figure 3. Illustration of the range mapping approach for species with a global range extending beyond West Asia. **a**, Global occurrence records are displayed as black dots; **b**, the Global range of the species, highlighted in green; **c**, the range of the species in West Asia, focusing only on the book coverage for consistency.



Visiting fish markets like this one in Hor Sosangerd (near the Hor Alazim wetland), Iran, enables contact with friendly, local experts. It is a long tradition in ichthyology and remains a good source of information and difficult-to-catch fish.

Fieldwork and data collection

Catching fish is challenging, but organising fieldwork to produce useful results is even more so. Catching fish is only part of the job; taking photographs of fish and habitats, collecting samples for DNA analysis, and collecting voucher material are also important. Finally, critical fieldwork components include documenting ecological and habitat conditions, collecting GPS data, and making all data available to the public. Catching fish depends largely on the choice of fishing gear designed for the specific habitat conditions. Different habitats require different gear, and different fish species and size groups may require different techniques and equipment. Planning fieldwork also involves applying for permits, assembling comprehensive sampling and

recording equipment for the activities to be undertaken, and assembling adequate staff to carry out the proposed work within the time allotted. It is beyond the scope of this book to provide detailed instructions on observing and collecting freshwater fish in the field. Several comprehensive manuals guide how to catch fish in specific environments and how to fix and preserve specimens for various purposes. These topics are only briefly discussed here.

Electrofishing is the least invasive method as the fish are not harmed, and those not required for further study can be released. However, electrofishing is relatively labor-intensive, special permits may be necessary, and the equipment is expensive and physically heavy. In many situations, nets or traps may sufficiently effectively catch the target fish.



Electrofishing is a method for catching fish in small- to medium-sized waters. It is animal-friendly and hurts fish much less than any other method.



Small aquarium to photograph fishes in the field. Note the black background used in the field.

Photographing fishes. Photography is an essential part of any ichthyological survey. The aim should be to photograph several representative individuals of each species from each collection site. The optimal way to photograph fish is in the field using a field aquarium as soon as possible after collection. In this way, the fish are in good physical condition, and their natural colours can still be seen. Live and preserved fish can be photographed similarly, with the hand positioned underwater in the field aquarium and photographed by another person. Photographing fish on the bottom, in the grass, or on a person's hand will always result in poor-quality images. Highly specialised professional equipment is

available for photographing fishes in the field, including special aquariums in which the fish can be fixed in any position under standard lighting conditions. Such equipment is ideal for large expedition teams with ample time and storage space. Underwater photographs, while aesthetically pleasing, often need to show fish in full detail, especially in locations where the water is murky or where fish are shy and not easily approached. **Further reading.** Garcia-Melo et al. 2019 (photographing fish).

Photographing live fish may be more time-consuming than photographing preserved fish. Still, images of live fish are more attractive, and you will find a wider range of uses for the photos than simply associating them with the voucher specimens. For photographic purposes, it is preferable to choose fully grown individuals with complete scale coverage and complete, undamaged fins. It is also interesting to photograph juveniles or individuals of different sexes. The usual procedure is as follows:

Add the reference number to the picture, e.g., on the bottom of the glass, to identify it from the image later.

- Place the live fish in the prepared field aquarium. An anaesthetised fish may be easier to handle. Fish can be anaesthetised with MS222, clove oil, or chlorobutanol. Avoid photographing dead fish. Even if the fish is freshly dead, the eye will fade, which can be spotted by experienced observers. Photograph the left side of the fish if it is undamaged.
- An operator immobilises the fish by gently pressing it against the front glass of the aquarium. Do not press too hard; the fish usually gives up trying to escape after a few seconds. Ensure the fins are in a natural position and you



Salmo brunoii photographed alive in the field. Note that the hand and fingers positioning the fish should not be seen behind the fins; this allows the fish to be cut out from the background using appropriate software. Below is the same image cleaned up by an image editing software.

cannot see the operator's hand behind a transparent fin. Position the fish's body parallel to the outer glass.

- Benthic fish such as loaches may look more natural if photographed on a rock rather than floating freely in the water column. Even nervous fish will remain calm if you gently redirect them a few times and sing a lullaby to them.
- Make sure the glass and water are clean and free of bubbles. The second operator photographs the fish through the glass. Ensure the fish remains parallel to get a good image of its side body.
- Take several shots to ensure that the fish's fins are in a neutral position and that its mouth is not open to breathe.
- Use a high f-number (small aperture) to ensure that different parts of the fish, from the eyes to the caudal fin, remain in sharp focus throughout the image. Start with f/8 or f/11 and adjust as needed. Higher f-numbers may require slower shutter speeds or increased ISO to maintain proper exposure, so a tripod can help prevent blur.
- Check the in-camera image to ensure that the entire fish is visible and in a natural position, that the image is not over- or underexposed, that there are no obvious reflections (at least not on the fish), and that the image, especially the eye, is in focus.
- If light reflection from the front glass is unavoidable, use a polarizing lens filter. Such a filter will slow down the shutter speed, so using a tripod will again improve the quality.



Figure 4. Safety comes first, both during fieldwork and when handling preserved fish in the laboratory.

Euthanizing and preserving fish. With a little experience, and especially some knowledge of the fauna of a particular area, most species can be identified alive, and euthanasia is not necessary. Sometimes, fish will be required to be

sacrificed for examination. Preserving the fish immediately in the field is preferable to ensure the best possible condition of the specimen and, thus, optimal identification. Remember that fish are living creatures that can feel pain and should not be treated carelessly.

Euthanasia. There are many national regulations regarding the euthanasia of fish. For best results, fish should be euthanised with an overdose of anesthetic (MS222, clove oil, or chlorobutanol) and, when dead, carefully washed and immediately placed in formalin. Fish should never be left to die naturally. A fish forgotten in a plastic bottle, with damaged fins, which has died from suffocation or careless handling and/or has been fixed several hours after death, is often difficult to identify and useless for scientific research. Animal welfare laws must be followed as they do not allow unnecessary stress to be inflicted on vertebrates such as fish. Fish should not be transported in a bottle or other container for any length of time, as stress can cause them to lose colour, making identification more difficult, not to mention the possibility of death or the larger fish eating the smaller ones.

Fixation. Fixation is the preparation of a specimen with chemicals (preservatives) to prevent decay and allow for later examination and long-term preservation and storage. Proper fixation of freshly caught individuals is very important for correct identification. Formalin is the only fixative that should be used. Ethanol does not provide adequate fixation for identification and long-term storage. Formalin is a 35–40 % aqueous formaldehyde solution (a gas). Formalin should first be diluted 1:10 with water (to give an approximately 4 % formaldehyde solution); clean water from the stream from which the fish were collected should be used. For fixation, use a bucket or large container where the specimens lie flat and their fins extended.

Larger numbers of fish (even several species) from the same locality may be fixed in the same container. The volume of liquid should be more than twice the volume of the specimens. Ensure they do not move in the container during transport to prevent fins from breaking. If a fish has died in an unnatural position or with its mouth open, remove it from the formalin, rinse it thoroughly, turn it upright, or close its mouth and return it to the formalin bath. Be careful not to remove scales or break fins accidentally. Always work near a water source (a river, running water, or a large bucket of clean water) and immediately and thoroughly rinse any tools that come into contact with formalin. Never bring formalin into a room or vehicle. When working with preserved fish, preventing formalin from coming into contact with a person's skin or eyes is important. If contact does occur, the affected area should be rinsed thoroughly with plenty of water. Contact with the

eyes will cause immediate and severe burning. Containers used to fix fish, especially larger species, should always be watertight and kept out of the reach of children and animals. It is best to avoid smoking when working with formalin. Formaldehyde is a carcinogen (can cause cancer in living tissue) and should not be inhaled. Nitrile or Neoprene gloves should be used, as even rubber or latex gloves may not protect the hands.

Larger fish (more than 150–250 mm long, depending on body shape and width) should be injected with pure formalin into the abdominal cavity. Alternatively, the body should be cut open slightly on the right side to allow immediate fixation of the viscera. The formalin used should be disposed of following local or national regulations. Do not dispose of it where it may be exposed to humans or animals. Used formalin that is no longer completely clear should be discarded. Fish from different locations should never be stored in the same container. Each container should be immediately labelled with the following information: province, river, locality, geographical coordinates, name of collector(s), and date. The label must always be placed inside the container and never glued or attached to the outside (it will eventually fall off, and specimens without locality data or uncertain locality data are useless). Use strong, waterproof, archival paper and write clearly with a waterproof pigment or archival ink or a soft pencil. Cheap paper without fibers (e.g., photocopy paper) is unsuitable as it disintegrates

within minutes. Ballpoint pens should never be used. Do not try to save money or time at this crucial stage.

Preservation and shipping. Preserved fish should be kept in formalin for at least a week. They may then be rinsed in water and transferred to a 25 % ethanol solution for one week. They are then transferred to a 50 % ethanol solution for a further week and finally stored in a 70 % ethanol solution. Isopropanol or methylated spirits are unsuitable as they alter the structure, bleach, dehydrate, or harden the fish. When shipping fish samples, it is preferable to keep fish samples in formalin in their original **leak-proof** containers. This is not possible if they are sent by post, courier, or air, in which case the formalin should be drained and replaced with water after a few days in formalin. The specimens can remain in this water (which retains some formalin) for 1–2 weeks without damage. Poor-quality containers should be avoided at all costs. Each container should be sealed in a plastic bag and placed in a strong box. If this method is inconvenient, wrap the specimens in cheesecloth or strong white (unstained) tissue soaked in formalin (or in ethanol if the specimens have already been transferred to ethanol), place them in a sealed plastic bag with the labels inside, and then put in a strong box; if the fish have strong spines, remember that the spines may puncture plastic bags and formalin may leak. Use several layers of plastic bags and place newspaper, cardboard, or polystyrene between them.



Figure 5. Tissue collections are essential for studies on fish, providing the genetic data necessary for analysis. Fin clips are commonly used for this purpose in freshwater fish.

Preserving tissue for DNA extraction. Preservation of tissue samples for DNA analysis is standard practise in field research. The same general rules for preserving whole fish should be applied, except that tissues sampled for DNA analysis should never be exposed to formalin, only ethanol. Voucher specimens are the individuals from which the tissue for DNA extraction was taken, and the preservation of vouchers is an essential part of scientific documentation.

- Euthanise the fish with an overdose of anesthetic (MS222, clove oil, or chlorobutanol).
- Cut the pectoral or pelvic fin or part of it from the right side of the fish and place it in pure ethanol.
- Fins preserved in pure ethanol for a few days or 1 week can be kept and transported dry for some time. However, this requires rapid and complete desiccation, which usually takes only a few minutes as the ethanol evaporates quickly. Long-term storage of dried fins is not recommended as we still need to learn more about the decomposition processes in the dried tissues.
- Label the fish with the same number as the tube number. We use paper strips with the number printed four times; cut and fold the strip and place it behind the gill cover. You can cut one of the small numbers and put it in the tube with the fin, so you do not have to write a new label. Always put the number inside the tube!
- Preserve the fish in approximately 4 % formalin, as mentioned above.

