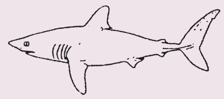
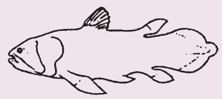
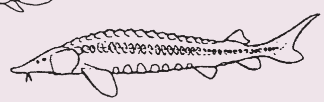
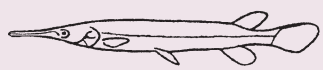
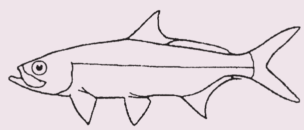
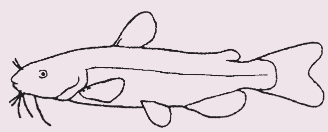
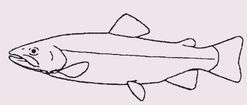
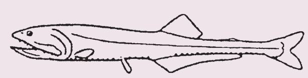
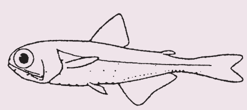
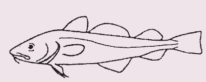
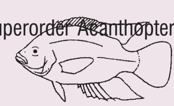
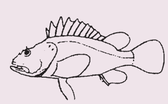
Table 1.1

The diversity of living fishes. Below is a brief listing of higher taxonomic categories of living fishes, in phylogenetic order. This list is meant as an introduction to major groups of living fishes as they will be discussed in the initial two sections of this book. Many intermediate taxonomic levels, such as infraclasses, subdivisions, and series, are not presented here; they will be detailed when the actual groups are discussed in Part III. Only a few representatives of interesting or diverse groups are listed. Taxa and illustrations from Nelson (2006).

Subphylum Cephalochordata – lancelets

- Subphylum Craniata
  - Superclass Myxinomorphi
    - Class Myxini – hagfishes 
  - Superclass Petromyzontomorphi
    - Class Petromyzontida – lampreys
  - Superclass Gnathostomata – jawed fishes
    - Class Chondrichthyes – cartilaginous fishes 
      - Subclass Elasmobranchii – sharklike fishes
      - Subclass Holocephali – chimaeras
    - Grade Teleostomi – bony fishes
      - Class Sarcopterygii – lobe-finned fishes
        - Subclass Coelacanthimorpha – coelacanths 
        - Subclass Dipnoi – lungfishes 
      - Class Actinopterygii – ray-finned fishes
        - Subclass Cladistia – bichirs 
        - Subclass Chondrostei – paddlefishes, sturgeons 
        - Subclass Neopterygii – modern bony fishes, including gars and bowfin[a] 
          - Division Teleostei
            - Subdivision Osteoglossomorpha – bonytongues
            - Subdivision Elopomorpha – tarpons, bonefishes, eels 
            - Subdivision Otocephala
              - Superorder Clupeomorpha – herrings
              - Superorder Ostariophysi – minnows, suckers, characins, loaches, catfishes 
            - Subdivision Euteleostei – advanced bony fishes
              - Superorder Protacanthopterygii – pickerels, smelts, salmons 
              - [Order Esociformes – pikes, mudminnows][b]
              - Superorder Stenopterygii – bristlemouths, marine hatchetfishes, dragonfishes 
              - Superorder Ateleopodomorpha – jellynose fishes
              - Superorder Cyclosquamata – greeneyes, lizardfishes 
              - Superorder Scopelomorpha – lanternfishes
              - Superorder Lampriomorpha – opahs, oarfishes
              - Superorder Polymixiomorpha – beardfishes
              - Superorder Paracanthopterygii – troutperches, cods, toadfishes, anglerfishes 
              - Superorder Acanthopterygii – spiny rayed fishes: mullets, silversides, killifishes, squirrelfishes, sticklebacks, scorpionfishes, basses, perches, tunas, flatfishes, pufferfishes, and many others  

[a] Gars and Bowfin are sometimes separated out as holosteans, a sister group to the teleosts (see Chapter 13).
[b] The esociform pikes and mudminnows are not as yet assigned to a superorder (see Chapter 14).

Table 2.1

Classification of Atlantic Herring, Yellow Perch, and Atlantic Mackerel.

Taxonomic unit	Herring	Perch	Mackerel
Division	Teleostei	→	→
Subdivision	Clupeomorpha	Euteleostei	→
Order	Clupeiformes	Perciformes	→
Suborder	Clupeoidei	Percoidei	Scombroidei
Family	Clupeidae	Percidae	Scombridae
Subfamily	Clupeinae	Percinae	Scombrinae
Tribe	Clupeini	Percini	Scombrini
Genus species subspecies	*Clupea* *harengus* *harengus*	*Perca* *flavescens*	*Scomber* *scombrus*
Author	Linnaeus	Mitchill	Linnaeus

Table 5.1

Diversity of fishes with air-breathing capabilities. Modified from Graham 1997a.

Order and family	No. genera/species	Habitat	Air-breathing organ	Respiratory pattern
Ceratodontiformes				
Ceratodontidae	1/1	F	Yes	AF
Lepidosireniformes				
Lepidosirenidae	1/1	F	Yes	AC, AmS
Protopteridae	1/4	F	Yes	AC, AmS
Polypteriformes				
Polypteridae	2/11	F	Yes	AC, AmV
Lepisosteiformes				
Lepisosteidae	2/7	F, B	Yes	AC
Amiiformes				
Amiidae	1/1	F	Yes	AC
Osteoglossiformes				
Osteoglossidae	2/2	F	Yes	AC (?)
Pantodontidae	1/1	F	Yes	AC
Notopteridae	3/5	F	Yes	AC
Gymnarchidae	1/1	F	Yes	AC/AF?
Elopiformes				
Megalopidae	1/2	F, M	Yes	AC
Anguilliformes				
Anguillidae	1/1	F	(Yes/no?)	AmV
Gonorhynchiformes				
Phractolaemidae	1/1	F	Yes	AC/AV?
Cypriniformes				
Cobitididae	4/7	F	Yes	AC + AF
Characiformes				
Erythrinidae	2/2	F	Yes	AC

Lebiasinidae	2/2	F	Yes	AC
Siluriformes				
Pangasiidae	1/4	F	Yes	AC
Clariidae	3/44	F	Yes	AC + AF, AmV + AmS
Heteropneustidae	1/2	F	Yes	AC, AmV + AmS
Aspredinidae	1/2	F	Yes	AF
Trichomycteridae	2/2	F	Yes	AF
Callichthyidae	4/131	F	Yes	AC
Loricariidae	10/14	F	Yes	AF
Gymnotiformes				
Hypopomidae	1/3	F	(Yes/no?)	AF
Gymnotidae	1/1	F	Yes	AF
Electrophoridae	1/1	F	Yes	AC
Salmoniformes				
Umbridae	2/5	F	Yes	AF
Lepidogalaxiidae	1/1	F	No	AF, AmS
Galaxiidae	3/10	F	No	AmV
Gobiesociformes				
Gobiesocidae	5/7	F, M	No	AmS

Table 5.1

Diversity of fishes with air-breathing capabilities. Modified from Graham 1997a.

Order and family	No. genera/species	Habitat	Air-breathing organ	Respiratory pattern
Cyprinodontiformes				
Aplocheilidae	1/5	F	No	AmV
Cyprinodontidae	1/4	F, M	No	AmV + AmS
Scorpaeniformes				
Cottidae	2/4	M	No	AmV
Perciformes				
Stichaeidae	4/5	M	No	AmS
Pholididae	3/5	M	No	AmS
Tripterygiidae	1/1	M	No	AmV
Labrisomidae	2/2	M	No	AmV
Blenniidae	7/32	M	No	AmV
Eleotridae	2/2	M	No	AF
Gobiidae	15/40	M, B	Yes/no	AF, AmV
Gobioididae	1/1	M, B	No	AF, AmS
Mastacembelidae	2/3	F, B	No	AmS
Anabantidae	3/24	F, B	Yes	AC, AmV + AmS
Belontiidae	12/44	F, B	Yes	AC, (AmV?)
Helostomatidae	1/1	F	Yes	AC
Osphronemidae	1/1	F	Yes	AC
Luciocephalidae	1/1	F	Yes	AC
Channidae	1/12	F	Yes	AC, AmS
Synbranchidae	3/14	F, B	Yes	AC + AF, AmV + AmS

Habitats: B, brackish; F, fresh water; M, marine.
Respiratory pattern: AC, aquatic continuous; AF, aquatic facultative; AmS, amphibious stranded; AmV, amphibious volitional.

