\SUPPORTING APPENDIX FOR

ECOMORPHOLOGICAL SELECTIVITY AMONG MARINE TELEOST FISHES DURING THE END-CRETACEOUS EXTINCTION

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I. Dataset assembly procedures.

Stratigraphic conventions.

Taxon occurrences are placed at the top of the interval in which they occur. In the case of taxa ranging through multiple stages, the terminal is placed in the stage from which the measured fossil example(s) derive. Fossil localities of uncertain dating (i.e., those whose dating is given by more than one stage) are binned in the geologically youngest stage with which they are associated. Branching between sister clades is placed 1 Ma below the first occurrence of the group with the oldest fossil exemplar included in the study. Throughout, dates of stage boundaries follow those in Gradstein *et al.* (2004).

Phylogenetic conventions.

This study concerns extinction selectivity in marine teleosts only. Implied boundary crossers are only assumed to be marine if their closest Mesozoic relative is known from fossils preserved in marine sediments. The taxonomic scope of this analysis is total-group Teleostei. Therefore all fossil groups more closely related to living teleosts (the crown) than to any other extant group are considered here, even though some essentialist, apomorphy-based defintitions of Teleostei exclude them from that group (e.g., Arratia 1997).

Genera in the dataset were divided into 23 (mostly ordinal- or sub-ordinal) clades for further analysis; these are reviewed in full in part II of this Supporting Appendix (pg. 7). Of these groups, 18 survived into the Cenozoic and required phylogenetic topologies to estimate the characteristics of implied lineages crossing the Cretaceous-Paleogene boundary. Three *incertae sedis* genera (†*Nardorex*, †*Apateodus*, †*Chanoides*) were considered independently, as was †Dercetidae, which is of uncertain placement within Aulopiformes. Phylogenetic hypotheses for clades were derived from published analyses, and were used in conjunction with models of character evolution to estimate trait values for lineages inferred to have survived the extinction.

Interrelationships within and among the clades discussed in the previous section are based on published systematic analyses. In cases in which there is either extreme conflict between solutions or no formal hypothesis of interrelationships, groups are collapsed into an unresolved polytomy. An exception to this general rule applies to clades with multiple post-Mesozoic fossil members for which no systematic solution is available. Since there is no formal hypothesis of interrelationships, the number of boundary-crossing lineages cannot be rigorously assessed. In such cases, all post-Mesozoic taxa are placed in an unresolved clade, and this group then placed in a polytomy with all older members. This procedure therefore conservatively and consistently infers only one boundary crossing lineage.

Morphometric conventions.

Jaw mechanics. The parameter considered here is jaw closing mechanical advantage, a unitless value that consists of the ratio of the jaw closing inlever to the outlever (Westneat 2004). Both of these linear measurements share one endpoint in common: the point at which the lower jaw articulates with the quadrate. The distance between this point and the tip of the jaw or the distalmost tooth (the larger of these two values is used in this analysis) is the outlever arm. The inlever arm is measured as the distance between the mandibular articulation and the insertion area of jaw closing muscles, which is marked by an osteological correlate in neopterygian fishes (the coronoid process). Relative measurements were either taken as direct measurements from fossil material, or digitally from specimen photographs or illustrations.

Body size. Fossil fishes are typically preserved as lateral compressions. Since length measurements alone ignore considerable variation in body depth among teleost fishes (e.g., an eel and angelfish of identical length have drastically different body sizes), body size is therefore measured as lateral area in this study. Size measurements for all fishes considered (i.e., both those represented by fossil and Recent materials) were made by calculating the area enclosed by an outline of the body, excluding those parts of the median fins supported only by lepidotrichia. All measurements were made using the program Scion Image for Windows. Values for extinct genera were taken from the largest fossil specimen reported or observed, while sizes for Recent taxa were taken from the largest examples perserved in the collection of the Division of Fishes, Department of Zoology, Field Museum. In the case of alcohol-preserved Recent material, MA values were taken from radiographs.

The largest examples of some fossil taxa consist of incomplete remains. In such cases, smaller, complete material was scaled isometrically to match elements of the largest specimen. Measurements were then taken from this rescaled example. A similar approach was used to infer body size in the case of fossil taxa where no examples were complete. In this case, a phylogenetically proximal taxon (i.e., sister genus) was scaled isometrically to match the dimensions of its incomplete relative. As in the previous example, measurements were taken from this rescaled specimen.

II. Groups of fishes analyzed.

†*Pycnodontiformes*.

Summary. †Pycnodonts are a diverse clade of stem teleosts (Gardiner *et al.* 1996, Nursall 1996) that range in age from Triassic to Eocene. Most pycnodonts are deep-bodied fishes with crushing dentitions, although some Cretaceous forms (†*Gabrielichthys*, †*Coccodus*, †*Trewavasia*, †*Ichthyoceros*) are characterized by highly divergent body forms. Here the analysis of Poyato-Ariza and Wenz (2002) is used as the phylogenetic framework for †pycnodonts; other published cladistic hypotheses of †pycnodont interrelationships (Poyato-Ariza 2003, Kriwet 2005) are based on analyses of the data matrix assembled by Poyato-Ariza (2002) either in part or in full. This solution implies that no fewer than five lineages of †pycnodonts crossed the Cretaceous/Paleogene boundary (†*Anomoeodus*, †*Pycnodus* + †*Oropycnodus* lineage, †*Nursallia veronae* lineage, †*Abdobalistum* lineage, †*Palaeobalistum* lineage).