Tissue preserved in ethanol can theoretically be stored for several decades without decaying. However, ethanol can evaporate very slowly from the vials. This reduces the concentration of ethanol, and the DNA samples may start to degrade. Deep freezing is one solution to reduce the speed of this process; an alternative is to replace the ethanol regularly. However, there needs to be more experience to advise on how to stop the process of long-term DNA degradation in tissue samples. There may be occasions when the voucher specimen cannot be preserved because it is too large, belongs to the fishers, or for other reasons. In these cases, it is preferable to take photographs of each voucher specimen. Small fish up to a few centimeters in length can be preserved in either 15- or 50-ml tubes of pure ethanol, whereas larger fish must be sampled individually. They must be euthanised by an overdose of anesthetic, as described above. A piece of tissue, usually the right pectoral or ventral fin, is removed and preserved in pure ethanol for larger specimens. It is the collector's responsibility to ensure that the tissue is labelled so that the tissue and voucher can be unambiguously linked later. Cutting fins from live fish is illegal in many countries. Different numbers of individually labelled specimens are ideal for other purposes, depending on the species and location. Typically, 5–10 individuals are appropriate for most study objectives.

Collecting DNA samples in areas where ethanol is not available

Ethanol is not always available, and the lack of ethanol is not a major obstacle. The main reason for using ethanol is to dry the fin tissue as quickly as possible. Fins can also be air-dried. Dehydration of the fins must be achieved as soon as possible, and the fins must remain dry during storage or transport. Even minor decomposition of dried tissues leads to DNA degradation and may result in loss of scientific material. Dehydrating chemicals without direct contact with the tissue sample(s) is often the solution. Using any type of cologne containing at least 80 % alcohol by weight is also effective in preserving fin tissues for some time. Placing the fins in ethanol and freezing them for long-term storage is highly recommended.

Publishing data. Data and conclusions should be made available to the scientific community or interested researchers, preferably by publication in a peer-reviewed journal or through an online platform such as ResearchGate (www.researchgate.net), which offers DOIs for citation. By making your data available through these channels, you increase the impact and visibility of your research, facilitate collaboration, and support the principles of open science. Journals specialising in publishing biodiversity data, such as the Biodiversity Data Journal (<https://bdj.pensoft.net>) or more specifically Freshwater Metadata Journal (<http://www.freshwaterjournal.eu/>), as well as dedicated ichthyology journals

that accept manuscripts describing the distribution of freshwater fishes, are particularly suitable for this purpose. Individual species records must be submitted with GPS coordinates, ideally in decimal format, to be added to existing maps or used in other analyses such as species distribution modelling. For species that are more difficult to identify, lateral colour photographs should accompany the data to help validate identifications. Uploading records and images to citizen science platforms such as www.inaturalist.org or <https://observation.org> is recommended, as these make the records publicly available through GBIF (www.GBIF.org). **Further reading.** Neumann 2010 (field techniques).

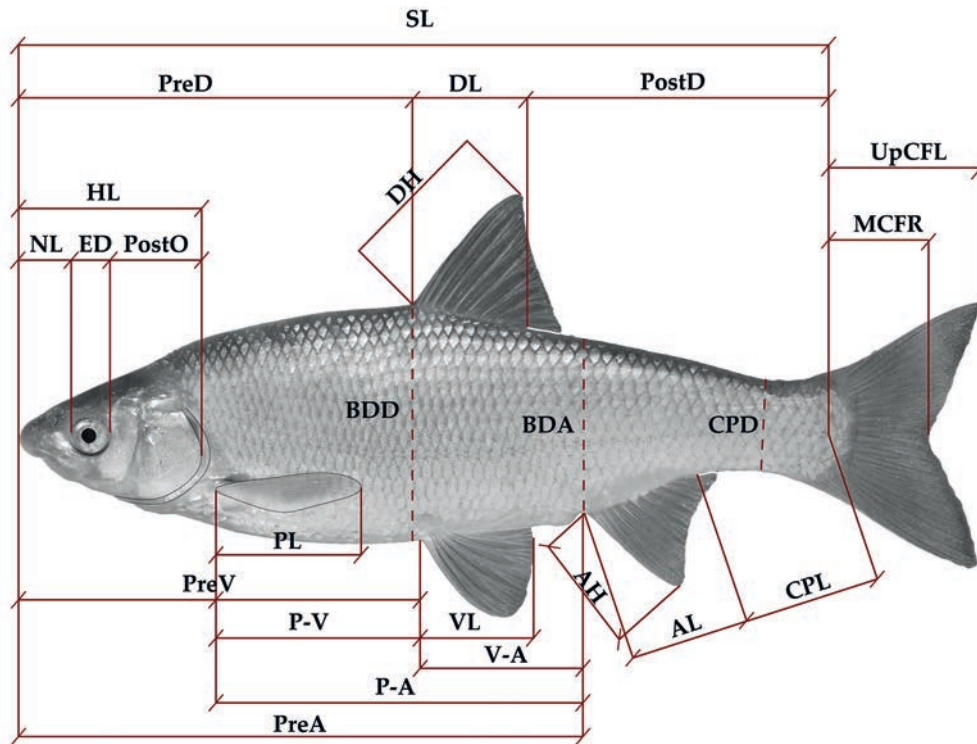


Figure 6. Morphometric characters: AH, anal fin height; AL, anal-fin base length; BDA, body depth at anal-fin origin; BDD, body depth at dorsal-fin origin; CPD, depth of caudal peduncle; CPL, length of caudal peduncle; DH, dorsal-fin height; DL, dorsal-fin base length; ED, eye diameter; HL, head length; MCFR, length of middle caudal-fin ray; NL, snout length; P-A, distance between pectoral and anal-fin origins; PL, pectoral-fin length; PostD, postdorsal length; PostO, postorbital distance; PreA, preanal length; PreD, predorsal length; PreV, prepelvic length; P-V, distance between pectoral and pelvic-fin origins; SL, standard length; UpCFL, length of upper caudal fin lobe; V-A, distance between pelvic and anal-fin origins; VL, pelvic-fin length.

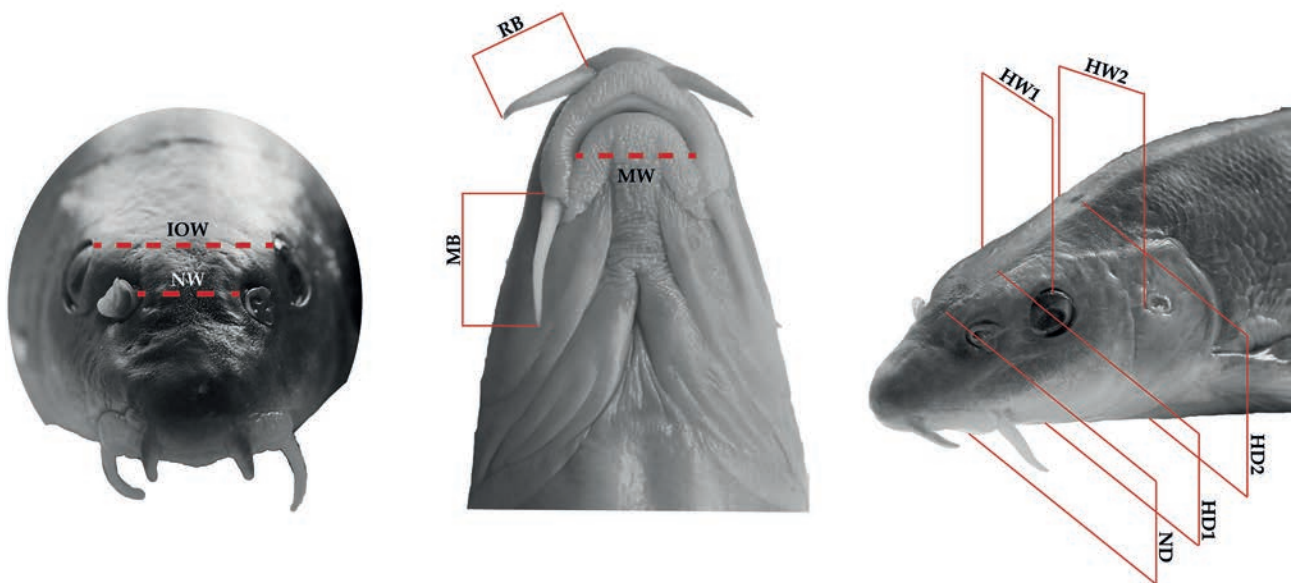


Figure 7. Morphometric characters: HD1, head depth at eye; HD2, head depth at nape; HW1, head width at eye; HW2, head width at nape; IOW, interorbital width; MB, length of maxillary barbel; MW, mouth width; ND, snout depth; NW, snout width or internasal; RB, length of rostral barbel.

Morphological characters

In the species chapters, terms are abbreviated as caudal-fin base, dorsal-fin origin, and similar terms, e.g., caudal base and dorsal origin.

Measurements. The standard measurements used are shown in Figures 6 and 7. All are taken as a straight line from point to point, not across the body curves or as projections along the longitudinal axis.

Standard length (SL) is measured from the foremost point of the body (usually the tip of the snout or upper lip) to the base of the median caudal-fin rays at the end of the hypural complex. The position of the end of the hypural complex is only sometimes obvious. Note that the base of the caudal fin rarely coincides with the last scales, as scales often extend onto the caudal fin. The end of the hypural complex is easily seen as a fold when the fin is bent from side to side (Figure 8). It is often located in front of the last 2–3 scales on the caudal peduncle, a point where the caudal fin can easily be bent against the body of the fish.

Total length (TL) is measured from the body's foremost point to the caudal fin's rearmost point. For most fish, SL is used as the reference length; for a few groups (e.g., eels), TL is used as the reference length. Although commonly used in fisheries, the fork length (from the anteriormost point of the head to the tip of the median caudal ray) is not used in ichthyology.

Head length (HL) is the distance from the body's foremost point to the opercular membrane's posteriormost point. Dorsal HL is measured from the foremost point of the body to the posteriormost point of the skull along the dorsal midline (occiput). Except for SL and the TL, which are given in millimeters, all other measurements are given either as a percentage (e.g., % SL or % HL) or as a ratio (e.g., HL four times in SL).

Dorso- and pelvic-hypural distance are measured, as shown in Figure 9.



Figure 8. Locating the end of the hypural complex is achieved by bending the caudal against the corpus of the fish.