Table 7.1

Percent of nitrogenous wastes eliminated as ammonia nitrogen and urea nitrogen through the gills and kidney of various fishes. From Wood (1993).

		Gill		Kidney		
Fishes	**Medium**	**Ammonia**	**Urea**	**Ammonia**	**Urea**	**Reference**
Agnatha						
Lamprey (*Lampetra*)[a]	FW	95	0	4	1	Read (1968)
Chondrichthes						
Dogfish (Squalus)[a]	SW	2	91	0	7	C. M. Wood & P. A. Wright (unpubl. data)
Sawfish (*Pristis*)[a]	FW	18	55	2	25	Smith & Smith (1931)
Bony fishes						
Carp (*Cyprinus*)[a]	FW	82	8	10	0	Smith (1929)
Goldfish (*Carassius*)[b]	FW	79	13	7	1	Smith (1929)
Catfish (*Heteropneustes*)[a]	FW	85	11	0	4	Saha et al. (1988)
Trout (*Oncorhynchus*)[a]	FW	86	11	1	2	Wood (1993)
Cichlid (*Oreochromis*)[b]	FW	61	25	0	14	Sayer & Davenport (1987)
Trout (*Oncorhynchus*)[a]	10% SW	56	32	10	2	Wright et al. (1992)
Mudskipper (*Periophthalmus*)[b]	25% SW	47	23	13	17	Morii et al. (1978)
Goby (*Boleophthalmus*)[b]	25% SW	61	14	11	14	Morii et al. (1978)
Poacher (*Agonus*)[b]	SW	41	9	43	7	Sayer & Davenport (1987)
Sculpin (*Taurulus*)[b]	SW	63	4	20	13	Sayer & Davenport (1987)
Wrasse (*Crenilabrus*)[b]	SW	67	2	28	3	Sayer & Davenport (1987)
Blenny (*Blennius*)[b]	SW	35	18	39	8	Sayer & Davenport (1987)

FW, freshwater; SW, sea water.

[a] Kidney excretion measured by urinary catheter. Therefore, any excretion via the skin or gut would be included in the "gill" component.

[b] Kidney excretion measured by placing the fish in a chamber with a water-tight curtain separating the anterior (head and gills) and posterior sections. Therefore, any excretion via the skin or gut is mostly included in the "kidney" (posterior) component.

Table 7.2

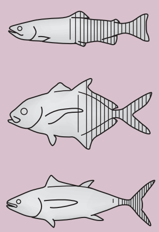
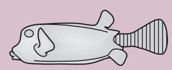
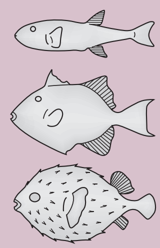
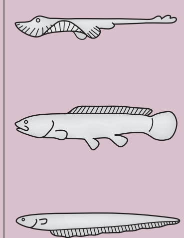
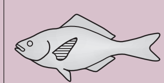
Plasma ionic concentrations (in milliosmoles per liter) of sea water, fresh water, and various fishes. From Evans (1993).

	Na	Cl	K	Mg	Ca	SO_4	Urea	TMAO	Total
Sea water	439	513	9.3	50	9.6	26	0	0	1050
Hagfish (*Myxine*)	486	508	8.2	12	5.1	3	–	–	1035
Lamprey (*Petromyzon*)	156	159	32	7.0	3.5	–	–	–	333
Shark[a]	255	241	6.0	3.0	5	0.5	441	72	1118
Teleost (*Lophius*)	180	196	5.1	2.5	2.8	2.7	–	–	452
Euryhaline teleost (*Pleuronectes*)	142	168	3.4	–	3.3	–	–	–	297
Fresh water (soft)	0.25	0.23	0.005	0.04	0.07	0.05	–	–	1
Lamprey (*Lampetra*)	120	104	3.9	2.0	2.5	–	–	–	272
Stingray (*Potamotrygon*)	150	150	–	–	–	–	1.3	–	308
Teleost (*Cyprinus*)	130	125	2.9	1.2	2.1	–	–	–	274
Euryhaline teleost (*Pleuronectes*)	124	132	2.9	–	2.7	–	–	–	240

[a] Na, Cl, urea, and total data from *Scyliorhinus canicula*; other data from *Squalus acanthias.*

Table 8.1

Form, function, and locomotion in fishes. About 12 generalized types of swimming are recognized among fishes. The body part or fin providing propulsion is indicated by cross-hatching; the density of shading denotes relative contribution to propulsion. These locomotory patterns correlate strongly with body shape, habitat, feeding ecology, and social behavior. Convergence among unrelated fishes in terms of body morphology, swimming, and ecology demonstrates the evolutionary interplay of form and function. See Lindsey (1978), Beamish (1978), Webb and Blake (1985), and Pough et al. (2001) for details. Line drawings from Lindsey (1978); used with permission.

	Swimming type					
	Via trunk and tail			Via fins		
		Via tail				
	Anguilliform	**Subcarangiform**[a] **Carangiform Thunniform**	**Ostraciiform**	**Tetraodontiform Balistiform Diodontiform**[b]	**Rajiform**[b] **Amiiform Gymnotiform**	**Labriform**[c]
						
Representative taxa	Eels, some sharks, many larvae	Salmon, jacks, mako shark, tuna	Boxfish, mormyrs, torpedo ray	Triggerfish, ocean sunfish, porcupinefish	Rays, Bowfin, knifefishes	Wrasses, surfperch
Propulsive force	Most of body	Posterior half of body	Caudal region	Median fin(s)	Pectorals, median fins	Pectoral fins
Propulsive form	Undulation	Undulation	Oscillation	Oscillation[d]	Undulation	Oscillation
Wavelength	0.5 to >1 wavelength	<1 (usually <0.5) wavelength			>>1 wavelength	
Maximum speed bl/s	Slow-moderate 2	Very fast – moderate 10–20	Slow?	Slow?	Slow to moderate 0.5	Slow 4
Body shape: lateral view cross-section	Elongate Round	Fusiform Round	Variable	Variable Often deep	Elongate Often flat	Variable
Caudal fin aspect ratio	Small Medium to low	Medium to large Low to high	Large Low	Small to medium Low	Variable Low	Large Low
Habitat	Benthic or suprabenthic	Pelagic, wc, schooling	Variable	wc	Suprabenthic	structure associated

bl/s, body lengths per second attainable; wc, up in water column.

[a] In subcarangiform types (salmons, cods) the posterior half of the body is used, carangiform swimmers (jacks, herrings) use the posterior third, and thunniform or modified carangiform swimmers (tunas, mako sharks) use mostly the caudal peduncle and tail (see text).

[b] Rajiforms (skates, rays) swim with undulating pectoral fins, amiiforms (Bowfin) undulate the dorsal fin, and gymnotiform swimmers (South American knifefishes, featherfins) undulate the anal fin.

[c] Labriform swimmers use the pectorals for slow swimming, but use the subcarangiform or carangiform mode for fast swimming.

[d] Balistiform and diodontiform swimming is intermediate between oscillation and undulation; porcupinefishes also use their pectoral fins.

Table 11.1

Repeated trends in fish evolution. Although fishes represent diverse and heterogeneous assemblages assigned to at least five different classes, certain repeated trends have characterized the evolution of these groups or of major, successful taxa within them. The following list summarizes traits or characteristics common to the evolution of several groups.