Topology used in analyses (Newick format; branch lengths given in Ma).

```
1 †Stemmatodus,
2 †Anomoeodus,
3 †Ocloedus,
4 †Tepexichthys,
5 †Neoproscinetes,
6 †Iemanja,
7 †Coelodus,
8 †Oropycnodus,
9 †Pycnodus,
10 †Nursallia,
11 †?Nursallia gutturosum,
12 †Abdobalistum,
13 †?Nursallia goedeli,
14 †Palaeobalistum;

(1:12.4,2:12.4,3:1.0,(4:2.0,(5:1.0,6:1.0,7:11.3,((8:1.0,9:14.1):35.8,(1
0:48.9,(11:3.0,(12:46.9,(13:1.0,14:45.9):1.0):1.0):1.0):1.0):2.1):1.0):
35.8):1.0
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†*Pachycormidae.*

Summary. †Pachycormids are a group of stem teleosts, convergent upon modern scombroid and xiphioid acanthomorphs. Two †pachycormids persist in the fossil record until the end of the Cretaceous: †*Protosphyraena* and †*Ichthypriapus*, which is conventionally placed in †*Protosphyraena* (†'*P.*' *gladius*) but seems not to belong in that genus (Stewart 1988; Lambers 1992). †*Protosphyraena* ranges from the Cenomanian of Cinto-Euganeo, Italy (Sorbini 1976) to the Maastrichtian of California, USA (David 1946) and Belgium (Dollo 1893), with numerous intervening occurrences (Lambers 1992). †*Ichthypriapus* is known only from North America, where it ranges from the Coniacian to Maastrichtian (Stewart 1988; Parris *et al.* 2007); the anatomy of this genus is too incompletely known at present to include in this analysis.

†*Aspidorhynchidae.*

Summary. †Aspidorhynchids are a clade of gar-like stem teleosts (Patterson 1977) known from the Jurassic and Cretaceous. This group includes four genera: †*Vinctifer*, †*Belonostomus*, †*Aspidorhynchus*, and †*Richmondichthys* (Brito 1997, Bartholomai 2004). †*Belonostomus*, which ranges from the Kimmeridgian of England and France (Brito 1997, Dineley and Metcalf 1999) to the Campanian-Maastrichtian of Nardò, Italy and the Maastrichtian chalks of Belgium and the Netherlands (Taverne 1998b, pers. obs.), is the latest occurring taxon in this clade. †*Belonostomus* is also present in Maastrichtian freshwater deposits of the western United States (Bryant 1989). Following Cavin (2001a), I consider the presymphsial bone of *Belonostomus* reported from late Paleocene of North Dakota (Bryant 1987) to be reworked from older (*i.e.*, Cretaceous) strata.

†*Ichthyodeciformes.*

Summary. †Ichthyodectiforms are radiation of stem teleosts (Patterson and Rosen 1977) known exclusively from Mesozoic deposits. Three ichthyodectiform genera make their last appearance in the Maastricthian: †*Saurodon*, from Nardò, Italy (Taverne and Bronzi 1999) the Navesink Formation of New Jersey, USA (Bardack and Sprinkle 1969), and the Moreno Formation of California, USA (Russell 1988); †*Saurocephalus*, from the chalks of Maastricht, the Netherlands (Bardack and Sprinkle 1969); †*Xiphactinus*, from the Navesink Formation of New Jersey, USA (Gallagher *et al.* 1986, Gallagher 1993, Schwimmer *et al.* 1997). David (1946) attributed a scale fragment from the Maastrichtian Panoche Formation of California, USA to †*Ichthyodectes*, did but not figure this specimen. At present, I consider that there is inadequate evidence that †*Ichthyodectes* persisted until the Maastrichtian.

There are persistent references in the literature to post-Cretaceous fossils of †ichthyodectiforms, but all of these accounts concern specimens of highly uncertain provenance. †*Prymnetes* is known from a single specimen from near Tuxtla, Chiapas state, Mexico. No stratigraphic position for this specimen was given by Cope (1871), but Frickhinger (1995; this volume mistakenly lists the genus as "*Prymnites*") indicated it is Tertiary in age. This might be traced to a personal communication from David Dunkle in Bardack (1963) that †*Prymnetes* might be Eocene in age, but the evidence given for a Cretaceous age in that same paper is more compelling. In the most recent review of Mexican fossil fishes, Alvarado-Ortega *et al.* (2006) suggested †*Prymnetes* might derive from Lower Cretaceous deposits. Maisey (1996: 171) alluded to Eocene ichthyodectiform remains from Brazil, but these specimens have never been described or figured, and their provenance remains undocumented (JG Maisey, pers. comm., 2007).

For the independent contrasts analysis, the following branching pattern among ichthyodectiforms is used: [†*Xiphactinus* [†*Saurodon* , †*Saurocephalus*]] (Stewart 1999).

Osteoglossomorpha.