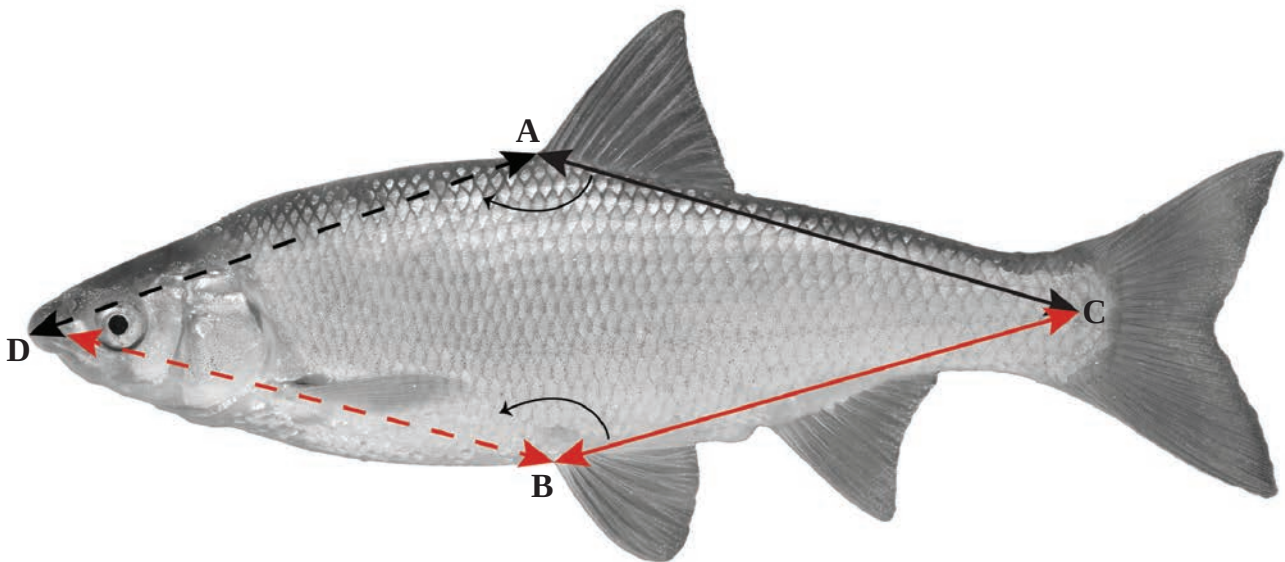


Figure 9. Dorso-hypural distance is measured from the origin of the dorsal fin to the base of the median caudal ray (A–C) and reported forward (A–D). The pelvic-hypural distance is measured from the origin or pelvic fin to the base of the median caudal ray (B–C) and reported forward (B–E).

Sources of data, data transformation, causes of errors, limitations of data

The data used to compile the species accounts come from various sources. Some are from our field observations and live, freshly preserved, or museum specimens. In such cases, we have ensured that the data are presented consistently. For some species, data have been obtained from the literature. Wherever possible, we have tried to verify such data with specimens; however, this was only sometimes achievable. Some authors may use their own methods of measuring or counting scales and rays or use different terminology. To make accurate comparisons, it is necessary to standardise these data. There are several systems for reporting morphometric (measured) and meristic (counted) characters. For some characters (e.g., dorsal or anal fin ray counts), the translation from one system to another is reasonably clear. For others, the translation requires interpretation of the data and a certain degree of speculation. For example, this may be the case with lateral line scale counts. We would have preferred to present them all in a single format (distinguishing scales on the body from those on the caudal fin base, e.g., 28–31+2–3), but converting total counts (including scales on the caudal fin base) to standard counts would have introduced a degree of subjectivity and potential error. We, therefore, decided to keep the data in the original format, which explains an apparent lack of consistency between some of the reports. We believe that the lack of consistency is less damaging than the risk of introducing errors.

It is impossible to describe the full range of variability in a character. There are always individuals with anomalous character traits due to injuries, poor health, etc. Moreover, very small or very large individuals may exhibit different appearances. Documenting all these subtleties here would be tedious and space-consuming if they are known at all. When measuring fish, it is important to remember that, besides rigid structures, they also contain soft tissues that can be deformed or damaged by tools. Furthermore, measurements of soft tissues are only partially reproducible. Therefore, specimens must be properly preserved, although this is only sometimes the case.

Whenever possible, conclusions drawn from morphometric characters should be based on a series of specimens rather than a single individual. If a diagnosis

indicates 18–23 % and the specimen examined shows 17 %, this does not automatically exclude it from a particular species, as the sample you have studied may not include the full range of variation in the species. Some scale or fin ray counts exhibit very little variability within a population or species, whereas others may show considerable variability. Again, conclusions should be based on several specimens. Unique or rare counts have been ignored in diagnoses (e.g., if an author reported having counted dorsal fin rays in 589 specimens and observed 7½ rays in 578 and 8½ rays in 11, we have ignored the low-frequency 8½ value).



Figure 10. Common types of caudal fin: from left: rounded; truncated; emarginate; forked.



Figure 11. Dorsal fins of salmoniform fishes; also seen in most catfishes: **a**, rayed dorsal fin; **b**, adipose dorsal fin without rays.

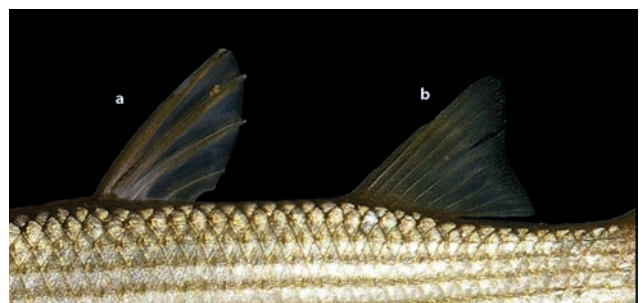


Figure 12. Dorsal fins of mullets, silversides, and others: **a**, first, spinous dorsal fin; **b**, second dorsal fin with unbranched and branched rays.

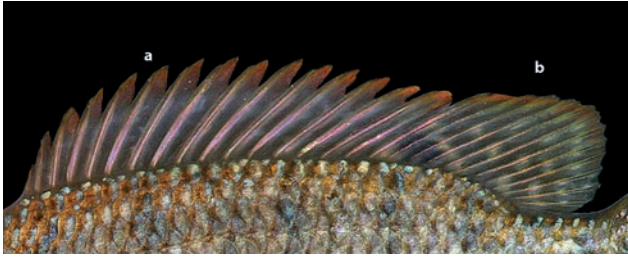


Figure 13. Dorsal fins of cichlids and many other percomorph fishes: **a**, first, spinous part of fin; **b**, second, soft part of fin.

Fins and fin rays. The dorsal, caudal, and anal fins are called unpaired fins, and the pectoral and pelvic fins are called paired fins. Different shapes of the caudal fin are shown in Figure 10. In fishes with two dorsal fins (Figures 11 and 12), the anterior one often consists only of spines, and the second one often consists of a single anterior spine followed by soft (or segmented) rays. Anatomically, true spines are median (unpaired) structures, never branched, never segmented, and generally hard and pointed. Soft rays comprise a right and a left part, usually segmented and branched (Figure 14b). In some species (e.g., many cyprinids), some anterior rays may be fused into unsegmented, hard, and inflexible rays, which may also be posteriorly serrate (e.g., have a series of indentations or teeth along their posterior margins). These are called “spinous” (“similar to or shaped like a spine”).

The base of a fin is the region where it attaches to the body. In some fishes, part of the rays and membranes are covered by scales, making it difficult to see the base of the ray. The origin of a fin is the insertion point of its most anterior ray (e.g., the most anterior point at the base of the fin). The heights of the dorsal and anal fins are measured from the origin of the fin to the uppermost (or lowermost) point on the fin. The respective positions of the fins are often given in the form “dorsal origin in front of anal origin” or “dorsal origin above pelvic base,” meaning that the origin of the dorsal fin on the back is in front of a vertical line through the origin of the anal fin or above the base of the pelvic fin.

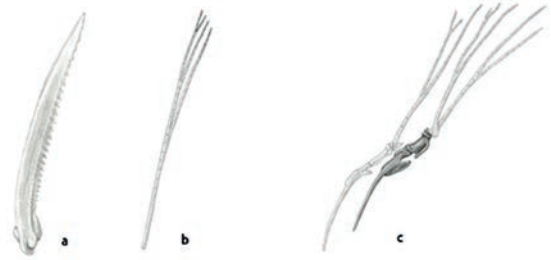


Figure 14. Main types of fin rays: **a**, spinous ray, here serrated posteriorly; **b**, schematised soft, segmented branched ray; **c**, posterior-most dorsal-fin rays and anal-fin rays showing the last two rays on a single pterygiophore (grey), which is counted as $1\frac{1}{2}$ rays (after Kottelat & Freyhof 2007).

Fin ray counts may include only soft or branched rays, unbranched and branched rays counted separately, or the total number of rays. Each method is explicitly stated. The last two branched dorsal rays and anal rays are carried by a single pterygiophore (the bones on which the rays articulate; Figure 14c) in many fish families. Anatomically speaking, the last pterygiophore consists of two fused pterygiophore bones. These two rays are counted as “ $1\frac{1}{2}$.” Therefore, $13\frac{1}{2}$ branched dorsal fin rays indicate that the dorsal fin contains 14 branched rays, the last two of which share the same pterygiophore (or sometimes appear as a single ray split to the base). Authors have been inconsistent in reporting fin ray counts or have often failed to explain their method. As a result, the same $13\frac{1}{2}$ count may appear in the literature as 13 if the last two rays are counted as one or 14 if they are counted as two. We prefer the $\frac{1}{2}$ notation because it immediately indicates that the author knows the problem with the last two rays. For caudal rays, “9+8 branched caudal rays” means nine branched rays in the upper lobe of the caudal fin and eight in the lower lobe. Usually, there is one principal unbranched ray above and one below the branched rays, along with several rudimentary rays in front that are not counted.

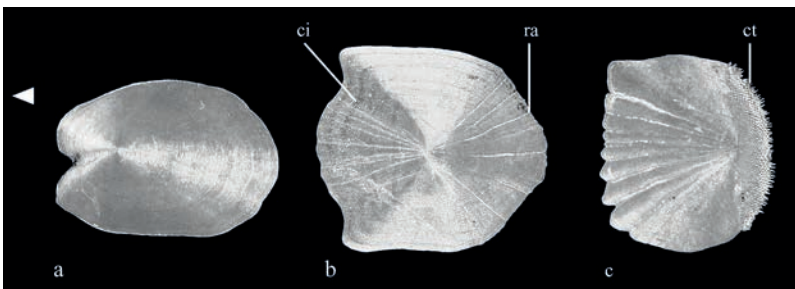


Figure 15. Main types of scales: **a**, *Esox lucius*, cycloid; **b**, *Squalius cephalus*, cycloid; **c**, *Sander lucioperca*, ctenoid. *ci*, circuli; *ct*, ctenii; *ra*, radii. The arrow points toward the head (from Kottelat & Freyhof 2007).