1 *Origin in oceans, radiation into fresh water*: thelodonts, pteraspidiforms, cephalaspidiforms, anaspids, placoderms, dipnoans, actinopterygians, teleosts, elasmobranchs

2 *Feeding and locomotion improvements*:

A. Diversification of dentition: acanthodians, placoderms, dipnoans, palaeoniscoids, teleosts, elasmobranchs

B. Improved inertial suction feeding: elasmobranchs, chondrosteans, neopterygians, teleosts

C. Increased caudal symmetry: dipnoans, osteolepidimorphs, coelacanthimorphs, palaeoniscoids, teleosts (reversed in pteraspidiforms and elasmobranchs)

D. Decreased external armor: pteraspidiforms, acanthodians, placoderms, dipnoans, osteolepidiforms, palaeoniscoids, teleosts

3 *Bases of spines become embedded in body musculature*: acanthodians, elasmobranchs

4 *Fusion of skull bones*: pteraspidiforms, acanthodians, placoderms, dipnoans, teleosts

5 *Bone preceded cartilage as skeletal support*: cephalaspidiforms (if ancestral to lampreys), dipnoans, acipenseriforms

6 *Electroreceptive ability*: pteraspidiforms, cephalaspidiforms, acanthodians, placoderms, dipnoans, actinistians, cladistians, chondrosteans, teleosts, elasmobranchs (for extinct groups, based largely on morphology of pits and canals in head and body; reinvented in modern teleosts) (see Pough et al. 1989; Chapters 6, 13)

Table 12.1

A summary of embryonic development and nutrition in chondrichthyans. From Nelson (2006), after Musick and Ellis (2005).

I All nutrition from yolk sac

A. Yolk sac viviparity (= lecithotrophic viviparity, ovoviparity): all living orders except heterodontiforms, lamniforms, and rajiforms

B. Yolk sac oviparity (= lecithotrophic oviparity): all living holocephalans, all heterodontiforms, and all Rajidae

II Some nutrition from mother (= matrotrophy)

A. Nutrition from uterine secretions (= histotrophy): many squaliforms and carchariniforms, and all myliobatiforms

B. Nutrition from eating unfertilized eggs (= oophagy): all lamniforms and some carchariniforms (includes embryophagy of *Carcharias taurus*) and pseudotriakids

Table 13.1

Characteristics of extant relict fishes. Presence (+) or absence (–) of a trait, or its condition, is indicated in the body of the table. Shared characteristics among unrelated forms are strong evidence of convergent evolution, since these groups have long histories of demonstrated, separate evolution.

Trait	Lungfishes			Chondrosteans				
	Australian	S. Am./Af.	Coelacanths	Sturgeons	Paddlefishes	Polypterids	Gars	Bowfin
Scales	Cycloid	Cycloid	Cycloid[a]	Scutes[b]	–[c]	Ganoid	Ganoid	Cycloid[d]
Gular plates	–	–	2	–	–	2	–	1
Spiracle	–	–	–	+	+?	+	–	–
Larva ext gills	–	+	–	–	–	+	–	–
Lungs[e]	Sing vent	Dbl vent	Fatfill gb	Dorsal gb	Dorsal gb	Dbl vent	Vasc gb	Vasc gb
Spiral valve	+	+	+	+	+	+	+ (remnant)	+ (remnant)
Centra	–	–	–	–	–	+	+[f]	+
Tail	Diphy	Diphy	Diphy	Hetero	Hetero	Hetero[g]	Abb hetero	Abb hetero
Lobed fins	+	–	+[h]	–	–	+	–	–
Electroreceptors	+	+	+	+	+	+	–	–
Chromosome 2N	54	38/34	48[i]	112	120	36	68	46

abb, abbreviate; Af., Africa; dbl, double; diphy, diphycercal; ext, external; hetero, heterocercal; gb, gas bladder; sing, single; S. Am., South America; vasc, vascularized, cellular; vent, ventral.

[a] Coelacanths are sometimes said to have cosmoid scales, however no extant fishes have scales containing cosmine (Jarvik 1980).

[b] Sturgeons have five longitudinal rows of bony scutes, plus "dermal ossifications" scattered around the body (Vladykov & Greeley 1963, p. 25). These scutes contain ganoin and could be considered ganoid.

[c] Paddlefishes are mostly naked, with four types of scales (fulcral, rhomboid, round-based, and denticular) scattered on the head, trunk, and tail; the histology of these scales is unclear. Trunk scales are more abundant on *Psephurus* than on *Polyodon* (Grande & Bemis 1991).

[d] Bowfin "cycloid" scales are convergent not homologous with those of teleosts (Grande & Bemis 1998).

[e] Outpocketings of the esophagus are gas bladders, but are often called lungs when their primary function is breathing atmospheric air.

[f] Gar centra are opisthocoelous (concave on rear face, convex on front).

[g] Lower lobe of brachiopterygian tail created by rays coming off the ventral surface of the notochord.

[h] Coelacanth fin bases are lobed except for first dorsal.

[i] Coelacanth chromosomes are more like those of ancient frogs than of other sarcopterygians such as lungfishes (Bogart et al. 1994).

Table 16.1

Numbers of species in selected genera of inshore fishes from the western Atlantic, estern Pacific, and Gulf of Guinea (numbers in parentheses indicate freshwater species of marine origin).

Family	Genus	Western Atlantic	Eastern Pacific	Eastern Atlantic
Scombridae	*Scomberomorus*	4	2	1
Belonidae	*Strongylura*	3 (+1)	2 (+1)	1
Hemiramphidae	*Hyporhamphus*	3 (+2)	4	1
Batrachoididae	*Batrachoides*	3 (+1)	3	1
Totals		13 (+4)	11 (+1)	4

Table 16.2

Primary, secondary, and selected peripheral freshwater fish families and the geographic areas where they occur.

Family*	Division	Nearctic	Neotropical	Palearctic	Ethiopian	Oriental	Australian
Petromyzontidae	per	x		x			
Geotriidae	per		x				x
Mordaciidae	per		x				x
Potamotrygonidae	per		x				
Ceratodontidae	1st						x
Lepidosirenidae	1st		x				
Protopteridae	1st				x		
Polypteridae	1st				x		
Acipenseridae	per	x		x		x	
Polyodontidae	1st	x		x			
Lepisosteidae	2nd	x	x				
Amiidae	1st	x					
Denticipitidae	1st				x		
Osteoglossidae	1st		x		x	x	x
Pantodontidae	1st				x		
Hiodontidae	1st	x					
Notopteridae	1st				x	x	
Mormyridae	1st				x		
Gymnarchidae	1st				x		

Salmonidae	per	x		x			
Plecoglossidae	per			x			
Osmeridae	per	x		x			
Salangidae	per			x		x	
Retropinnidae	per						x
Prototroctidae	per						x
Galaxiidae	per		x		x		x
Aplochitonidae	per		x				x
Lepidogalaxiidae	?						x
Esocidae	1st	x		x			
Umbridae	1st	x		x			

Table 16.2

Primary, secondary, and selected peripheral freshwater fish families and the geographic areas where they occur.

Family*	Division	Nearctic	Neotropical	Palearctic	Ethiopian	Oriental	Australian
Kneriidae	1st				x		
Phractolaemidae	1st				x		
Characidae	1st	x	x		x		
Erythrinidae	1st		x				
Ctenoluciidae	1st		x				
Hepsetidae	1st				x		
Cynodontidae	1st		x				
Lebiasinidae	1st		x				
Parodontidae	1st		x				
Gasteropelecidae	1st		x				
Prochilodontidae	1st		x				
Curimatidae	1st		x				
Anostomidae	1st		x				
Hemiodontidae	1st		x				
Chilodontidae	1st		x				
Distichodontidae	1st				x		
Citharinidae	1st				x		
Ichthyboridae	1st				x		
Gymnotidae	1st		x				

Electrophoridae	1st		x				
Apteronotidae	1st		x				
Rhamphichthyidae	1st		x				
Cyprinidae	1st	x		x	x	x	
Gyrinocheilidae	1st					x	
Psilorhynchidae	1st					x	
Catostomidae	1st	x		x			
Homalopteridae	1st					x	
Cobitidae	1st			x	x	x	
Diplomystidae	1st		x				
Ictaluridae	1st	x					

Table 16.2

Primary, secondary, and selected peripheral freshwater fish families and the geographic areas where they occur.