Summary. Osteoglossomorphs are the extant sister-group of all remaining living teleosts, and first appear in the fossil record in Lower Cretaceous strata (Patterson 1993b). A diverse set of marine osteoglossomorphs are known from lower Paleogene deposits, most notably the Danatinsk Suite (Thatnetian, Turkmenistan; Danil'chenko 1968), London Clay (Ypresian, UK; Casier 1966), Fur Formation (Ypresian, Denmark: Bonde 1997, 2008), and Bolca (Ypresian, Italy: Taverne 1998a), but all convincing records of Cretaceous osteoglossomorphs are from freshwater deposits. For this reason, this clade has not been included in the present analysis.

†*Crossognathidae.*

Summary. †Crossognathids are a group of Mesozoic teleosts of uncertain phylogenetic placement. Rosen and Patterson (1977) suggested a basal, but *incertae sedis*, position. Taverne (1988) associated this group with †pachyrhizodontoids, uniting the two clades within the †Crossognathiformes, which he placed within the teleost crown. Cavin (2001b) has argued that †crossognathids and †pachyrhizodontoids are not closely related. He placed †pachyrhizodontoids within Elopocephala above elopomorphs, and †crossognathids outside the elopocephalan radiation. †Crossognathids share some derived features with †varasichthyids (Cavin 2001b, Cavin and Grigorescu 2005), a clade of stem teleosts (Arratia 1997), indicating that they might fall outside the teleost crown, as first proposed by Rosen and Patterson (1977).

The latest surviving †crossognathid is †*Apsopelix*, which last occurrs in the Campanian-Maastricthian Mason River Formation of Canada and the Maastrichtian Fox Hills Sandstone of Colorado (Dunkle 1960, Russell 1988).

Elopomorpha.

Elopomorph phylogeny is largely adapted from Forey *et al.* (1996), Forey (1973), and Belouze (2002). Among non-anguilliform elopomorphs, the following familial assignments for fossil taxa are used here, where families concerned are treated as total-groups: Elopidae: †*Ichthyemidion* (Berriasian-Valanginian; Poyato-Ariza 1995), †*Davichthys* (Cenomanian-Santonian; Forey 1973), †*Ctenodentelops* (Cenomanian; Forey *et al.* 2003); Megalopidae: †*Arratiaelops* (Berriasian-Valanginian; Taverne 1999a), †*Sedenhorstia* (Cenomanian-Campanian; Forey 1973), †*Promegalops* (Ypresian; Forey 1973), †*Protarpon* (Ypresian; Forey 1973); Albulidae: †*Lebonichthys* (Cenomanian-Santonian; Forey 1973) (the various fossil dentitions and highly incomplete specimens from Cretaceous strata attributed to *Albula* are not considered here, although many of these are undoubtedly albulids), †*Deltaichthys* (uncertain, but probably Turonian; Fielitz and Bardack 1992); Pterothrissidae: †*Hajulia* (Cenomanian: Forey 1973), *Isteus* (Santonian-Recent; Forey 1973, here I consider the genus *Pterothrissus* a junior synonym of *Isteus*, cf. Robins 1989); Halosauridae: †*Echidnocephalus* (Campanian: Siegfried, 1954); †*Laytonia* (Messinian: David 1943, 1946). †*Anaethalion* has been associated with elopids (Forey *et al.* 1996), but I regard the placement of this taxon as too uncertain to incorporate it into the present analysis. †*Brannerion* (Albian; Blum 1991), †*Parelops* (Albian; Maisey and Blum 1991), †*Baugeichthys* (Hauterivian; Fillieul 2000) and †*Osmeroides* (Albian-Coniacian; Forey 1973) are considered stem albuloids (*i.e.*, branching below the split between albulids and pterothrissids). Since there is no clear evidence that notocanthids and halosaurids (inclusive of the fossils attributed to them) are reciprocally monophyletic, I conservatively consider only a single notocanthiform lineage crossing the K-P boundary.

Several eel body fossils are known from Cretaceous deposits, and the bulk of these appear to be stem anguilliforms (Belouze 2002). There are two body-fossil records of crown-group eels from Cretaceous deposits. The first of these is the Cenomanian †*Enchelion*, which was identified as a stem-group saccophyrangoid by Patterson (1993b), an interpretation later corroborated by the cladistic analysis presented by Belouze (2002). The second example is the Campanian-Maastrichtian genus †*Nardoechelys* was described by Taverne (2002b) as an ophichthid. This latter taxon is incompletely known, and excluded from the present analysis. The apical placement of saccopharyngoids within anguilliform phylogeny implies many eel lineages crossed the K-P boundary.

Topology used in analyses (Newick format; branch lengths given in Ma).

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1 †Ichthyemidion,
2 †Davichthys,
3 †Ctenodentelops,
4 Elops,
5 †Arratiaelops,
6 †Sedenhorstia,
7 †Protarpon,
8 †Promegalops,
9 †Lebonichthys,
10 †Brannerion,
11 †Parelops,
12 †Baugeichthys,
13 †Osmeroides,
14 †Deltaichthys,
15 Albula,
16 †Isteus,
17 †Echidnocephalus,
18 †Laytonia,
19 †Luenchelys,
20 †Urenchelys,
21 †Hayenchelys,
22 †Anguillavus,
23 †Abisaadia,
24 †Libanenchelys,
25 †Mylomyrus,
26 Anguilla,
27 †Eoanguilla,
```