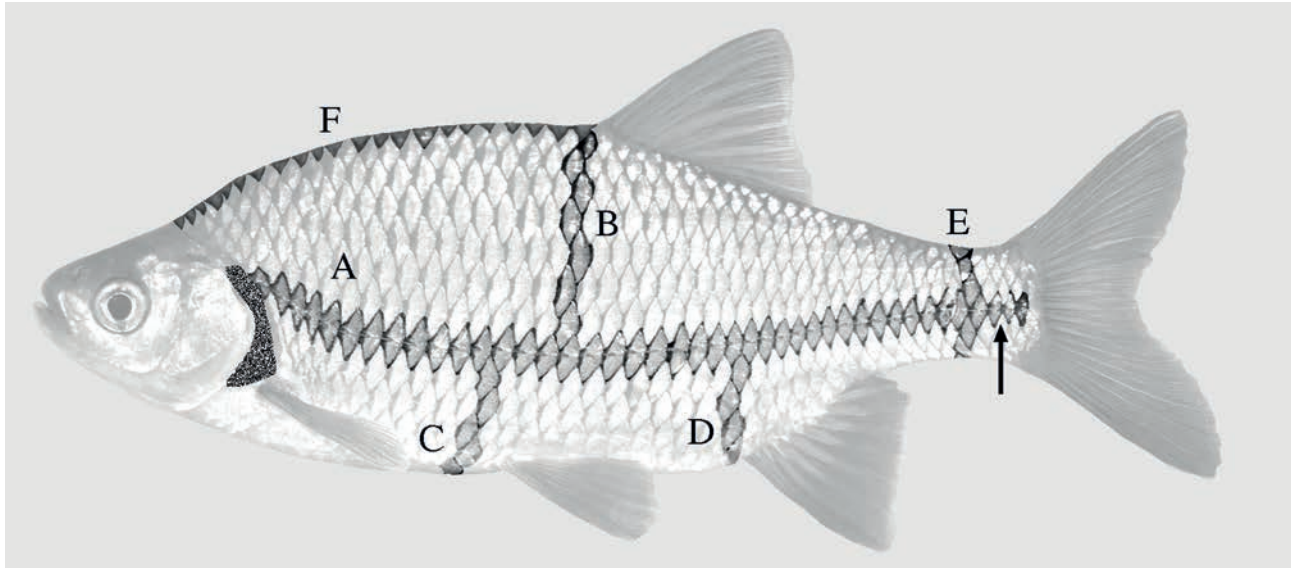


Figure 16. Illustration of principal scale counts. (A) Lateral-line scales (midlateral row); (B) transverse scales between lateral line and origin of dorsal fin; (C) transverse scales between lateral line and midline of belly; (D) transverse scales between lateral line and origin of anal fin; (E) circumpeduncular scales; (F), predorsal scales; (arrow) scales on caudal-fin base (from Kottelat & Freyhof 2007).

Scales. The lateral line scale count (Figure 16) is the number of scales on the lateral line. In the absence of lateral line pores in all scales, the midlateral series is the number of transverse scale rows counted at the mid-height of the flank. The most anterior scale counted is the one in contact with the shoulder girdle. **Counting ends at the base of the caudal fin.** Scales on the caudal fin are not counted, even if they are well-developed and porous. In such cases, they are best indicated with a “+.” For example, the lateral line scale count of the fish in Figure 16 is given as 38+3, meaning that there are 38 scales along the lateral line of the body and 3 on the caudal fin. The total lateral line scale counts given in the text are those where the authors do not distinguish between scales on the body and those on the caudal fin. In this instance, the same fish has a total of (38+3) 41 scales. Fish can lose scales due to various factors, including predatory attacks and during courtship or spawning. This also happens when fish are handled frequently, for example, at sites used for annual censuses or research. Lost scales are replaced, but replacement scales often show growth or positional anomalies. Scales may also be deformed, fused, split, displaced, etc. In some species, counts will show minimal variation, whereas in others, the variability is greater. Where there is a great deal of variability, it is usually due to small, deciduous scales that are partially embedded in the skin or irregularly arranged scale rows. Counts should

be checked on several specimens; extreme or anomalous counts should be disregarded, as should counts based on damaged individuals.

Transverse scale counts indicate the number of scale rows between the lateral line and the origin of the dorsal fin (or the first dorsal fin if more than one) and between the lateral line and the midline of the abdomen (anterior to either the pelvic fins or the origin of the anal fin, depending on the context). For these purposes, the scale on the dorsal or ventral midline (e.g., immediately anterior to the dorsal and anal fins) is recorded as $\frac{1}{2}$. For example, the transverse scale count for the fish shown in Figure 16 is $\frac{1}{2}7/1/6\frac{1}{2}$, meaning one scale immediately anterior to the dorsal (predorsal row), seven scales between the lateral line and the predorsal scale, one pore scale in the lateral line, six scales between the lateral line and the preanal scale, in addition to the preanal scale itself. The transverse scale count in front of the pelvic fins is $\frac{1}{2}7/1/5\frac{1}{2}$. The predorsal scale count includes all scales on the dorsal midline in front of the dorsal fin origin (usually between the occiput and the dorsal fin origin). Predorsal scales are sometimes difficult to count accurately as the rows are not always regular. Circumpeduncular scale counts represent the number of scale rows crossing a line around the caudal peduncle at its narrowest point (16 in Figure 16, with a transverse count of $\frac{1}{2}3/1/3\frac{1}{2}$).



Figure 17. *Coptodon zillii* has two dark-grey stripes, four red stripes, six dark-grey-bars, three dark-grey bands on the forehead, and one below the eye. A large ocellus, a black blotch with a white margin, is in the dorsal fin.

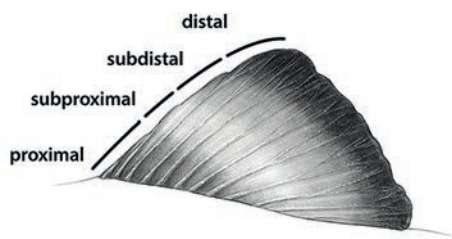


Figure 18. Positions of colour marks on fins (from Kottelat & Freyhof 2007).



Figure 19. Principal types of mouth position: from left: superior, terminal, subterminal, and inferior.

Other characters used for identification. The nomenclature for mouth positions and gill arches is shown in Figures 19. There are, of course, subtle differences between different mouth positions. It is often not trivial to decide whether a mouth is terminal (when the tip of the lower lip or jaw reaches the vertical of the upper lip, upper jaw, or rostral cap) or subterminal (when the upper lip, jaw, or rostral cap protrudes from the lower jaw or lip). The same difficulty arises when distinguishing between subterminal and inferior or superior and terminal mouth positions.

Gill rakers are the anterior bony projections usually present on all gill arches (Figure 20). There is a different number of rakers on each arch of the same individual, and all counts given here refer to the outer gill rakers on the first (anteriormost) gill arch on the right side of the head. Unless otherwise stated, these counts encompass all gill

Colour marks. Bars refer to vertical marks, and stripes denote longitudinal marks. Other elongated marks are called bands (Figure 17). Usually, round marks that are more or less the size of a pupil or smaller are called spots. Even smaller round marks are called dots, and larger ones are blotches. However, some inconsistencies exist, especially when round marks of different sizes are present. In such cases, spots mean smaller marks, and blotches mean larger marks. Irregularly shaped marks are called blotches. Ultimately, there are gradual differences between dots, spots, blotches, and bars, and no clear-cut definition exists to distinguish them. For example, an “irregularly shaped, short bar” and a “vertically elongated, large blotch” might be different descriptions for the same colour mark. On the fins, a proximal band is located along the base of the fin, a distal band along the outside margin of the fin, a median band in the middle of the fin, and subdistal and subproximal bands are located in intermediate positions.

rakers, including formed rudiments. It is sometimes given as $A+B+C$, where A is the number of gill rakers on the upper limb (epibranchial), C is the number on the lower limb (ceratobranchial), and B is the angle between the upper and lower limbs (if any). It is sometimes necessary to cut and remove the gill arch to count the gill rakers. In ichthyology, dissection is always done on the right side, leaving the left side intact for identification, photography, etc.

The rostral barbel is located above the upper lip or upper jaw (see Figure 21); the maxillary barbel is situated on the lower jaw or at the corner of the mouth. A nasal barbel is a barbel-like extension of the anterior nostril (most fish have a nares on each side of the head, each with an anterior and posterior nostril) and a barbel-like extension on the lower lip of some cobitid loaches.

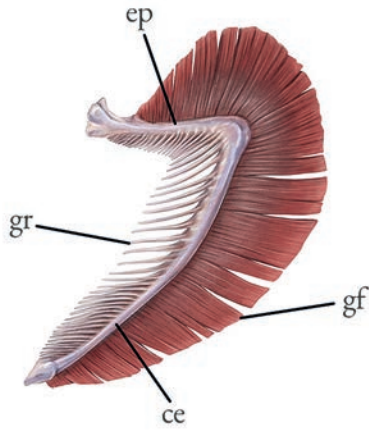


Figure 20. First gill arch, inner view. ce, ceratobranchial or lower limb; ep, epibranchial or upper limb; gf, gill filament; gr, gill rakers (after Freyhof et al. 2020).

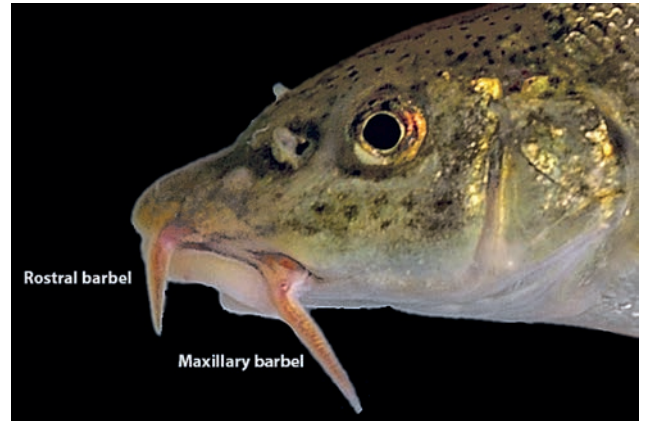


Figure 21. Head of a *Barbus* showing the two barbels typical for most cyprinids.



Taxonomic work relies heavily on fish collections, especially those containing type specimens, which are essential as references.

Taxonomy and nomenclature

Taxonomy is the theory and practise of describing the diversity of organisms and organising that diversity into a system that reflects their evolutionary relationships. Giving names to objects and living things seems natural and important to humans because it allows us to communicate with each other. This explains why most things that play a role in human life, positive or negative, have been given names, and animals are no exception. Every language, country, and region has its own set of names. Biologists have developed a nomenclature (naming) system that gives every animal species one (and only one and unique!) name to achieve high accuracy. Carl Linnaeus (1707–1778) first developed the current naming system, and the 10th edition of his **Systema Naturae**, published in 1758, is considered the starting point of modern zoological nomenclature. This system is now governed by a set of rules known as the **International Code of Zoological Nomenclature** (or “the Code”). The Code prescribes a system of naming, including rules for accepting valid names and deciding between duplicate names. This is vital to all biologists because unambiguous communication depends on names, and the name is the unique identifier that links to information on all aspects of the species. It is important to note that strict rules for describing and naming new species are set out in the International Code of Zoological Nomenclature. In modern times, for example, every newly described species must be associated with a “name-bearing type specimen,” the **holotype**, a reference for the corresponding scientific name. Often, holotypes are associated with **paratypes**; specimens are usually collected with the holotype, which allows a better understanding of the variability of characters in a particular species.