Family*	Division	Nearctic	Neotropical	Palearctic	Ethiopian	Oriental	Australian
Bagridae	1st			x	x	x	
Cranoglanididae	1st					x	
Siluridae	1st			x		x	
Schilbeidae	1st				x	x	
Pangasiidae	1st					x	
Amblycipitidae	1st					x	
Amphiliidae	1st				x		
Akysidae	1st					x	
Sisoridae	1st			x		x	
Clariidae	1st			x	x	x	
Heteropneustidae	1st					x	
Chacidae	1st					x	
Olyridae	1st					x	
Malapteruridae	1st				x		
Mochokidae	1st				x		
Doradidae	1st		x				
Auchenipteridae	1st		x				
Aspredinidae	1st		x				
Pimelodontidae	1st		x				
Ageneiosidae	1st		x				
Hypophthalmidae	1st		x				
Helogeneidae	1st		x				

Cetopsidae	1st		x				
Trichomycteridae	1st		x				
Callichthyidae	1st		x				
Loricariidae	1st		x				
Astroblepidae	1st		x				
Amblyopsidae	1st	x					
Aphredoderidae	1st	x					
Percopsidae	1st	x					

Table 16.2

Primary, secondary, and selected peripheral freshwater fish families and the geographic areas where they occur.

Family*	Division	Nearctic	Neotropical	Palearctic	Ethiopian	Oriental	Australian
Oryziatidae	2nd			x		x	
Adrianichthyidae	2nd					x	
Horaichthyidae	2nd					x	
Cyprinodontidae	2nd	x	x	x	x	x	
Goodeidae	2nd	x					
Anablepidae	2nd		x				
Jenynsiidae	2nd		x				
Poeciliidae	2nd	x	x				
Melanotaeniidae	2nd						x
Neostethidae	per					x	
Phallostethidae	per					x	
Gasterosteidae	per	x		x			
Indostomidae	per					x	
Channidae	1st			x	x	x	
Synbranchidae	per		x	x	x	x	x
Cottidae	per	x		x			
Cottocomephoridae	per			x			
Comephoridae	per			x			
Percicthyidae	per	x	x	x			x
Centrarchidae	1st	x					
Percidae	1st	x		x			
Toxotidae	per					x	x
Scatophagidae	per				x	x	x

Enoplosidae	per						x
Nandidae	1st		x		x	x	
Embiotocidae	per	x		x			
Cichlidae	2nd	x	x		x	x	
Gadopsidae	per						x
Bovichthyidae	per		x				x
Rhyacichthyidae	per					x	x

Table 16.2

Primary, secondary, and selected peripheral freshwater fish families and the geographic areas where they occur.

Family*	Division	Nearctic	Neotropical	Palearctic	Ethiopian	Oriental	Australian
Kurtidae	per					x	x
Anabantidae	1st				x	x	
Belontiidae	1st			x		x	
Helostomatidae	1st					x	
Osphronemidae	1st					x	
Luciocephalidae	1st					x	
Mastacembelidae	1st			x	x	x	
Chaudhuriidae	1st					x	

* The following widely distributed peripheral families (mostly marine) are omitted from this analysis. Carcharhinidae, Elopidae, Megalopidae, Anguillidae, Clupeidae, Engraulidae, Chanidae, Ariidae, Plotosidae, Batrachoididae, Gadidae, Ophidiidae, Hemiramphidae, Belonidae, Atherinidae, Syngathidae, Alabetidae, Centropomidae, Ambassidae, Teraponidae, Kuhiidae, Sparidae, Sciaenidae, Monodactylidae, Mugilidae, Polynemidae, Gobiidae, Soleidae, Tetraodontidae.
1st = primary; 2nd = secondary; per = peripheral.
From Berra 1981.

Table 17.1

Chromosome number, nuclear genome size, and mitochondrial genome size in select fishes. C-values indicate the amount of DNA in a haploid complement (a single copy of the chromosomes), measured in picograms per cell. References for chromosome number and C-value are available from the Animal Genome Size database (http://www.genomesize.com). The nuclear genome sizes, in millions of base pairs (mb), are from Roest Crollius and Weissenbach (2005). References for mitochondrial genome sizes are given, and sizes are presented in thousands of base pairs (kb). In some cases the chromosome number could not be obtained from the same species used to estimate genome size, so values are obtained from congeners (fish in the same genus) as follows: the chromosome number for *Anguilla japonica* is based on congeners *A. rostrata* and *A. anguilla*; for *Sardinops* it is based on *S. sajax*; for *Fugu* on *F. niphobles*; and for *Tetraodon* on *T. palembangensis*. The mtDNA genome size for dogfish is based on *Scyliorhinus canicula*.

Species	Number of chromosomes	Nuclear genome size (C-value/mb)	Mitochondrial genome size (kb)
Sea lamprey *Petromyzon marinus*	168 (Vialli 1957)	2.44/n.a.	16.201 (Lee & Kocher 1995)
Great White Shark *Carcharodon carcharias*	82 (Schwartz & Maddock 1986)	6.45/n.a.	n.a.
Dogfish *Squalus acanthias*	60 (Pedersen 1971)	6.88/n.a.	16.696 (Delarbre et al. 1998)
Coelacanth *Latimeria* spp.	48 (Cimino & Bahr 1974)	3.61/n.a.	16.446 (Inoue et al. 2005)
Lungfish *Protopterus dolloi*	68 (Vervoort 1980)	81.6/n.a.	16.646 (Zardoya & Meyer 1996)

Bichir *Polypterus ornatipinnis*	36 (Bachmann 1972	5.85/n.a.	16.624 (Noack et al. 1996)
Eel *Anguilla japonica*	38 (Hinegardner & Rosen 1972)	1.40/n.a.	16.685 (Inoue et al. 2001)
Sardine *Sardinops melanostictus*	48 (Ida et al. 1991)	1.35/n.a.	16.881 (Inoue et al. 2000)
Carp *Cyprinus carpio*	100 (Hinegardner & Rosen 1972)	1.70/n.a.	16.575 (Chang et al. 1994)
Zebrafish *Danio rerio*	48 (Hinegardner & Rosen 1972)	1.8/1700	16.596 (Broughton et al. 2001)
Stickleback *Gasterosteus* spp.	42 (Hinegardner & Rosen 1972)	0.70/675	
Chinook Salmon *Oncorhynchus tshawytscha*	56 (Ojima et al. 1963)	3.04/3100	16.644 (Wilhelm et al. 2003)
Rainbow Trout *Oncorhynchus mykiss*	60 (Rasch 1985)	2.60/2700	16.660 (Zardoya et al. 1995)
Medaka *Oryzias* sp.	48 (Uwa 1986)	0.95/800	
Pufferfish *Fugu rubripes*	44 (Ojima & Yamamoto 1990)	0.42/380	16.447 (Elmerot et al. 2002)
Green Pufferfish *Tetraodon nigroviridis*	42 (Hinegardner & Rosen 1972)	0.35/350	

n.a., not available.

Table 17.2

Population genetic diversity averaged across three types of fishes, for allozymes (113 species; Ward et al. 1994) and for microsatellites (32 species; DeWoody & Avise 2000). Heterozygosity (H) values are progressively higher in freshwater, anadromous, and marine fishes. Population structure (F_{ST}) values from the allozyme survey are progressively lower in freshwater, anadromous, and marine fishes.

Habitat	H allozymes	H microsatellites	F_{ST} allozymes
Freshwater	0.046	0.54	0.22
Anadromous	0.052	0.68	0.11
Marine	0.059	0.77	0.06

Table 17.3

Comparison of pelagic larval duration and population structure in 15 Atlantic reef fishes. Pelagic larval duration does not have a significant correlation with population structure (ϕ_{ST} values). Surveys are based on mtDNA cytochrome *b* sequences except for the Pygmy Angelfish, which employed mtDNA control region sequences. The pelagic larval duration for Trumpetfish, Rock Hind, Soapfish, and Pygmy Angelfish are estimates from other members of the genus or family. An asterisk indicates species with deep population structure and suspected cryptic evolutionary lineages. From Bowen et al. (2006b).