28 †*Proteomyrus*,
29 †*Bolcyrus*,
30 †*Voltaconger*,
31 †*Anguilloides*,
32 *Simenchelys*,
33 *Conger*,
34 *Ariosoma*,
35 *Hoplunnis*,
36 *Nettastoma*,
37 *Serrivomer*,
38 *Coloconger*,
39 *Derichthys*,
40 †*Milananguilla*,
41 *Synaphobranchus*,
42 †*Goslinophis*,
43 *Myrophis*,
44 *Ophicthus*,
45 *Chilorhinus*,
46 †*Patavichthys*,
47 *Muraena*,
48 †*Paranguilla*,
49 †*Nemichthys*,
50 †*Enchelion*,
51 *Cyema*,
52 *Eurypharynx*;

```
(((1:1.0,2:43.9,3:43.9,4:137.4):4.8,(5:1.0,6:47.7,(7:1.0,8:1.0):91.6):1
.0):1.0,((10:31.4,11:31.4,12:1.0,13:37.5,(16:24.9,(9:1.0,(14:1.0,15:38.
2):7.7):35.5):1.0):1.0,((17:1.0,18:66.268):44.9,(23:22.0,(19:21.0,(22:2
0.0,(21:19.0,(20:28.0,(24:17.0,(25:69.1,(26:68.1,(27:58.9,(28:57.9,((29
:2.0,(30:1.0,31:1.0):1.0):54.9,(32:104.5,((33:3.0,34:3.0,((36:1.0,35:1.
0):1.0,37:2.0):1.0):100.5,(38:102.5,(39:101.5,(((40:1.0,41:49.6):1.0,(4
2:1.0,(43:1.0,44:1.0):48.6):1.0):49.9,(45:99.5,(46:49.9,(47:97.5,(48:47
.9,(49:95.5,(50:1.0,(51:1.0,52:1.0):93.5):1.0):1.0):1.0):1.0):1.0):1.0)
:1.0):1.0):1.0):1.0):1.0):1.0):1.0):1.0):1.0):1.0):1.0):1.0):1.0):1.0):
1.0):1.0):15.5):11.2):1.0;
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†*Tselfatiiformes.*

Summary. †Tselfatiiforms are an extinct radiation of crown-group teleosts that include three nominal families: †Protobramidae, †Eoplethodidae and †Plethodidae (Taverne and Gayet 2004, 2005). †Protobramids are relatively small and deep-bodied, and superficially convergent upon some early acanthomorphs. †Plethodids are the most taxonomically diverse group of †tselfatiiforms, and are typically large with thunniform body profiles, consistent with an epipelagic habit.

The youngest †tselfatiiform fossils are fragmentary remains from the Maastricthian Ghareb Formation of Israel, which have been identified by Chalifa and Lewy (1992) as similar to †*Bananogmius crieleyi* from the Campanian of Alabama, USA (Applegate 1970). This species has been reassigned to the genus †*Pentanogmius* by Taverne (2000), which is known from articulated material from the Niobrara chalks of the western USA (Taverne 2004a). Remains attributed to a tselfatiiform similar to †*Bananogmius* are also reported from the very base of the Danian Hornerstown Formation of New Jersey, USA (Gallagher 2003). This material derives from a basal lag above a non-conformable contact with underlying Maastrichtian formations (Tinton and New Egypt formations; Landman *et al.* 2004). This concentrated fossil bed yields specimens with a strong Mesozoic character, indicating that these materials are reworked from underlying deposits (Landman *et al.* 2004).

Clupeomorpha.

Clupeomorphs include living fishes commonly referred to as herrings. The most comprehensive systematic review of this group based on morphology is Grande (1985), and this has recently been supplemented by molecular analyses based on complete mitochondrial genomes (Lavoué *et al.* 2007). Molecular studies agree with some aspects of the morphological solution, and help to clarify features of clupeomorph phylogeny not apparent from anatomical analyses. Both sets agree that Denticepidae is the living sister group of Clupeoidei, and that Engraulidae and Denticipitidae fall outside of Clupeidae. Molecular analyses indicate that engraulids and denticipitids are successively more distal outgroups to clupeids. The non-monophyly of most clupeid subfamilies, suspected on the basis of morphological investigation (Grande 1985), is corroborated by molecular analyses. Only Pellonulinae form a clade. Clupeinae and Alosinae are polyphyletic, but Dorosomatinae and Dussumeriinae are parphyletic, the latter because it includes the monogeneric Chirocentridae (Lavoué *et al.* 2007).

Grande (1985) identified a clade of Cretaceous fishes, †Paraclupeidae (= his †Ellimmichthyidae), as stem-group clupeomorphs. Most Cretaceous clupeomorphs can be assigned to this extinct radiation, and include: †*Armigatus* (Cenomanian; Forey *et al.* 2003), †*Sorbiniclupea* (Cenomanian; Bannikov and Bacchia 2000), †*Triplomystus* (Albian-Cenomanian; Forey *et al.* 2003, Alvarado-Ortega and Ovalles-Damían 2008), †*Ellimma* (Aptian-Albian; Chang and Maisey 2003), †*Paraclupea* (Lower Cretaceous; Chang and Grande 1997) and †*Ellimmichthys* (Barremian; Grande 1982). †*Diplomystus*, which first appears in marine Cenomanian deposits, is the only †paraclupeid to persist into the Eocene, with the youngest specimens of this genus known from China and the western USA (Grande 1982, 1985). Chang and Maisey (2003) have presented a hypothesis of †paraclupeid interrelationships, but this solution included only a limited taxon sample. For this reason, I have collapsed all members of this clade into an unresolved polytomy, but accept their interpretation of †*Armigatus* as a member of this clade (contra Grande 1985, Forey *et al.* 2003).

Three clupeomorphs are known from the Cretaceous (Campanian-Maastrichtian) of Nardò, Italy: †*Italoclupea* (Taverne 2007), †*Pugliaclupea* (Taverne 2004c) and †*Nardoclupea* (Taverne 2002). All of these taxa fall within the crown, and have been attributed to Clupeidae. The placement of †*Pugliaclupea* among clupeids is uncertain, but Taverne (2002a) has argued that †*Nardoclupea* is a member of Dussumieriinae and that †*Italoclupea* (2007) is a member of 'Clupinae'. Multiple post-Cretaceous exemplars represent these subfamilies in this analysis.

The presence of clupeids in the Cretaceous implies that at least four more lineages of clupeomorphs can be drawn into the Mesozoic based on current molecular phylogenies (Lavoué *et al.* 2007): Pristigasteridae, Denticepitidae, Engraulidae and Sundasalangidae. Cenozoic fossil exemplars include the Santonian-Thanetian (Gayet and Meunier 1998) †*Gasteroclupea* (Pristigasteridae), the Lutetian †*Palaeodenticeps* (Denticepitidae) and the Messinian †*Engraulis tethensis* (Engraulidae). Sundasalangidae, which are only known from freshwater environments today, are not included here.

Topology used in analyses (Newick format; branch lengths given in Ma).

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†Sorbinichthys,
†Triplomystus,
†Ellimma,
†Ellimmichthys,
†Armigatus,
†Diplomystus,
```