Holotypes and paratypes are of inestimable value and are kept in natural history museums where experts can freely examine them. **Further reading.** ICZN 1999 (International Code of Zoological Nomenclature).

Species and populations. Species is the “currency unit” in most fields of biology, and it is not surprising that its definitions and concepts have been (and continue to be) the subject of much debate. Here is just a summary of some of the basic concepts. The species concept we follow in this book is the **Evolutionary Species Concept (ESC)**, which is defined as follows: a species is an entity composed of organisms that maintain their identity distinct from similar entities through time and space, in addition to having its independent evolutionary fate and historical tendencies. Fate, in this context, refers to each species’ unique evolutionary pathways, including diversification, adaptation, and extinction. Species are discrete entities in nature. They participate in natural processes, evolve, have an origin, can give rise to other species (speciation), and will have an end (extinction). Of course, the future of a living species cannot be predicted, but we know that it will have a fate; the concept also applies to fossil species whose fates are already known. Because species are made up of individuals, they can never be fully defined, nor can all members of a species be expected to fit exactly into a definition. However, like individuals, species can be described and diagnosed, evolutionary lineages can be identified, and changes over time can be observed (given enough time and appropriate tools). Experience shows that most of the characters that define a species tend to vary, often in ways that are empirically predictable to some extent. It is, therefore, not surprising that most diagnoses include exceptions. Species are known from samples of individuals and samples of characters. In some cases, it can



Species have evolved from reproductively isolated populations, and there is no strict boundary between the two categories. The *Alburnus chalcoides* complex is an example of several previously recognised species consolidated into one. This may be revised in the future.

be difficult to distinguish whether differences between two populations result from phenotypic adaptations to particular environmental conditions or evolutionary adaptations that are genetically fixed.

In taxonomic discussions, a population was originally defined as a segment of a species whose members breed mostly or exclusively among themselves, usually due to physical isolation. This is a common challenge, especially in species with populations that are isolated from each other, such as many freshwater fishes. It can be difficult to decide whether two discrete groups of closely related individuals are two distantly related populations of a single species or two closely related species. The widely accepted criterion is that gene flow occurs between populations of a species but not between species. However, there are many exceptions and complexities, so broad generalisations should be avoided, and each case should be evaluated individually. The definitions of the terms “population” and “species” have not evolved in a coordinated way, and there is sometimes a grey area between them, especially when fine-scale molecular methods are used. Therefore, the rule of thumb among taxonomists is that fine-resolution molecular characters (such as those provided by increasingly available genomic methods) should be used cautiously and only when they are congruent with another set of characters (morphological, ecological, ethological, etc.). Conceptually, there is a continuum in the variability of different species populations, whereas in practice, there is a gap between the respective variabilities of two species. Of course, reconciling theory with the facts observed in nature is difficult. In West Asia, we have several groups of species (*Salmo*, Iranian *Glyptothorax*, *Esmaeilius*, some *Oxynoemacheilus*, *Alburnus*, *Barbus*, and *Garra*) where very different opinions have been published as to whether different populations are conspecific or not. We have tried our best to

resolve some of these cases. Still, as this involves treating some species described by colleagues as synonyms, these colleagues frequently reject options (often without giving reasons). This is one of the reasons why the species list in this book differs from other publications, such as simple country checklists. **Further reading.** Cracraft 1989 (Phylogenetic Species Concept [PSC]); Mayden & Wood 1995 (ESC, ESU); Mayden 1997 (hierarchy of species concepts); Kottelat 1997 (PSC); Kullander 1999 (species); Mayden 2002 (species as individuals).

Nomenclature. Each species has a name comprising two words, a **generic name** (in the first position, starting with a capital letter) and a **specific name** (in the second position, beginning with a lower-case letter), for example, *Leuciscus aspius*. Each combination of two words is unique and applies to a single species. The generic name indicates affinities (or relationships) with other species. For example, several species share the generic name *Leuciscus*, suggesting they are quite similar and share a common ancestor in the group’s phylogenetic (evolutionary) history. A third name (the subspecies name) was formerly used to indicate that an organism belonged to a more or less geographically distinct form of its species. Subspecies is a category that is no longer used by ichthyologists (the subspecies category is not defensible under the evolutionary species concept, and the boundaries are arbitrary under other species concepts). The name of a species is often followed by a combination of the name of one or more persons and a year, e.g., *Leuciscus aspius* (Linnaeus, 1758). This indicates the author of the species’ first description (formally called the original description) and the year that description was published. If the author’s name is given without parentheses, the species was placed in the same genus in the original description as it is today. If the author’s name is given in parentheses, the species was originally placed in a different genus. In our



Franz Steindachner (Vienna) described *Nemacheilus angorae* in 1897. It was later placed in the genera *Orthrias* and *Barbatula* and is now recognised as a species in *Oxynoemacheilus*.

example, Linnaeus originally described *Leuciscus aspius* (Linnaeus, 1758) as *Cyprinus aspius*. Indication of author and year is not mandatory and is only justified in taxonomic publications if needed. Authors' names are not used in the species accounts below but are listed in the Appendix of this book. **We wish to emphasise the importance mistakenly attached to the unnecessary inclusion of authors' names in non-taxonomic literature.**

Many readers will notice that the nomenclature used in this book sometimes differs from that used in earlier sources. These changes are explained in several scientific publications written in recent years. This does not mean that the older publications were wrong; rather, as time passes, new scientific discoveries are made, new concepts are advanced (and old ones are sometimes discarded), and our understanding of evolution and the relationships between species evolves. This evolution of our knowledge is reflected in changes in the names of some species. Discoveries are certainly still to come, so the nomenclature in this book is likely to change in the future. Ideally, the system will one day be perfected, but that day is unlikely to come in our lifetime! In this book, we have used the nomenclature available in July 2025. Based on current scientific knowledge, these are the valid and correct names; other names are no longer valid and should not be used. By publishing this book in an open-access electronic format, we can more easily revise and update the nomenclature in future editions, ensuring that the content remains current with ongoing scientific developments. **Further reading.** Kottelat 1997 (species concepts); ICZN 1999 (Code).

The biological species concept. Textbooks still often refer to the biological species concept—the idea that different

species do not interbreed in nature—although practicing taxonomists have long abandoned it because it is not testable. It can only be used to determine the distinctness of species if the species occur in sympatry, and only for a small number of species on Earth, as the most common form of speciation is allopatric. Most species for which we need to determine distinctness are found in allopatry, a situation that is particularly pronounced among freshwater taxa. We should also remember that the biological species concept only works in natural systems. Species A and B brought together in captivity, or species A introduced in the habitat of species B, represent artificial situations. Furthermore, many congeneric species found in sympatry hybridise, as demonstrated by frequent cases of introgression. This means that hybrids also occur in nature and that genetic exchange between species is still possible after speciation. **Further reading.** Mayden 1997 (hierarchy of species concepts); Kottelat 1997; Kunz 2012 (species concepts); Kullander 1999 (species).

Hybrid fertility. Hybrid fertility is often used as the main criterion for deciding whether two populations are conspecific, but this is an outdated approach. Hybrid infertility occurs at different ages in different lineages and even within a single lineage. Within some groups, species that diverged 2–100 million years ago can still produce fertile offspring; in other groups, species that diverged much more recently cannot. The latter is observed, for example, when there are chromosomal incompatibilities. In fishes, hybrid infertility is rare at the species level but more common at the genus, subfamily, or family level. **Further reading.** Cracraft 1989 (Phylogenetic Species Concept); Mayden 1997 (hierarchy of species concepts); Kottelat 1997 (hybrid fertility and species



A hybrid between *Squalius orientalis* and *Chondrostoma colchicum*. Such hybrids are often fertile. To our knowledge, only two species of possible hybrid origin occur in West Asia: *Coregonus sevanicus* and *Chondrostoma esmaeili*.

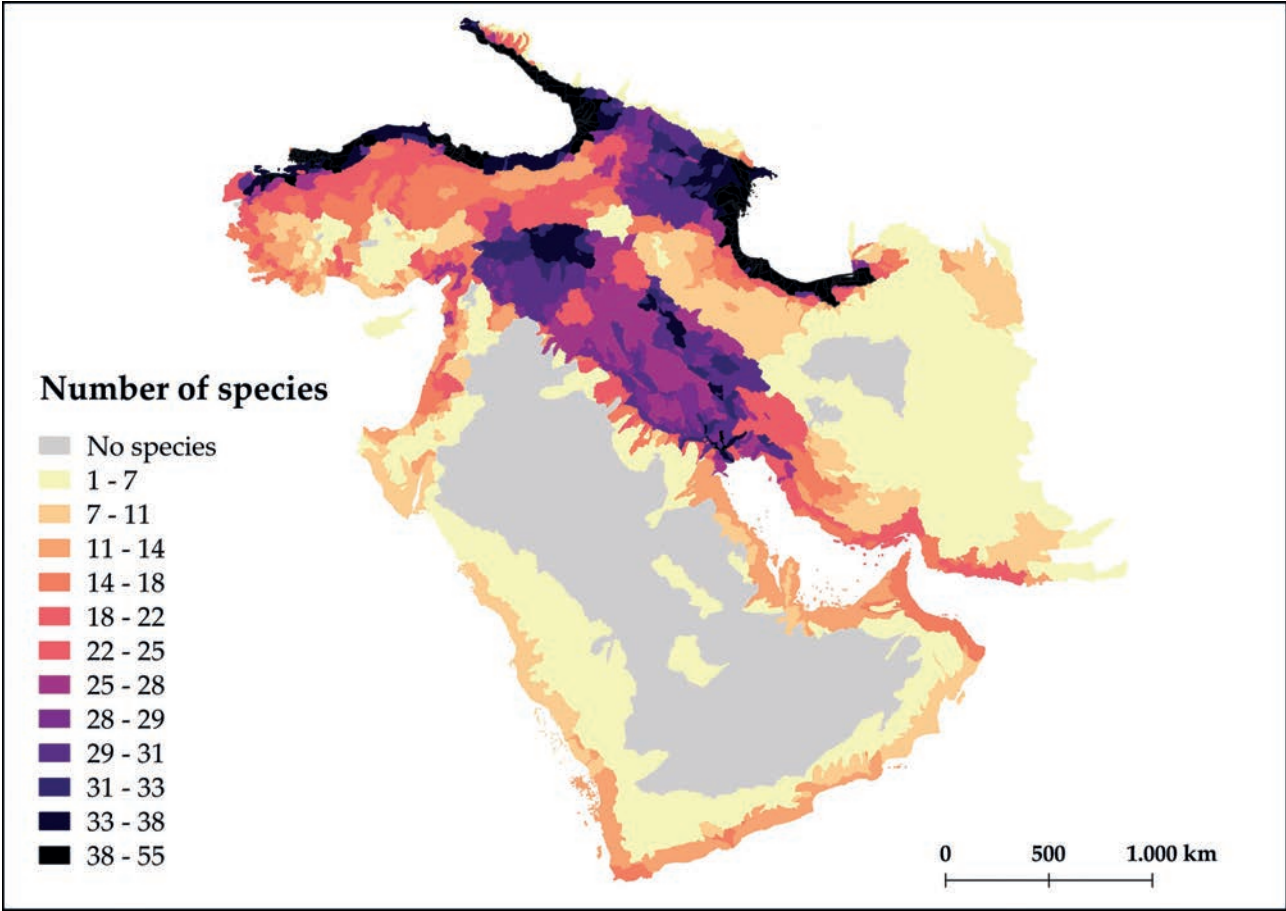


Figure 22. Species richness of native freshwater fishes in West Asia.

concepts); Geiger et al. 2014 (consistency of species and COI sequences).