Species	Mean pelagic duration (days)	Population structure (ϕ_{ST})	Reference for pelagic duration	Reference for population structure
Slippery Dick *Halichoeres bivittatus*	24	0.77*	Sponaugle & Cowen 1997	Rocha et al. (2005a)
Black-ear Wrasse *H. poey*	25	0.23	Sponaugle & Cowen 1997	Rocha et al. (2005a)
Pudding Wife *H. radiatus*	26	0.83*	Sponaugle & Cowen 1997	Rocha et al. (2005a)
Clown Wrasse *H. maculipinna*	29	0.88*	Sponaugle & Cowen 1997	Rocha et al. (2005a)
Pygmy Angelfish *Centropyge* spp.	33	0.62*	Thresher & Brothers 1985	Bowen et al. (2006a)
Redlip Blenny *Ophioblennius atlanticus*	38	0.93*	D. Wilson, pers. comm.	Muss et al. (2001)
Greater Soapfish *Rypticus saponaceous*	40	0.87*	Lindeman et al. 2000	Carlin et al. (2003)
Rock Hind *Epinephelus adscensionis*	40	0.93*	Lindeman et al. 2000	Carlin et al. (2003)
Ocean Surgeonfish *Acanthurus bahianus*	52	0.72*	M. Bergenius, pers. comm.	Rocha et al. (2002)
Blue Tang *A. coeruleus*	52	0.36	B. Victor, pers. comm.	Rocha et al. (2002)
Doctorfish *A. chirurgus*	55	0.02	Bergenius et al. 2002	Rocha et al. (2002)
Blackbar Soldierfish *Myripristis jacobus*	58	0.01	Tyler et al. 1993	Bowen et al. (2006b)
Longjaw Squirrelfish *Holocentrus ascensionis*	71	0.09	Tyler et al. 1993	Bowen et al. (2006b)
Goldspot Goby *Gnatholepis thompsoni*	89	0.47	Sponaugle & Cowen 1994	Rocha et al. (2005b)
Trumpetfish *Aulostomus strigosus*	93	0.59	H. Fricke & P. Heemstra, pers. comm.	Bowen et al. (2001)

Table 17.4

The number of management units and evolutionary significant units (ESUs) within each species of salmon on the West coast of the United States. Note that management units can be defined with ecology and life history, as well as shallow population genetic structure. The higher level designation of ESU requires deep population structure or other evidence of evolutionary divergence. From Waples et al. (2001).

	Management units				
Species	**Genetics**	**Ecology**	**Life history**	**Total**	**ESUs**
Pink	2	2	1	5	2
Chum	2	4	1	7	4
Sockeye	9	4	6	19	7
Coho	2	6	1	9	7
Chinook	10	11	7	28	17
Steelhead	7	11	7	25	15
Cutthroat	3	6	2	11	6

Table 18.1

Representative teleostean taxa from the three major deepsea habitat types. The approximate number of deepsea families is given in parentheses the first time a group is listed. Based on Marshall (1971, 1980); Wheeler (1975); Gage and Tyler (1991); Nelson (2006). Figures from Marshall (1971), used with permission.

Mesopelagic (750 spp.)

Superorder Elopomorpha
- Albuliformes (3): Notacanthidae – spiny eels
- Anguilliformes (6): Nemichthyidae – snipe eels; Synaphobranchidae – cutthroat eels

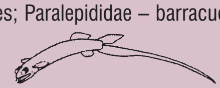
Superorder Protacanthopterygii
- Argentiniformes (5): Microstomatidae – deepsea smelts; Opisthoproctidae – barreleyes; Alepocephalidae – slickheads; Platytroctidae – tubeshoulders

Superorder Stenopterygii
- Stomiiformes (5): Gonostomatidae – bristlemouths; Sternoptychidae – hatchetfishes; Stomiidae – barbeled dragonfishes


hachetfish

Superorder Cyclosquamata
- Aulopiformes (11): Evermannellidae – sabertooth fishes; Alepisauridae – lancetfishes; Paralepididae – barracudinas; Giganturidae – telescopefishes

Superorder Scopelomorpha
- Myctophiformes (2): Neoscopelidae – blackchins; Myctophidae – lanternfishes

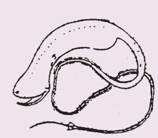

giganturid

Superorder Lampriomorpha
- Lampriformes (4): Stylephoridae – tube-eyes

Superorder Acanthopterygii
- Stephanoberyciformes: Mirapinnidae – hairyfish
- Perciformes: Chiasmodontidae – swallowers; Gempylidae – snake mackerels

Bathypelagic (200 spp.)

Superorder Elopomorpha
- Anguilliformes: Nemichthyidae – snipe eels; Serrivomeridae – sawtooth eels
- Saccopharyngiformes: Saccopharyngidae – swallower and gulpers; Eurypharyngidae – pelican eels

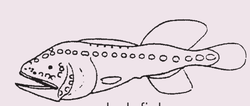

gulper

Superorder Protacanthopterygii
- Argentiniformes: Alepocephalidae – slickheads

Superorder Stenopterygii
- Stomiiformes: Gonostomatidae – bristlemouths

Superorder Paracanthopterygii
- Gadiformes: Melanonidae – pelagic cods; Macrouridae – grenadiers and rattails
- Ophidiiformes: Ophidiidae – cusk-eels; Bythitidae – viviparous brotulas
- Lophiiformes (12): Ceratioidei – deepsea anglerfishes, seadevils (11)

Superorder Acanthopterygii
- Stephanoberyciformes: Melamphaidae – bigscale fishes; Stephanoberycidae – pricklefishes; Cetomimoidea – whalefishes (3)
- Beryciformes (9): Anoplogastridae – fangtooths
- Perciformes: Chiasmodontidae – swallowers


whalefish

Benthal[a] (1000 benthopelagic and benthic spp.)
Superorder Elopomorpha
Albuliformes: Halosauridae – halosaurs; Notacanthidae – spiny eels
Anguilliformes: Synaphobranchidae – cutthroat eels
Superorder Cyclosquamata
Aulopiformes: Synodontidae – lizardfishes; Chlorophthalmidae – greeneyes; Ipnopidae – spiderfishes and tripodfishes
Superorder Paracanthopterygii
Gadiformes: Macrouridae – grenadiers; Moridae – morid cods; Merlucciidae – merlucciid hakes
Ophidiiformes: Ophidiidae – cusk-eels; Bythitidae – viviparous brotulas; Aphyonidae – aphyonids
Lophiiformes: Ogcocephalidae – batfishes
Superorder Acanthopterygii
Scorpaeniformes: Liparidae – snailfishes
Perciformes: Zoarcidae – eel-pouts; Bathydraconidae – Antarctic dragonfishes; Caproidae – boarfishes


brotula

[a] Chimaeras and many squaloid sharks are benthopelagic. Most benthal fishes live above 1000 m, although some grenadiers and rattails live between 1000 and 4000 m, macruronid southern hakes live somewhat deeper, tripodfish live to 6000 m, snailfishes to 7000 m, and neobythitine cusk-eels live down to 8000 m.

Table 18.2

A sampling of freshwater fishes that inhabit torrent and rapid zones of streams and rivers. Most if not all have converged on body shapes and proportions, fin arrangements and shapes, and other traits that reflect the need to hold position on the bottom in swift flowing water.