7 †*Palaeodenticeps*,
8 *Engraulis*,
9 †*Nardoclupea*,
10 *Etrumeus*,
11 *Spratelloides*,
12 †*Sahelinia*,
13 †*Pugliaclupea*,
14 †*Italoclupea*,
15 *Clupea*,
16 †*Knightia*,
17 †*Gosiutichthys*,
18 *Alosa*,
19 †*Gasteroclupea*,
20 †*Xyne*;

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((1:32.5,2:32.5,3:14.0,4:1.0,5:32.5,6:77.4):1.0,(7:30.1,(8:64.168,(19:6
.8,(((11:1.0,12:1.0,10:1.0):60.168,9:1.0):1.0,13:2.0,14:2.0,(15:8.2,16:
16.4,17:8.2,18:51.468):10.7):1.0):1.0):1.0):56.5);
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Gonorhynchiformes.

Gonorhynchiforms are a major group within Ostariophysi, and comprises two suborders: Chanoidei and Gonorhynchoidei. *Sorbininardus*, from Nardò, appears to branch from the gonorhynchiform stem, prior to the split between chanoids and gonorhynchoids (Taverne 1999b). The milkfish *Chanos* is the only extant chanoid. In addition to this Recent exemplar, there are numerous fossil members of this group which are considered in this analysis. These are, in increasing proximity to the crown: †*Aethalionopsis* (Berriasian), [†*Rubiesichthys* + †*Gordichthys*] (Berriasian-Valanginan), †*Parachanos* (Aptian), †*Dastilbe* (Aptian-Albian) and †*Tharrias* (Aptian-Albian) (Grande and Poyato-Ariza 1999). Extant gonorhynchoid diversity is greater, and includes the marine *Gonorhynchus* and the freshwater kneriids. Several fossil gonorhynchoids are included here in addition to *Gonorhynchus*. These include: †*Apulichthys* (Campanian-Maastrichtian; Taverne 1997); †*Judeichthys* (Cenomanian; Gayet 1985a); †*Charitosomus* (Santonian-Campanian; Gayet 1993); †*Haekliosomus* (Cenomanian; Gayet 1993); †*Ramallichthys* (Cenomanian; Gayet 1993); †*Charitopsis* (Cenomanian; Gayet 1993); †*Lecceichthys* (Campanian-Maastrichtian; Taverne 1998c); †*Notogoneus* (Maastrichtian-lower Miocene; this taxon is known only from freshwater deposits, and is therefore not placed within the pool of survivors; Grande and Grande 1999). Relationships among gonorhynchoids are adapted from Grade and Poyato-Ariza (1999). †*Apulichthys* is placed as sister to all remaining gonorhynchoids (Taverne 1997), and †*Lecceichthys* is the sister to [†*Notogoneus* + *Gonorhynchus*] (Taverne 1998c).

Topology used in analyses (Newick format; branch lengths given in Ma).

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†Sorbininardus,
†Aethaelionopsis,
†Dastilbe,
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4 †*Parachanos*,
5 †*Tharrias*,
6 *Chanos*,
7 †*Gordichthys*,
8 †*Rubiesichthys*,
9 †*Apulichthys*,
10 †*Judeichthys*,
11 †*Charitosomus*,
12 †*Hakeliosomus*,
13 †*Ramallichthys*,
14 †*Charitopsis*,
15 †*Lecceichthys*,
16 †*Notogoneus*,
17 *Gonorhynchus*;

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(1:77.7,((2:1.0,((7:1.0,8:1.0):1.0,(3:13.4,4:1.0,(5:1.0,6:100.6):12.4):
25.4):2.8):1.0,(9:30.0,(10:1.0,11:11.0,12:1.0,13:1.0,14:1.0,(15:2.0,(16
:17.9,17:66.5):1.0):27.0):1.0):46.7):1.0);
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Otophysi.

Otophysans are a spectacularly diverse radiation of primarily freshwater fishes, and include cypriniforms, characiforms and siluriforms. Of these, only characiforms are represented by articulated remains from Mesozoic marine deposits. Gayet (1985a) has claimed that the diminutive †*Salminops*, from the Cenomanian of Portugal, is the oldest characiform, but this interpretation has been met with considerable skepticism (Fink and Fink 1996). This taxon is not included here. Apart from this problematic genus, there is only one plausible Cretaceous characiform represented by articulated material: †*Sorbinicharax*, from the Campanian-Maastrichtian of Nardò, Italy (Taverne 2003b). In addition to this plesiomorphic characiform, one problematic otophysan is also included here: the Cretaceous-Eocene †*Chanoides* (Patterson 1984, Taverne 2005a). It is uncertain whether this genus falls within the otophysan crown or branches from the stem (Patterson 1984); it is placed as the sister group of †*Sorbinicharax* in comparative analyses.

†Pachyrhizodontoidei.

Summary. †Pachyrhizodontoids are an extinct group of predatory fishes that are known from Cretaceous and Paleogene strata. The relationships and limits of †pachyrhizodontoids given here are those proposed by Cavin (2001b). †Pachyrhizodontoids have been divided into two families: †Pachyrhizodontidae, containing the genera †*Rhacolepis* (Aptian-Albian), †*Goulmimichthys* (Turonian; Cavin 2001b), and †*Pachyrhizodus* (Albian-Maastrichtian; Forey 1977), and †Notelopidae, which contains †*Notelops* (Aptian-Albian). These two families are placed in a polytomy along with †*Elopopsis* (Cenomanian-Turonian; Forey 1977, Taverne 1993) by Cavin (2001b). Two additional genera have been placed within †Pachyrhizodontoidei, as successive sister-groups to the †pachyrhizodontid/†notelopid/†*Elopopsis* clade: †*Tingitanichthys* (Cenomanian; Taverne 1996) and †*Platinx*. Of these taxa, all are confined to the Cretaceous with the exception of †*Platinx*, which is known from the Paleocene (Thanetian) of Turkmenistan (Danil'chenko 1968; †*P. cognitus*) and the Eocene (Ypresian) of Bolca (Taverne 1980; †*P. macropterus*). Incomplete material labeled as †*Platinx*, from the Eocene of Syria, is housed housed at MNHN, Paris (K 1258). †*Pachyrhizodus* is the latest surviving †pachyrhizodontoid excluding †*Platinx*, with its final occurrences in the Campanian-Maastrichtian of New Zealand (Wiffen 1983) and Maastrichtian of the Netherlands (e.g., BMNH 42978a) and California, USA (David 1946).