Diversity of freshwater fishes. In the region covered by this book, we recognise 632 different freshwater fish species (July 2025), including non-native, diadromous, and marine species that regularly enter freshwater habitats. Figure 22 covers 597 native species, including five known but not yet described species and excludes 35 non-native species. There are numerous unresolved taxonomic issues, many of which are mentioned in the various species remarks, and this number is very unlikely to be stable. The effort to identify freshwater fish species in the area has been massive in recent years, and 259 native species (41 %) have been described since 2000 alone. This trend will certainly continue in the coming years. Several scientists in the region build their careers solely on the description of new species, so additional descriptions are expected following the publication of this book. However, species diversity in several genera may already be overestimated, and revisions will reveal some as synonyms in the future. Many marine species occasionally enter freshwater bodies, particularly in the lower Shatt al-Arab/Arvand and adjacent marshes in

the northernmost Persian Gulf region. In this region alone, 130 marine species have been recorded, but freshwater habitats are not an essential part of their life cycle, so these species are excluded from this guide. Of course, we know that the line drawn between marine and freshwater fish is artificial, and other authors might include more marine species in the freshwater lists. Furthermore, the fauna will undoubtedly experience the invasion and introduction of several additional non-native species, such as the *Ameiurus* catfish, the Asian *Misgurnus*, and the Amur sleeper *Perccottus glenii*. Therefore, as with any book project, the species count will likely be outdated when the book is in your hands.

Total number of species covered by this book	632	100 %
Native species	597	94 %
Endemic species	467	74 %
Non-native species	35	6 %
Established non-native species	29	5 %
Cypriniformes	437	69 %
Species described since the year 2000	259	41 %



Figure 23. Information board on fish diversity at Eflatunpınarı in Türkiye to raise awareness for the spring.

Conservation status. The IUCN Red List status of each species is given, followed by a short description of the main threats to the species, if any, and related comments. The details of the evaluations are available from the IUCN Red List of Threatened Species webpage (<http://www.iucnredlist.org>). Most freshwater fishes in West Asia were twice assessed for extinction risk and conservation status using the International Union for Conservation of Nature (IUCN) criteria (Table 1). All assessments consider the global extinction risk. It is important to note that although several species are classified as Least Concern throughout the region, many of the isolated populations may be under significant threat. Of the 583 species assessed in the most recent assessments, 12 species (2 %) are considered extinct (including one extinct in the wild) and 238 species (41 % of assessed species) are in a threat category (assessed as Critically Endangered, Endangered, or Vulnerable) (Figure 24). The distribution of threatened species is given in Figure 25. It is important to note that the IUCN Red List is a tool designed to assess extinction risks, and not to determine conservation measures needed or even less a tool to fix priorities.

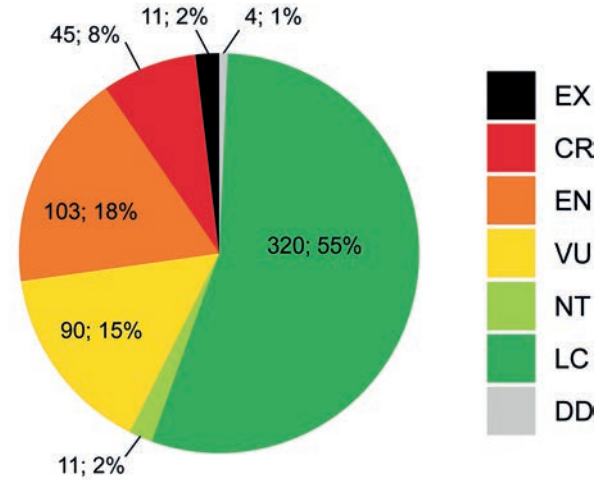


Figure 24. Relative proportions of the conservation status of 583 species of native freshwater fishes in West Asia. EX includes species that are extinct in the wild ($n = 1$), and CR includes potentially extinct species ($n = 2$).

Some important definitions: The **extent of occurrence** (EOO) is the area within the shortest continuous boundary within which the species is known to occur. It is defined as

the convex polygon that includes all the known localities of a species. Of course, for freshwater organisms, this is of little value as they are unable to survive more than a few seconds on dry land; it results in a species restricted to a few coastal marshes around the Mediterranean (e.g., *Aphanius fasciatus*) having an extent of occurrence larger than the whole area of the Mediterranean.

The **area of occupancy (AOO)** is the area within the extent of the species' occurrence. Naturally, a species will usually only occur in some places within its extent of occurrence. For example, it will be absent in unsuitable (or, in the case of fish, terrestrial) habitats. The AOO includes only the habitats where the species normally forages and reproduces and the areas essential for its survival. For example, the area of occupancy of a homing species with an obligatory single spawning ground is the area of that spawning ground. It may be only a few square meters in extent (see also "location" below). In lacustrine habitats, a deep-water species may occasionally be observed in shallow coastal waters; these coastal waters are part of its extent of occurrence but not of its area of occupancy; the reverse would be true for a benthic littoral species occasionally observed to be pelagic in the middle of the lake. Indeed, knowledge about the exact distribution of most species is missing, and the river length is usually taken as a proxy for the AOO

A **location** (in the Red List context) is defined as a geographically or ecologically distinct area in which a single threatening factor can rapidly affect all individuals of the taxon present. A location may include part of one or many subpopulations. The location should be distinct from the locality.

The categories are as follows:

EXTINCT (EX): A taxon is Extinct when there is no reasonable doubt that the last individual has died. A taxon is presumed Extinct when exhaustive surveys in known and/or expected habitat, at appropriate times (diurnal, seasonal, annual), throughout its historic range have failed to record an individual. Surveys should be over a time frame relevant to the taxon's life cycle and life form. Available information leading us to believe that a species is extinct is given in the species account. [Extinct is used when the species has totally disappeared. If it has disappeared only in part of its range, it is referred to as extirpated].

EXTINCT IN THE WILD (EW): A taxon is Extinct in the Wild when it is known only to survive in cultivation, in captivity, or as a naturalised population (or populations) well outside the past range.

CRITICALLY ENDANGERED (CR): A taxon is Critically Endangered when the best available evidence indicates that it meets any of the criteria A to E for Critically Endangered

(see below and Table 1), and it is therefore considered to be facing an extremely high risk of extinction in the wild.

ENDANGERED (EN): A taxon is Endangered when the best available evidence indicates that it meets any of the criteria A to E for Endangered (see below and Table 1). It is, therefore, considered to be facing a very high risk of extinction in the wild.

VULNERABLE (VU): A taxon is Vulnerable when the best available evidence indicates that it meets any of the criteria A to E for Vulnerable (see below and Table 1). It is, therefore, considered to be facing a high risk of extinction in the wild.

NEAR THREATENED (NT): A taxon is Near Threatened when it has been evaluated against the criteria but does not qualify for Critically Endangered, Endangered, or Vulnerable now but is close to qualifying for or is likely to qualify for a threatened category in the near future.

LEAST CONCERN (LC): A taxon is Least Concern when it has been evaluated against the criteria and does not qualify for Critically Endangered, Endangered, Vulnerable, or Near Threatened. Widespread and abundant taxa are usually included in this category.

DATA DEFICIENT (DD): A taxon is Data Deficient when there is inadequate information to make a direct or indirect assessment of its risk of extinction based on its distribution and/or population status. A taxon in this category may be well studied, and its biology is well known, but appropriate data on abundance and/or distribution are lacking. Data Deficient is therefore not a category of threat. Listing of taxa in this category indicates that more information is required and acknowledges the possibility that future research will show that a threatened classification is appropriate. It is important to make positive use of whatever data are available. In many cases, great care should be exercised in choosing between DD and a threatened status. If the range of a taxon is suspected to be relatively circumscribed, and a considerable period of time has elapsed since the last record of the taxon, threatened status may well be justified.

NOT EVALUATED (NE): A taxon is Not Evaluated when it has not yet been evaluated against the criteria.

The categories **CR**, **EN**, and **VU** are defined by quantified criteria:

A Reduction of the size of the population (reduction of the number of individuals, the area of occupancy, the extent of occurrence, quality of habitat, an increase of exploitation, pollution, parasites, competitors, or other stresses; introductions).

B Small extent of occurrence or area of occupancy.

C Small population size related with some degree of continuing decline.

D Very small population size.

E A quantitative analysis shows the probability of extinction in the wild within a short number of generations or years.

For all criteria, the threshold values are different according to the different category levels. The criteria and the values are listed in Table 1.