Order	Family	Scientific name[a]	Common name
Gonorynchiformes	Kneriidae	*Kneria*	Knerias
Cypriniformes	Cyprinidae	*Rhinichthys cataractae*	Longnose Dace
Cypriniformes	Psilorhynchidae	*Psilorhynchus*	Mountain carps
Cypriniformes	Gyrinocheilidae	*Gyrinocheilus*	Algae eaters
Cypriniformes	Balitoridae	*Balitora*, *Gastromyzon*	Hillstream loaches
Characiformes	Parodontidae	*Parodon*	Parodontids
Siluriformes	Amphiliidae	*Amphilius*	Loach catfishes
Siluriformes	Nematogenyidae	*Nematogenys inermis*	Mountain Catfish
Siluriformes	Astroblepidae	*Astroblepus*	Climbing catfishes
Siluriformes	Loricariidae	*Otocinclus*, *Farlowella*	Suckermouth armored catfishes
Siluriformes	Amblycipitidae	*Amblyceps*	Torrent catfishes
Siluriformes	Sisoridae	*Sisor rheophilus*	Sisorid catfishes
Perciformes	Cheimarrhichthyidae	*Cheimarrichthys fosteri*	New Zealand Torrentfish
Perciformes	Gobiesocidae	*Gobiesox fluviatilis*	Mountain Clingfish
Perciformes	Rhyacichthyidae	*Rhyacichthys*	Loach goby
Perciformes	Gobiidae	*Lentipes concolor*	O'opu Alamo'o

[a] The specific name is given for representative or monotypic species, and the generic name is given when several species exist.

Table 21.1

A summary of components of breeding systems in fishes, with representative taxa. Accurate categorization is often hampered by the difficulty of following individual fish over extended periods in the wild. Although families are listed for some components, exceptions are common within a family. Modified from Wootton (1990), used with permission.

I. *Number of breeding opportunities*
- A. Semelparous (spawn once and die): lampreys, river eels, some South American knifefishes, Pacific salmons, Capelin
- B. Iteroparous (multiple spawnings):
  1. A single, extended spawning season: most annuals (rivulines)
  2. Multiple spawning seasons: most species (elasmobranchs, lungfishes, perciforms)

II. *Mating system*
- A. Promiscuous (both sexes with multiple partners during breeding season): herrings, livebearers, sticklebacks, greenlings, epinepheline seabasses, damselfishes, wrasses, surgeonfishes
- B. Polygamous:
  1. Polygyny (male has multiple partners each breeding season): sculpins, sunfishes, darters, most cichlids; or polygyny (haremic): serranine seabasses, angelfishes, hawkfishes, humbug damselfishes, wrasses, parrotfishes, surgeonfishes, trunkfishes, triggerfishes
  2. Polyandry (female has multiple partners each breeding season): anemonefishes (in some circumstances)
- C. Monogamous (mating partners remain together for extended period or the same pair reforms to spawn repeatedly): bullheads, some pipefishes and seahorses, *Serranus*, hamlets, jawfishes, damselfishes, tilefishes, butterflyfishes, hawkfishes, cichlids, blennies

III. *Gender system*
- A. Gonochoristic (sex fixed at maturation): most species (e.g., elasmobranchs, lungfishes, sturgeons, bichirs, bonytongues, clupeiforms, cypriniforms, salmoniforms, beryciforms, scombroids)
- B. Hermaphroditic (sex may change after maturation):
  1. Simultaneous (both sexes in one individual): *Kryptolebias*, hamlets, *Serranus*
  2. Sequential (individual is first one sex and then changes to the other):
     - a. Protandrous (male first, change to female): anemonefishes, some moray eels, *Lates calcarifer* (Centropomidae)
     - b. Protogynous (female first, change to male): *Anthias*, humbug damselfishes, angelfishes, wrasses, parrotfishes, gobies
- C. Parthenogenetic (egg development occurs without fertilization):
  1. Gynogenetic: *Poeciliopsis*, *Poecilia formosa* (no male contribution, only egg activation)
  2. Hybridogenetic: *Poeciliopsis* (male contribution discarded each generation)

IV. *Secondary sexual characteristics* (traits not associated with fertilization or parental care)
- A. Monomorphic (no distinguishable external difference between sexes): most species (clupeiforms, carp, most catfishes, frogfishes, mullets, snappers, butterflyfishes)
- B. Sexually dimorphic:
  1. Permanently dimorphic (sexes usually distinguishable in mature individuals): *Poecilia*, anthiine seabasses, dolphinfishes, *Cichlasoma*, some angelfishes, wrasses, parrotfishes, chaenopsid blennies, dragonets, Siamese Fighting Fishes
  2. Seasonally dimorphic (including color change only during spawning act): many cypriniforms, Pacific salmons, sticklebacks, lionfishes, epinepheline seabasses, some cardinalfishes (female), darters, some angelfishes, damselfishes, wrasses, blennies, surgeonfishes, porcupinefishes (female)
  3. Polymorphic (either sex has more than one form): precocial and adult male salmon; primary and secondary males in wrasses and parrotfishes

V. *Spawning site preparation* (see Table 21.2)
- A. No preparation: most species of broadcast spawners (e.g., herring)
- B. Site prepared and defended: sticklebacks, damselfishes, sunfishes, cichlids, blennies, gobies

VI. *Place of fertilization*
- A. External: most species (lampreys, lungfishes, Bowfin, tarpons, eels, herrings, minnows, characins, salmons, pickerels, codfishes, anglerfishes, sunfishes, marlins, flatfishes, pufferfishes, porcupinefishes)
- B. Internal: elasmobranchs, coelacanths, livebearers, freshwater halfbeaks, scorpionfishes, surfperches, eel-pouts, clinids
- C. Buccal (in the mouth): some cichlids

VII. *Parental care* (see Table 21.2)
- A. No parental care: most species
- B. Male parental care: sea catfishes, sticklebacks, pipefishes, greenlings
- C. Female parental care:
  1. Oviparity with post-spawning care: *Oreochromis*
  2. Ovoviviparity without post-spawning care: rockfishes (*Sebastes*)
  3. Viviparity without post-spawning care: elasmobranchs, *Poecilia*, surfperches
- D. Biparental care: bullheads, discus, *Cichlasoma*, anemonefishes
- E. Juvenile helpers: some African cichlids (*Lamprologus*, *Neolamprologus*, *Julidochromis*)

Table 21.2

A classification of reproductive guilds in teleost fishes, based largely on spawning site and parental care patterns. Specific examples of many groups are given in Table 20.1. From Moyle and Cech (2004) and Wootton (1990, 1999), based on Balon (1975, 1981) with modifications.

I. *Nonguarding species*
   A. Open substrate spawners:
      1. Pelagic spawners
      2. Benthic spawners:
         a. Spawners on coarse bottoms (rocks, gravel): (i) pelagic free embryo and larvae; (ii) benthic free embryo and larvae
         b. Spawners on plants: (i) nonobligatory; (ii) obligatory
         c. Spawners on sandy bottoms
   B. Brood hiders:
      1. Benthic spawners
      2. Cave spawners
      3. Spawners on/in invertebrates
      4. Beach spawners
      5. Annual fishes

II. *Guarders*
   A. Substrate choosers:
      1. Rock spawners
      2. Plant spawners
      3. Terrestrial spawners
      4. Pelagic spawners
   B. Nest spawners:
      1. Rock and gravel nesters
      2. Sand nesters
      3. Plant material nesters:
         a. Gluemakers
         b. Non-gluemakers
      4. Bubble nesters
      5. Hole nesters
      6. Miscellaneous materials nesters
      7. Anemone nesters

III. *Bearers*
   A. External bearers:
      1. Transfer brooders
      2. Forehead brooders
      3. Mouth brooders
      4. Gill chamber brooders
      5. Skin brooders
      6. Pouch brooders
   B. Internal bearers:
      1. Ovi-ovoviviparous
      2. Ovoviviparous
      3. Viviparous

Table 23.1

Diel activity patterns – defined as when fishes feed – of better known groups and families of teleostean fishes. For many families, activity patterns are only known for a few species. Some large families appear under more than one heading because of intrafamilial variability. From Helfman (1993) and other sources, especially Lowe and Bray (2006).