Topology used in analyses (Newick format; branch lengths given in Ma).

```
1 †Rhacolepis,
2 †Goulmimichthys,
3 †Pachyrhizodus,
```

4 †*Notelops*,
5 †*Tingitanichthys*,
6 †*Patinx*,
7 †*Elopopsis*;

(6:54.0,(5:8.1,(1:1.0,2:11.3,3:17.1,4:1.0,7:7.1):1.0):1.0);

'Protoacanthopterygii'.

There is considerable disagreement surrounding the interrelationships of the various extant 'protoacanthopterygian' groups (salmoniforms *sensu stricto*, argentoids, osmeroids, alepocephaloids, esociforms; Ishiguro *et al.* 2003 and references therein), although it is clear that these radiations do not form a clade to the exclusion of neoteleosts. The absence of a clear phylogenetic framework for living taxa makes it exceptionally difficult to place fossil ‘protoacanthopterygians’. Most Mesozoic ‘protoacanthopterygians’ have been attributed to ‘salmoniformes’ in the broad sense (e.g, Patterson 1970, Taverne 1992), a placement so imprecise that it differs little from assignment to ‘Protoacanthopterygii’ *incertae sedis*. Two Cretaceous fishes historically associated with stomiiforms have been reinterpreted as ‘salmoniforms’ sensu lato: †*Spaniodon* (said to have osmeroid affinities; Taverne and Filleul 2003) and †*Paravinciguerria* (said to be salmonoid or salmoniform *sensu stricto*; Taverne 1994). Support for these interpretations is weak. In this analysis I maintain the ‘traditional’ placement of †*Paravinciguerria* as a stomiiform, and regard †*Spaniodon* and the very similar †*Protostomias* and †*Pronotocanthus* (both of which have been interpreted as stomiiforms by Taverne 1991), as ‘Protoacanthopterygii’ *incertae sedis*.

The Cretaceous ‘protoacanthopterygians’ that can be identified most precisely derive from freshwater deposits. These include esociforms from North America (Wilson *et al.* 1992) and a galaxiid from South Africa (Anderson 1998), although the identification of the latter is disputed (Lee *et al.* 2007). In the absence of compelling evidence supporting the placement of any of the Cretaceous marine ‘salmoniforms’, I have not considered any ‘protoacanthopterygian’ groups in this analysis.

Stomiiformes.

Many Cretaceous fishes have been associated with Stomiiformes. Ignoring the tenuous link between stomiiforms and †enchodontids (now considered aulopiforms), which was a fashionable arrangement in the early 20th century (Regan 1911, Gregory and Conrad 1936), these taxa include: †*Tomognathus*, †*Idrissia*, †*Protostomias*, †*Pronotocanthus*, and †*Paravinciguerria*. In most cases, the systematic interpretation of these taxa appears to have been developed on the basis of a morphological gestalt rather than distinctive stomiiform characters. Forey and Patterson (2006) have since shown that †*Tomognathus* is an apomorphic amioid halecomorph. Taverne (1991) has revived the notion, earlier rejected by Fink (1985), that †*Protostomias* and †*Pronotocanthus* are stomiiforms. I am unconvinced by his arguments for stomiiform affinites, but am impressed by a series of close correspondences in cranial anatomy between these fossil genera and †*Spaniodon*, a Cretaceous 'protoacanthopterygian' (Taverne and Filleul 2003). Particularly striking is the anatomy of the lower jaw, which is stout in all three genera, bearing an enormous coronoid process plus three enlarged fangs. The putative stomiiform †*Idrissia* supposedly ranges in age from early Late Cretaceous (Cenomanian) to Late Oligocene (Rupelian); it is doubtful whether these materials are congeneric or if even they belong to a stomiiform (Weitzman 1967). †*Paravinciguerria* is the sole putative Cretaceous stomiiform retained here; it is joined by a diversity of Cenozoic representatives from three crown-group families (Phosichthyidae, Gonostomidae, Sternoptychidae) ranging in age from Eocene to Miocene. The interrelationships of fossil stomiiforms follow Prokofiev (2005), with †*Paravinciguerria* placed on the stem.

Topology used in analyses (Newick format; branch lengths given in Ma).

1 †*Paravinciguerria*,
2 †*Sytchevskia*,
3 †*Scopeloides*,
4 †*Primaevistomias*,
5 †*Eovinciguerria*,
6 *Vinciguerria*,
7 †*Discosternon*,
8 *Polyipnus*,
9 *Polyipnoides*,
10 †*Archaeolicus*,
11 *Argyropelecus*,
12 †*Horbatshia*;

```
(((2:1.0,5:13.0,6:29.792):2.0,((4:1.0,3:13.0):1.0,(7:29.792,8:13.0,9:1.
0,10:13.0,11:13.0,12:13.0):1.0):1.0):51.1,1:1.0):1.0;
```

Aulopiformes.

Aulopiforms include four major extant radiations: synodontoids, chloropthamoids, alepisauroids, and giganturoids. All but the last of these are represented by body fossil remains. Many of the the diverse Cretaceous aulopiform groups (e.g. †dercetids) are of unclear relationship to living clades and are best considered *incertae sedis*. I have therefore broken this discussion into four sections: the first three review synodontoids, chloropthalmoids and alepisauroids, while the fourth discusses *incertae sedis* aulopiforms (which are often associated with alepisauroids) that are treated independently of these other groups here.