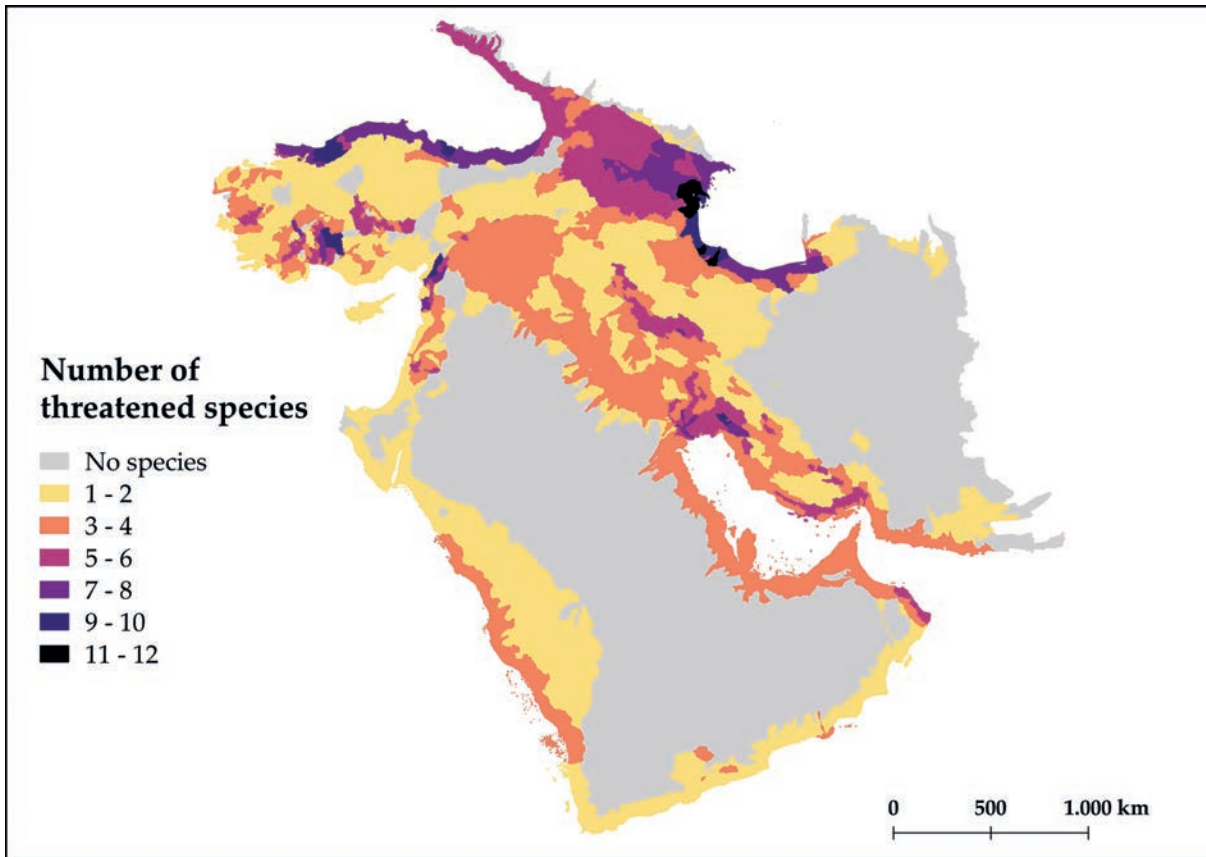


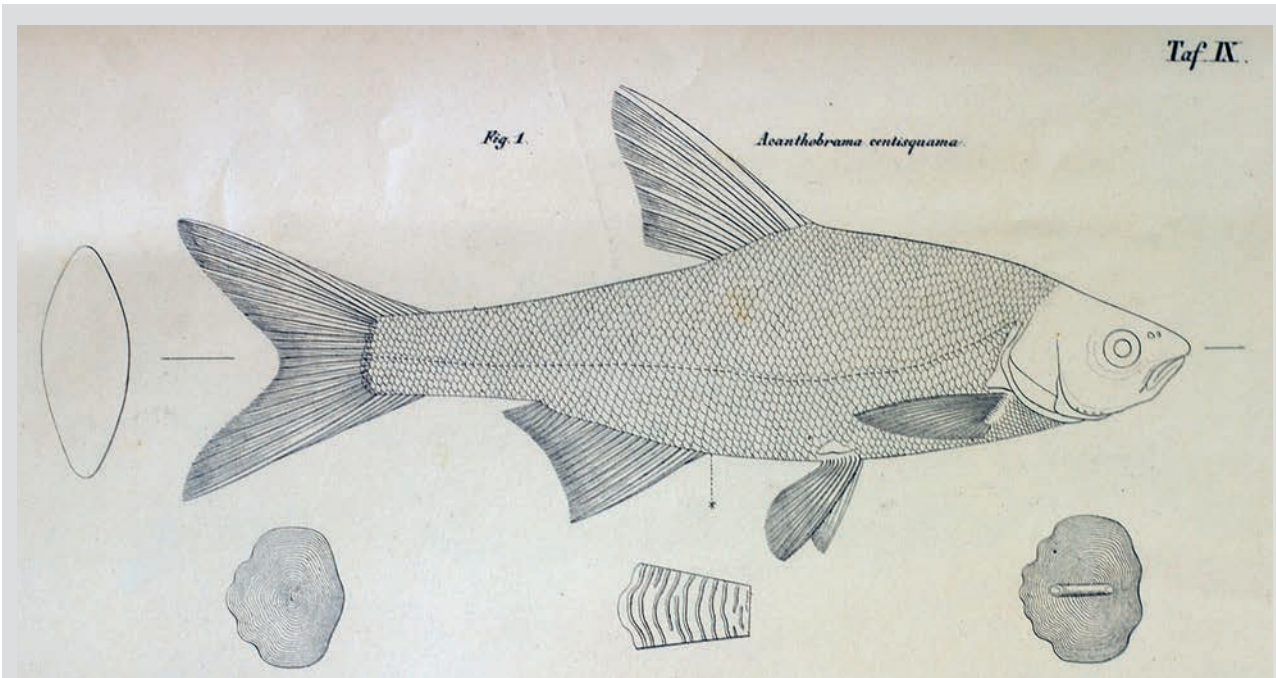
Figure 25. Species richness of threatened (VU, EN, CR) freshwater fishes in West Asia.



The entrance to Azraq Wetland Reserve in Jordan is dedicated to the conservation of birds and the endemic killifish *Aphaniops sirhani*.

Table 1. Summary of the five criteria (A–E) used to evaluate if a species belongs in a category of threat (Critically Endangered, Endangered, or Vulnerable) (from IUCN 2001).

Use any of the criteria A–E	Critically Endangered	Endangered	Vulnerable
A. Population reduction Declines measured over the longer of 10 years or 3 generations			
A1	>90 %	>70 %	>50 %
A2, A3, A4	>80 %	>50 %	>30 %
A1. Population reduction observed, estimated, inferred, or suspected in the past where the causes of the reduction are clearly reversible AND understood AND ceased based on and specifying any of the following:			
	(a) direct observation		
	(b) an index of abundance appropriate to the taxon		
	(c) a decline in AOO, EOO, and/or habitat quality		
	(d) actual or potential levels of exploitation		
	(e) effects of introduced taxa, hybridisation, pathogens, pollutants, competitors, or parasites.		
A2. Population reduction observed, estimated, inferred, or suspected in the past where the causes of reduction may not have ceased OR may not be understood OR may not be reversible, based on (a) to (e) under A1.			
A3. Population reduction projected or suspected to be met in the future (up to a maximum of 100 years) based on (b) to (e) under A1.			
A4. An observed, estimated, inferred, projected, or suspected population reduction (up to a maximum of 100 years) where the time period must include both the past and the future and where the causes of reduction may not have ceased OR may not be understood OR may not be reversible, based on (a) to (e) under A1.			
B. Geographic range in the form of either B1 (extent of occurrence) OR B2 (area of occupancy)			
B1. Extent of occurrence	<100 km ²	<5000 km ²	<20,000 km ²
B2. Area of occupancy and 2 of the following 3:	<10 km ²	<500 km ²	<2000 km ²
(a) Severely fragmented or # locations	=1	<5	<10
(b) Continuing decline in any of: (i) extent of occurrence; (ii) area of occupancy; (iii) area, extent, and/or quality of habitat; (iv) number of locations or subpopulations; (v) number of mature individuals			
(c) Extreme fluctuations in any of: (i) extent of occurrence; (ii) area of occupancy; (iii) number of locations or subpopulations; (iv) number of mature individuals			
C. Small population size and decline			
Number of mature individuals and either C1 or C2 :	<250	<2500	<10,000
C1. An estimated continuing decline of at least:	25 % in 3 years	20 % in 5 years	10 % in 10 years
up to a maximum of 100 years or 1 generation		or 2 generations	or 3 generations
C2. A continuing decline and (a) and/or (b):			
(a i) # mature individuals in all sub-populations:	<50	<250	<1000
(a ii) or % individuals in one sub-population at least	90 %	95 %	100 %
(b) extreme fluctuations in the number of mature individuals			
D. Very small or restricted population			
Either:			
(1) number of mature individuals OR	<50	<250	<1000
(2) restricted area of occupancy	na	na	AOO < 20 km ² or # of locations <5
E. Quantitative analysis			
Indicating the probability of extinction in the wild to be at least:	50 % in 10 years or 3 generations (100 years max)	20 % in 20 years or 5 generations (100 years max)	10 % in 100 years



Extinct *Acanthobrama centisquama*; Orontes, Türkiye (from Heckel 1843).

Extinct freshwater fishes in West Asia

A dozen freshwater fish species are thought to be extinct, meaning they are no longer found alive in the wild. Eleven extinct species, and one more extinct in the wild sound a lot, but only 2 % of the native species are known from West Asia. The other 98 % have survived despite massive habitat change, severe water stress, and the presence of many non-native species. Despite considerable stress, West Asia's freshwater fishes have shown amazing resilience and adaptability to anthropogenic stressors. This may be due to the evolutionary and biogeographical past of the species, which have survived several difficult climatic and geological periods. Furthermore, *Esmailius persicus* has survived in captivity, and we cannot completely exclude that this species, *Cobitis amphilekta*, and *C. kellei*, may be rediscovered in the future, as not all potential habitats have been revisited yet. This is also true for the species that were found to be possibly extinct. Others, such as *Tristramella sacra*, may be conspecific

with surviving species and not extinct. More research is needed to search for lost fishes and to resolve remaining taxonomic questions. This does not mean that freshwater fishes are invulnerable to stressors. Fish will disappear when all the water is gone. There are still springs, small streams, and enough rain to create perennial water bodies, but efforts to withdraw all water for human use have failed. However, the future is bleak for much of West Asia, a major disaster area due to climate change.

Extinct and Extinct in the wild

Acanthobrama centisquama, *Alburnus adanensis*, *Alburnus akili*, *Anatolichthys splendens*, *Cobitis amphilekta*, *Cobitis kellei*, *Esmailius persicus*, *Mirogrex hulensis*, *Pseudophoxinus handlirschi*, *Rutilus sojuchbulagi*, *Salmo ischchan*, *Tristramella sacra*

Possibly extinct

Acanthobrama tricolor, *Caecocypris basimi*, *Oxynoemacheilus galilaeus*, *Salmo aestivalis*, *S. gegarkuni* (surviving in non-native range)



Proper waste disposal is poorly managed in many regions of West Asia.

Threats to freshwater fish in West Asia. Freshwater fish face several threats, most related to increasing human development. These include uncontrolled water abstraction, dam construction, habitat loss, domestic and industrial

wastewater pollution, agricultural run-off, and invasion by non-native species. Although these issues do not pose significant threats in all parts of the region, they are particularly relevant to fish populations, which are often small and located in geographically isolated habitats. In such cases, even relatively low levels of environmental stress to these small populations can significantly impact their overall health and likelihood of survival.