All or most species diurnal

Acanthuridae (surgeonfishes), Ammodytidae (sandeels), Anthiinae (anthiine seabasses), Atherinopsidae (surfsmelts), Chaetodontidae (butterflyfishes), Characoidei (characins), Cichlidae (cichlids), Cirrhitidae (hawkfishes), Cyprinodontidae (killifishes), Embiotocidae (surfperches, except Walleye and Rubberlip), Esocidae (pikes), Gasterosteidae (sticklebacks), Gobiidae (gobies), Kyphosidae (sea chubs), Labridae (wrasses), Mugillidae (mullets), Mullidae (goatfishes), Percidae (perches, darters, except pikeperches), Pomacanthidae (angelfishes), Pomacentridae (damselfishes), Scaridae (parrotfishes), Siganidae (rabbitfishes), Synodontidae (lizardfishes)

All or most species nocturnal

Anguilliformes (most true eels, some morays, and congers are diurnal), Anomalopidae (flashlight fishes), Apogonidae (cardinalfishes), Batrachoididae (toadfishes), Clupeidae (herrings), Diodontidae (porcupinefishes), Grammistidae (soapfishes), Gymnotoidei (South American knifefishes), Haemulidae (grunts), Holocentridae (squirrelfishes), Kuhliidae (aholeholes), Lutjanidae (snappers), Mormyridae (elephantfishes), Ophidiidae (cusk-eels), Pempheridae (sweepers), Priacanthidae (glasseye snappers), Sciaenidae (drums), Siluriformes (catfishes)

Both diurnal and nocturnal species

Carangidae (jacks), Catostomidae (suckers), Centrarchidae (sunfishes), Congridae (conger eels), Cyprinidae (minnows), Gadoidei (cods), Leiognathidae (ponyfishes), Mullidae (goatfishes), Pleuronectiformes (flatfishes), Salmonidae (salmon, trout), Scorpaenidae (rockfishes: diurnal juveniles, nocturnal adults), Serranidae (groupers), Sphyraenidae (barracudas)
Several crepuscular species[a] Carangidae (jacks), Elopidae (tarpons), Fistulariidae (cornetfishes), Gadoidei (cods), Lutjanidae (snappers), Serranidae (groupers)
Several species without distinct activity periods Aulostomidae (trumpetfishes), Muraenidae (moray eels), Pleuronectiformes (flatfishes), Scombridae (mackerels, tunas), Scorpaenidae (scorpionfishes, rockfishes), Serrandiae (groupers)

[a] Also active at other times.

Table 23.2

Families of known diadromous fishes. Modified from McDowall (1987).

Anadromous	Catadromous	Amphidromous
Petromyzontidae, lampreys	Anguillidae, true eels	Clupeidae, herrings
Geotriidae, southern lampreys	Galaxiidae, galaxiids	Plecoglossidae, Ayu
Mordaciidae, southern lampreys	Scorpaenidae, scorpionfishes	Prototroctidae, southern graylings
Acipenseridae, sturgeons	Moronidae, temperate basses	Galaxiidae, galaxiids
Clupeidae, herrings	Centropomidae, snooks	Syngnathidae, pipefishes
Ariidae, sea catfishes	Kuhliidae, aholeholes	Cottidae, sculpins
Salmonidae, salmons	Mugilidae, mullets	Mugiloididae, sandperches
Osmeridae, smelts	Bovichthyidae, bovichthyids	Eleotridae, sleepers
Retropinnidae, New Zealand smelts	Pleuronectidae, righteye flounders	Gobiidae, gobies
Galaxiidae, galaxiids		
Gadidae, cods		
Gasterosteidae, sticklebacks		
Cottidae, sculpins		
Moronidae, temperate basses		
Gobiidae, gobies		
Soleidae, soles		

Table 24.1

A life table for a cohort of Brook Trout, *Salvelinus fontinalis*, in Hunt Creek, Michigan for the year 1952. Survivorship (l_x) is the probability that an individual female will live to age x, reproductive output (m_x) is the mean number of daughters produced by a female of that age (estimated as half the number of eggs produced). The reproductive rate of the population (net reproductive rate, R_0) is the sum of the survivorship and reproductive output columns ($= \Sigma l_x m_x$), which equals the average number of females being produced per female in the cohort. When R_0 is greater than 1 the population is growing, when it is less than 1 the population is shrinking. After Wootton (1990), based on data of McFadden et al. (1967).

Age class, in years (x)	Survivorship (l_x)	Reproductive output per female (m_x)	Reproductive rate of population ($l_x m_x$)
0	1.0000	0	0
1	0.0528	0	0
2	0.0206	33.7	0.6952
3	0.0039	125.6	0.4898
4	0.00051	326.9	0.1667
			$R_0 = 1.352$

Table 25.1

Top-down effects of fishes in temperate lakes and streams. Whether the same suite of effects and relationships occurs in tropical freshwater systems or marine systems remains largely unstudied. Adapted from Northcote (1988).

Activity	Factors affected	Mechanism and consequence
Direct feeding	Water transparency	• Searching stirs up bottom sediments and lowers transparency • Intense herbivory may increase transparency through removal of phytoplankton; turbidity may increase due to excretion and fertilization
	Nutrient release, cycling	• Benthic food searching increases mud–water nutrient cycling • Littoral vegetation grazing and processing increase nutrient cycling
	Phytoplankton	• Littoral vegetation grazing and processing increase nutrient cycling and water transparency • Heavy grazing commonly increases production
	Periphyton	• Strong cropping leads to increase in biomass
	Macrophytes	• Strong cropping leads to increase in biomass
	Zooplankton	• Strong cropping has an effect on abundance especially of larger forms • Some evidence of increased production
	Zoobenthos	• Strong cropping effect on abundance is common but may vary in lakes and streams • Marked seasonality in effects due to distribution and size of feeding fish • Production is often increased in lakes but not in streams
Selective predation (due to size, visibility, motility)	Phytoplankton	• Shifts in relative abundance of algal size and species composition
	Zooplankton	• Shifts in relative abundance of species reduces algal grazing efficiency and water transparency • Changes in clutch size and timing of maturation
	Zoobenthos	• Heaviest predation on large forms affects their cover selection, activity patterns, and reproductive behavior
	Nutrient release	• Shift to smaller body size of zooplankton increases nutrient release
Excretion	Nutrient release	• Liquid release provides quick, patchy availability • Feces release provides slower patchy availability after remineralization • Epidermal mucous release increases iron availability to algae via chelation
Decomposition	Nutrient release	• Carcass remineralization provides slow, patchy releases
Migration with excretion or decomposition	Nutrient enrichment	• Transport of excreta or body decomposition products from high nutrient to low nutrient regions (sea to inland water, stream lower to upper reaches, lake layers)

Table 26.1

Endangered and threatened freshwater[a] fishes of North America, as recognized and protected by federal authorities under the US Endangered Species Act (ESA), the Canadian Species at Risk Act (SARA), and the Mexican Norma Oficial Mexicana NOM-059-ECOL-2001. "Endangered" species face imminent extinction through all or a significant part of their range. "Threatened" species are likely to become endangered in the near future.