Synodontoidei.

Cretaceous synodontoids include the Campanian †*Nematonotus*, the Turonian †*Volcichthys* and the Campanian †*Sardinius* (Rosen 1973). Patterson (1993b) attributed the last genus to Myctophidae, but the resemblances here are only superficial. Cenozoic synodontoids included in this study are the London Clay (Ypresian) genera †*Agrillichthys* (Synodontidae), †*Aulopopsis* and †*Labrophagus* (both Aulopodidae), and *Synodus* from the Messinian of Algeria.

Topology used in analyses (Newick format; branch lengths given in Ma).

```
1 †Nematonotus,
2 †Volcichthys,
3 †Sardinius,
4 †Agrillichthys,
5 Synodus,
6 †Aulopopsis,
7 †Labrophagus;

(1:1.0,2:5.2,3:23.9,((4:1.0,5:44.268):1.0,(6:1.0,7:1.0):1.0):43.9
):1.0;
```

Chloropthalmoidei.

Recognized Mesozoic chloropthalmoids are limited to the Cenomanian-Santonian genus †*Acrognathus* (Patterson 1993b). There are no Cenozoic body fossils of chloropthalmoids, so I have used the recent *Chloropthalmus* as the post-Cretaceous exemplar for this group.

Topology used in analyses (Newick format; branch lengths given in Ma).

```
1 †Acrognathus,
2 Chloropthalmus;

(1:1.0,2:94.5):1.0;
```

Alepisauroidei.

There are two extant families of alepisauroids: alepisaurids (lancetfishes) and paralepidids (barracudinas) (Baldwin and Johnson 1996). Fielitz (2004) has shown that †enchodontids (inclusive of †*Eurypholis*, †*Rharbichthys* and †*Saurorhamphus*) and †cimolichthyids are stem alepisaurids. Post-Mesozoic alepisaurids are represented by a Miocene fossil assigned to the extant genus *Alepisaurus* (D'Erasmo 1924). I have adopted the topology recovered by Fielitz (2004), with the addition of †*Prionolepis* as the sister taxon of †*Cimolichthys* (Goody 1968, 1970). Although alepisaurids are common in Cretaceous rocks, no paralepidids of Mesozoic age are known. Cenozoic paralepidids include a series of Eocene-Oligocene forms assigned to the genus †*Holosteus*. It is unclear to me whether the Russian †*Holosteus* is congeneric with the type, †*H. esocinus*, from Bolca; both species are therefore included here as separate terminals.

Topology used in analyses (Newick format; branch lengths given in Ma).

```
1 Paralepis,
2 †Holosteus mariae,
3 †Holosteus esocinus,
4 †Cimolichthys,
5 †Prionolepis,
6 †Rharbichthys,
7 †Palaeolycus,
8 †Eurypholis,
9 †Saurorhamphus,
10 †Enchodus,
11 Alepisaurus;

((1:44.268,3:1.0,2:21.2):50.9,(11:94.168,((4:8.7,5:1.0):4.0,(6:4.
0,(7:25.9,((9:5.2,8:5.2):1.0,10:24.9):1.0):1.0):1.0):1.0):1.0);
```

Aulopiformes incertae sedis.

Here I deal with three groups of aulopiforms that are of uncertain phylogenetic placement: †Nardorexidae, †Ichthyotringidae and †Dercetidae. †Nardorexidae is known from a single genus, †*Nardorex*, from the Campanian-Maastrichtian of Nardó (Taverne 2004d). This taxon has been described as an alepisauroid, but its position within that clade is unclear. The only †ichthtyotringid known from Maastrichtian deposits is †*Apateodus* (Kruzinga 1924); this genus is also known from earlier deposits, including the English Chalk (Goody 1969) and the Niobrara Formation (Carpenter 2003; AMNH 11560). A diversity of †dercetids are known from terminal Cretaceous deposits. The Campanian-Maastrichtian assemblage from Nardó contains four genera (†*Apuliadercetis*; †*Nardodercetis*; †*Ophidercetis*; †*Caudadercetis*; Taverne 2005a, b, 2006a, b), and the Maastrichtian chalks of Holland yield the remains of †*Rhynchodercetis* (NHMM 1993119) and †*Dercetis*-like forms (NHMM 1990027; other specimens in private collections). The Danian †*Scanidercetis* is the only post-Cretaceous member of this radiation, but is too poorly preserved to be included here.

Myctophiformes.

Myctophiforms are the living sister-group of acanthomorphs (Rosen 1973; Johnson 1992; Stiassny 1996; Smith and Wheeler 2006), and comprise two extant families: Myctophidae and Neoscopelidae. Mesozoic myctophiforms are limited to †*Sardinoides* (specifically the Campanian †*S. monasteri*; Rosen 1973), which has been associated with neoscopelids (Patterson 1993b), but is probably a stem myctophiform (Prokofiev 2006). The Paleocene (Thanetian) †*Neocassandra* also branches crownward of †*Sardinoides*. Crown mycophiforms are limited to the Cenozoic, and exemplars include the Eocene (Lutetian) †*Beckerophotus* (Neoscopelidae), and the Oligocene (Rupelian) †*Eomyctophum* and †*Oligophus* (both Myctophidae).

Topology used in analyses (Newick format; branch lengths given in Ma).

```
1 †Sardinoides,
2 †Neocassandra,
3 †Beckerophotus,
4 †Eomyctophum,
5 †Oligophus;

(1:1.0,(2:1.0,(3:1.0,(4:1.0,5:1.0):12.0):15.4):14.8);
```

Lampridiformes.