Water abstraction. West Asia is the first region in the world to run out of water effectively. In the arid parts of the area, surface water and groundwater are abstracted in large quantities and rarely sustainably, making it the main threat to most fishes and humans in arid and semi-arid landscapes. Large parts of Central and Western Anatolia, Iran, and the Levant, where pumps abstract surface water from streams and rivers, are most affected by water abstraction. In smaller streams, digging large holes in the streambed is common so water can be abstracted even when the stream is dry in late summer. Water is also often abstracted by pump trucks and transported to more distant locations. In West Asia, it is very common and natural for sections of streams and rivers to run dry in summer. However, dams and weirs impeding runoff that would otherwise be “lost” to human use leave little or no water flowing downstream. This reduces habitat availability for freshwater fish, even in ecosystems adapted to seasonal drought, where fish survival often depends on small refugia. Continued over-abstraction of water, coupled with the increasing frequency and severity of droughts, leads to the desiccation of these refugia and the extirpation (and extinction) of fish.



Pumping water from every river, stream, and spring is common in arid parts of West Asia, and surprisingly, there have been so few freshwater fish extinctions in the region.

Much of West Asia is losing groundwater reserves at an alarming rate, and the region has one of the highest water deficits in the world, second only to India. Water resources must meet the needs of intensive agriculture and a growing population. For example, the Iraqi marshes, the Turkish Sultan marshes, the Eşmekaya marshes, the Lakes Hotamış and Acıgöl, the Jordanian Azraq marshes, the Lebanese Ammiq marshes, and many others have all almost or completely dried up. The lowering of groundwater levels is affecting streams throughout the region, many of which have dried up; the Anatolian Küçük Menderes is one example. Another example is the loss of the Qweiq River, which once flowed through the Syrian city of Aleppo but has virtually disappeared. Today, only two very small headwaters remain of what was once a great river. Other examples include the once extensive spring areas of Ras Al Ain in northern Syria, which have almost completely dried up, and the famous Barada spring near Damascus, along with virtually the entire Damascus hydrological basin, as most of the water is extracted for the expanding city of Damascus.

All the countries considered here have water policies, but these are only sometimes enforced in a way that

preserves or protects biodiversity. Apart from Israel, which introduced a “Water for Biodiversity” policy in the early 2000s, we are unaware of any country where a water policy is being implemented to ensure that enough water remains in lakes, marshes, streams, and rivers to meet the needs of biodiversity. In Israel and the Arabian Peninsula, seawater is increasingly desalinated in large quantities, reducing the pressure on freshwater supplies. Studies show that streams and springs can quickly recover when the amount of water withdrawn is reduced. However, desalination is expensive, requires access to seawater, is powered by fossil fuels, and should not be considered the sole answer to the region’s water needs. The rapidly growing water needs of many West Asian countries cannot be met by further exploitation of water resources, except by developing desalination facilities or reallocating water resources from agriculture. Increased innovative efforts and financial support are needed to create desalination systems powered by solar or wind energy, not only to conserve freshwater biodiversity but also to benefit the overall water needs of West Asia. **Further reading.** Shacham 2003 (Israel water program); Allan 2001, Voss et al. 2013 (water stress); GegenStrömung 2011, International Rivers 2014 (dams in Türkiye).



This huge spring at Göksu, in the Mardin province of Türkiye, has fallen victim to water abstraction and drought. Much of West Asia will receive less rainfall in the future.



Thousands of dams are massively impacting the rivers of West Asia, and countries continue to invest in more dams, ignoring the negative environmental consequences.



Fish passes are often thought to compensate for the negative effects of dams. However, like the one in the picture, most are impossible for fish to use and do not support upstream migration. Nor do they compensate for the complete transformation of the river into a novel lake ecosystem dominated by non-native species.

Dams and reservoirs. Determining the exact number of dams and weirs in the region is impossible. Different sources give different figures, even for Türkiye, where information is available. Türkiye has more than 2000 dams and weirs and plans to build another 1700 within its borders, making it one of the most active dam-building countries in the

world, with hardly a river in the country unaffected. Other countries, such as Iran and the countries of the Caucasus, have also followed Türkiye's lead in exploiting rivers for hydroelectric power. Iran, Iraq, and countries in the Levant have built dams on almost all suitable rivers. The impacts of dams on biodiversity and society remain largely unknown.



Clean water is a limiting factor for many human activities. Surprisingly, domestic, industrial, and agricultural pollution is a widespread threat to West Asia's freshwaters.

West Asia's reservoirs evaporate large amounts of water needed elsewhere and significant amounts of methane, but their contribution to climate change is poorly understood. The region is home to few long-distance migratory fish species, the most important of which are sturgeons. However, their need for free-flowing rivers has rarely been considered. The main threat associated with dams is not the dam itself, which prevents fish from migrating, but the reservoir, which transforms a flowing river into a stagnant lake, a habitat unsuitable for many fish species. While most rivers in the region are now dammed, it is usually a single dam, or in many cases, a few dams, rather than a "cascade of dams" that essentially turns the river into a series of lakes. However, this scenario is slowly changing as many new dams and weirs are being built across the region. The construction of new dams, especially for hydropower and water storage, is a major concern for freshwater fish

conservation throughout the region. Hydropower is widely presented as a "green technology," leading many countries to aim to exploit their full hydropower potential.

Pollution. Throughout West Asia, particularly in the vicinity of urban areas, pollution is one of the major threats to freshwater fish. Most rivers and streams are heavily polluted downstream of urban areas, mainly by sewage, such as the Kura downstream of Tbilisi in Georgia, the Tigris downstream of Diyarbakir, and the Shatt Al-Arab in Iraq. However, it is in the rivers of Western Anatolia, such as the Bakırcay, Gediz, Küçük, and Büyük Menderes, that water pollution is most widespread and severe. The Küçük Menderes has virtually disappeared, and the lower part is filled with sewage from towns and industries. The Gediz and Bakırcay are so polluted that only *Gambusia holbrooki* seems to exist in the middle and lower parts of the main rivers. There are also high pollution levels in many other



Fieldwork over many years has shown a steady decline in habitat size and quality in many places. This is why so many fish species are listed as CR, EN, and VU in an IUCN threat category.

areas; for example, the upper Köprüçay, south of Isparta, is largely polluted with sewage, as is the Orontes and many coastal rivers in Syria. However, data on these rivers' chemical and biological water quality are sparse, and there are few continuous monitoring programs for open surface waters. As a result, little is known about the region's extent and intensity of urban and agricultural pollution. Pollution can be cleaned up relatively quickly, and we hope readers will prove us wrong in the years to come when all these rivers are clean again.

Climate change. West Asia is predicted to become much drier and warmer. Published scenarios suggest a more

challenging future for freshwater fish in much of the region, with many areas already drying up and many once widespread fish species now being restricted to small refuges. Dramatic reductions in river flows (due to water abstraction and increased frequency of droughts) will cause significant environmental, economic, and political problems that only increase in the future unless there is a radically different approach to water management across the region. The long-term effects of climate change on the unique and endemic freshwater fishes of West Asia are not difficult to imagine, as climate change will only accelerate the ongoing desiccation of the region's springs, lakes, and rivers.



The desertification of the Fertile Crescent in West Asia has long been underway, and the process has been accelerated by water extraction and climate change



The Qweiq in Syria was still a major river in the 19th century. Today, even its reservoirs are dry, and finding traces of the river is difficult. Water comes now from the Euphrates to the city of Aleppo.



In some regions of West Asia, such as Central Anatolia, marble quarrying is a major source of fine sediment in streams, threatening freshwater biodiversity.

Climate endgame

We humans are driving the Earth into a Pliocene, possibly Miocene climate scenario. Temperatures more than 2°C above pre-industrial levels have not been sustained at the Earth's surface since the Pleistocene epoch (or more than 2.6 million years ago). Despite 30 years of effort and some progress under the United Nations Framework Convention on Climate Change, anthropogenic greenhouse gas emissions (GHG) continue to rise. Even if anthropogenic GHG emissions were to decline soon (which seems unrealistic), there is feedback in the carbon cycle and potential tipping points that could lead to high GHG concentrations often missing from models. Examples include the thawing of Arctic permafrost releasing methane and CO₂, the loss of carbon from intense droughts and fires in the Amazon, and the apparent slowing of mitigating feedback such as the capacity of natural carbon sinks. These are unlikely to be proportional to warming, as is sometimes assumed. Instead, abrupt and/or irreversible changes may be triggered at a temperature tipping point. This is particularly worrying as human societies are locally adapted to specific climatic niches and the cumulative effects of warming are very likely to overwhelm societal adaptive capacity. Climate change will also directly trigger other catastrophic risks, such as international conflicts, or intensify the spread of infectious diseases and spillover risks. These could be powerful multipliers of extreme hazards. Climate change could aggravate vulnerabilities and cause multiple indirect stresses (such as economic damage, land loss, and water and food insecurity) that combine into system-wide synchronous failures. Extreme temperatures can affect the yields of major cereal crops, and deadly heat could also significantly affect populated areas in West Asia. There is a striking overlap between current vulnerable states and future areas of extreme warming, highlighting the political fragility of our region, but the 'four horsemen' of the climate change endgame are likely to be famine and malnutrition, extreme weather events, armed conflict, and vector-borne diseases. **Further reading.** Kemp et al. 2022 (climate change scenarios).

Introduction of non-native species. Many freshwater fish species are threatened by invasive non-native species, with many fish assemblages being replaced by communities dominated by non-native fish species. We know that 35 non-native freshwater fish species have been introduced, and 29 species have become established in West Asia. This does not include the unknown number of cichlids introduced from Lake Malawi into the warm spring of Nahal Amal in Israel or the many tropical species introduced by aquarium hobbyists into the hot springs of the upper Sakarya drainage in Türkiye. Four species of Xenocypridae are or have been

regularly stocked but have yet to become established in the region. Similarly, rainbow trout (*Oncorhynchus mykiss*), despite being the most commonly farmed and escaped freshwater fish species, has yet established very few populations recorded in the region. Species such as *Carassius auratus*, *Clarias gariepinus*, *Coptodon zillii*, *Cyprinus carpio*, *Gambusia holbrooki*, *Hemiculter leucisculus*, *Heteropneustes fossilis*, *Lepomis gibbosus*, *Oreochromis aureus*, *Poecilia latipinna*, *Pseudorasbora parva*, and *Rhinogobius* sp. have expanded their ranges within the region. They are believed to be negatively impacting native fish communities where

they occur. Although there are very few specific studies of the impact of these non-native species, it appears that they are out-competing native species, and the situation is particularly alarming in many regions as native habitats shrink due to habitat degradation, water scarcity, and

environmental changes. Research on the impact and distribution of non-native species is strongly recommended to understand their effects, behaviour better, and, in particular, ways and means to limit their spread.



The rapid spread of invasive species is a widespread threat throughout West Asia. Here, *Gambusia holbrooki* is in the habitat of *Anatolichthys transgrediens*.