Family	Species native to North America[b]	Number of taxa designated as:					
		Endangered[c]			Threatened		
		USA	CA	MX	USA	CA	MX
Petromyzontidae, lampreys	20	0	1	2	0	1	1
Acipenseridae, sturgeons	8	4	1	1	2	0	0
Polyodontidae, paddlefishes	1	0	1	0	0	0	0
Lepisosteidae, gars	6	0	0	0	0	1	1
Cyprinidae, minnows	298	22	3	22	17	2	22
Catostomidae, suckers	72	6	1	2	2	1	7
Characidae, characins	8	0	0	1	0	0	1
Ictaluridae, bullhead catfishes	46	3	1	2	3	0	2
Pimelodidae, longwhiskered cats	6	0	0	0	0	0	3
Osmeridae, smelts	9	0	0	0	1	1	0
Salmonidae, trouts[d]	46	6	3	0	27	0	1
Amblyopsidae, cavefishes	6	1	0	0	1	0	0
Atherinopsidae, NW silversides	56	0	0	3	1	0	6
Aplocheilidae, rivulines	3	0	0	1	0	0	0
Fundulidae, topminnows	40	0	0	1	0	0	1
Profundulidae, MA killifishes	5	0	0	1	0	0	0
Poeciliidae, livebearers	93	5	0	9	0	0	9
Goodeidae, goodeids	47	3	0	10	1	0	4
Cyprinodontidae, pupfishes	44	7	0	18	0	0	5
Gasterosteidae, sticklebacks	5	1	6	1	0	0	0
Synbranchidae, swamp eels	3	0	0	1	0	0	0
Cottidae, sculpins	121	0	0	0	1	3	0
Cichlidae, cichlids	46	0	0	3	0	0	1
Percidae, perches	189	13	0	2	7	2	2
Gobiesocidae, clingfishes	38	0	0	1	0	0	1
Gobiidae, gobies	101	1	0	0	0	0	0
Totals		72	11	81	63	11	67

Sources queried in July 2007 were, for the USA, http://ecos.fws.gov/tess_public; for Canada, www.sararegistry.gc.ca; and for Mexico, Norma Oficial Mexicana, www.ine.gob.mx/ueajei/publicaciones/normas/rec_nat/no_059_a2f.html.

CA, Canada; US, United States; MA, middle American; MX, Mexico; NW, New World.

[a] Few marine species are listed in any of the three countries: four in Canada, 15 in Mexico, and one in the USA (and another 16 are considered "Species of concern"; www.nmfs.noaa.gov/pr/species/fish).

[b] From Nelson et al. (2004), who list only described species but not subspecies. Includes extinct but not introduced species.

[c] Endangered designation in Canada and Mexico includes extinct and extirpated species (see Helfman (2007) for a rationale).

[d] Many protected salmonids in the USA represent distinct population segments or evolutionarily significant units.

Table 26.2

Ten commonly introduced but controversial fish species. Species listed have often been effective in terms of the original purpose for which they were introduced, but have subsequently posed serious ecological problems. From Helfman (2007), based on Courtenay et al. (1984), Welcomme (1984, 1988), Lever (1996), and Fuller et al. (1999). The number of countries and island groups where established is from Lever (1996), the number of US states where introduced is from Fuller et al. (1999). Adapted from Helfman et al. (1997), and presented in roughly phylogenetic order.

Species	Number of countries where established	Number of states where introduced	Native area	Original purpose of introduction
Cyprinus carpio, Common Carp	49	49	Eurasia	Food, ornamental
Carassius auratus, Goldfish	>40	49	East Asia	Ornamental
Ctenopharyngodon idella, Grass Carp	9	45	East Asia	Vegetation control
Oncorhynchus mykiss, Rainbow Trout[a]	56	48	Western North America	Gamefish, aquaculture
Gambusia spp., Mosquitofish	67	35	Eastern North America	Mosquito control
Poecilia reticulata, Guppy	34	15	Northern South America	Mosquito control
Micropterus salmoides, Largemouth Bass[b]	53	43	E. North America	Gamefish
Lates niloticus, Nile Perch[c]	3	1	East Africa	Food
Tilapiine cichlids[d]	94	13	East, Central, and South Africa	Aquaculture, vegetation control
Cichla ocellaris, Peacock Cichlid	6	2	Amazon Basin	Gamefish

[a] Related species: Eurasian Brown Trout, *Salmo trutta* (28 countries, 47 states), and North American Brook Trout, *Salvelinus fontinalis* (31 countries, 38 states).
[b] Related species: *Micropterus dolomieu*, Smallmouth Bass.

[c] *Lates longispinus* or *L. macrophthalmus* may have also been introduced into Lake Victoria (see Ribbink 1987; Witte et al. 1992).
[d] Numbers are for *Oreochromis mossambicus* and *O. niloticus*; other widely introduced tilapiines include *O. aureus*, *O. macrochir*, *O. urolepis* ssp., *Tilapia rendalli*, *T. zilli*, and others, including hybrids.

Table 26.3

Examples from field studies demonstrating reproductive and developmental impairment after exposure to endocrine disrupting compounds and other chemical pollutants. From Helfman (2007), expanded from Arukwe and Goksoyr (1998); see that review for references.

Xenobiotic/source	Effect	Species
BKME	Masculinization of females	Mosquitofish, eel-pout, Fathead Minnow
Columbia River pollutants, DDT	Phenotypic sex reversal	Chinook Salmon, Ricefish
Sewage estrogenic compounds	Intersexuality	Roach
PCBs, DDT/sewage effluent, oil spill	Increased egg mortality	Sand Goby, Arctic Char
Oil spill	Premature hatch, deformities	Pacific Herring
North Sea pollutants, DDE	Embryonic deformities	Flatfishes, cod
PCBs, DDT/various discharges	Chromosomal aberrations	Whiting
PCBs, PAHs/urban discharge, landfill leachate	Precocious maturation, decreased gonad development	English Sole, Eurasian Perch, Brook Trout
Crude oil, BKME/oil spill	Altered ovarian development	Plaice, White Sucker
Alkylphenols/sewage effluent	Altered vitellogenesis	Rainbow Trout, etc.
Pulp mill effluent, oil spill	Reduced plasma steroids, sperm motility	White Sucker, Atlantic Salmon, flounder
Textile mill, vegetable oil effluent	Retarded/reversed ovarian recrudescence	Airsac catfish, snakehead

EE2/sewage effluent	Reduced territory acquisition	Fathead Minnow

BKME, bleached kraft mill effluent; DDE, metabolic byproduct of DDT; DDT, dichlorodiphenyltrichloroethane; EE2, ethynylestradiol; PAH, polycyclic aromatic hydrocarbons; PCB, polychlorinated biphenyl.

Table 26.4

Conservation status of some of the world's largest freshwater fish species. Conservation status taken from the IUCN Red List (www.redlist.org). After Allan et al. 2005.

Species	Maximum size	Distribution[a]	IUCN Red List Rank[b]	Threatened by
Pristis microdon, Largetooth Sawfish	650 cm, 600 kg	SE Asia rivers	EN	Harvest, habitat loss
Himantura chaophraya, Freshwater Whipray	500 cm, 600 kg	Mekong R.	VU	Harvest, habitat loss
Psephurus gladius, Chinese Paddlefish	300 cm, 300 kg	Yangtze R.	CR	Harvest, habitat loss
Atractosteus spatula, Alligator Gar	305 cm, 137 kg	Mississippi R.	NE	
Arapaima gigas, Pirarucu	450 cm, 200 kg	Amazon R.	DD	Harvest
Barbus esocinus, Tigris River "salmon"	230 cm, 136 kg	Tigris R.	NE	
Catlocarpio siamensis, Giant Barb	300 cm, 300 kg	Mekong R.	NE	
Probarbus jullieni, Julien's Golden Carp[c]	180 cm, 100 kg	Mekong R.	EN	Harvest
Ptychocheilus lucius, Colorado Pikeminnow	200 cm, 50 kg?	Colorado R.	VU	Habitat loss
Silurus glanis, Wels Catfish	500 cm, 306 kg	Europe, Asia	NE	
Brachyplatysoma filamentosum, Piraíba Catfish	360 cm, 200 kg	Amazon R.	NE	
Pangasianodon gigas, Mekong Giant Catfish[c]	300 cm, 300 kg	Mekong R.	CR	Harvest, habitat loss
Pangasius sanitwongsei, Giant Pangasius	300 cm, 300 kg	Mekong R.	DD	Harvest
Hucho hucho, Huchen Salmon	150 cm, 52 kg	Danube R.	EN	Harvest, habitat loss
Hucho taimen, Taimen Salmon	200 cm, 100 kg	Selenge R., FSU	NE	
Maccullochella peelii, Murray Cod	200 cm, 113 kg	Murray R.	CR	Harvest, habitat loss

FSU, former Soviet Union.
[a] River names include mainstem and tributaries in the river basin.
[b] CR, Critically endangered; DD, data deficient; EN, Endangered; NE, status not evaluated; VU, Vulnerable.
[c] CITES Appendix I species.