The relationships and content of Lampridiformes given here follows systematic revision being conducted by the author. 'Aipichthyoids' are placed in a polytomy on the lampridiform stem, and two are included here: †*Aipichthys* and †*Aipichthyoides*, both of which are Cenomanian in age. †*Aspesaipichthys* is an ‘aipichthyoid’ represented by a single incomplete specimen from Nardò (Taverne 2004b), but is too poorly preserved to be included in this analysis. The Campanian-Maastrichtian †*Veronavelifer* (Sorbini and Sorbini 1999) is more primitive than extant lampridiforms in mandibular and caudal structure, and I regard it as branching from the lampridiform stem crownward of 'aipichthyoids'. Known crown lampridiforms are limited to the Cenozoic, and representatives incorporated in this study include: †*Veronavelifer* (a veliferid), from the Ypresian of Bolca; †*Bathysoma* (a stem taeniosome), from the Danian of Sweden; †*Analectis* (a stem taeniosome), from the Rupelian of the Caucasus.

Topology used in analyses (Newick format; branch lengths given in Ma).

```
1 †Aipichthyoides,
2 †Aipichthys,
3 †Nardovelifer,
4 †Veronavelifer,
5 †Bathysoma,
6 †Palaeocentrotus,
7 †Analectis;

(2:2.0,(1:1.0,(3:1.0,(4:15.1,(5:1.0,6:14.1,7:34.3):1.0):2.8):28.0):1.0)
;
```

Polymixiiformes.

Cretaceous polymixiids are represented by a diversity of taxa; those considered for this study include: †*Omosomopsis*, from the Cenomanian of Morocco (Gaudant 1978); †*Pycnosterinx*, from the Santonian of Sahel Alma (Patterson 1964); †*Omosoma*, from the Cenomanian-Santonian of several localities (Patterson 1964); †*Dalmatichthys* from the Turnonian of the Balkans (Radovčić 1975); †*Berycopsia*, from the Turonian of Balkans (Radovčić 1975); †*Berycormus*, from the Campanian of Westphalia (Patterson 1964); †*Homonotichthys*, from the Cenomanian of the English Chalk (Patterson 1964). In addition to named forms, this analysis incorporates an undescribed polymixiid (cf. *Omosoma*) from the type Maastrichtian of the Netherlands. Previously considered rare (Patterson 1993a, b), there are several occurrences of polymixiids in Cenozoic deposits. These include the Rupelian *Digoria* (Bannikov and Parin 1997) and two unnamed taxa from Scandinavia: one from the Danian of Sweden ('*Hoplopteryx*' of Davis 1890 is in fact a polymixiid broadly similar to †*Homonotichthys*; pers. obs.) and another from the Ypresian Fur Formation of Denmark (Patterson 1993a, b). There is currently no hypothesis of relationships among fossil polymixiids. I have therefore united all Cenozoic taxa in a clade, and placed this radiation in an unresolved polytomy with Cretaceous forms such that a single that lineage crosses the K-P boundary.

Topology used in analyses (Newick format; branch lengths given in Ma).

```
1 †Omosomopsis,
2 †Pycnosterinx,
3 †Omosoma,
4 †Berycopsia,
5 †Dalmatichthys,
6 †Maastrichtian polymixiid,
7 †Berycopsis,
8 †Homonotichthys,
```

9 †Danian polymixiid,
10 †Fur polymixiid,
11 †*Digoria*;

(1:1.0,2:10.1,3:10.1,4:5.2,5:5.2,6:29.0,7:23.9,8:1.0,(9:1.0,10:14.1,11:34.3):31.8);

†*Asineopidae*.

Following Patterson (1993a, b), I consider the Eocene †*Asineops* closely related to the Cretaceous (Campanian-Maastrichtian) †*Nardoichthys*; here these two are placed as sister taxa within the nominal family Asineopidae.

Topology used in analyses (Newick format; branch lengths given in Ma).

```
1 †Asineops,
2 †Nardoichthys;

(1:26.1,2:1.0);
```

Zeiformes.

Cretaceous zeiforms are represented by †*Cretzeus* (Tyler *et al.* 2000) from the Campanian-Maastrichtian of Nardò, Italy. This genus is placed within the crown group, most closely related to *Stethopristes* and *Cyttopsis*. Another Cretaceous acanthomorph, the Cenomanian †*Palaeocyttus* (Gaudant 1978) has been identified as a zeiform (but see Tyler *et al.* 2003); if this interpretation is correct, the genus branches from the stem. Two stem zeiforms are described from the early Eocene Fur Formation of Denmark: †*Archaeozeus* and †*Protozeus* (Tyler *et al.* 2000). The cladogram given by Tyler and Santini (2005: fig. 9) indicates survival of at least five zeiform lineages across the K-P boundary. In this analysis, members of these lineages include: †*Archaeozeus*, †*Protozeus*, *Cyttopsis*, [*Cyttus* + *Neocyttus*], and [*Zenopsis* + *Zeus*]. Zeid genera are represented by two lower Oligocene species (reviewed in Baciu *et al.* 2005).

Topology used in analyses (Newick format; branch lengths given in Ma).

```
1 †Archaeozeus,
2 †Protozeus,
3 †Cretzeus,
4 Cyttopsis,
5 Cyttus,
6 Neocyttus,
7 Zenopsis,
8 Zeus;

(1:21.9,(2:20.9,((5:1.0,6:1.0):67.5,((3:1.0,4:66.5):1.0,(7:1.0,8:1.0):3
8.1):1.0):1.0):1.0);
```

'Beryciformes'.

There are conflicting hypotheses concerning the interrelationships of the four nominal 'beryciform' groups. Morphological character sets have been used to argue for two arrangements that render 'beryciforms' *sensu lato* paraphyletic: Stiassny and Moore (1992) and Moore (1993a, b) argued holocentroids are more closely related to 'higher' acanthomorphs than other 'beryciforms', but Patterson and Johnson (1993) recognized stephanoberycoids and [Berycoidei + Trachichthyoidei + Holocentroidei] as successively more proximal clades outside their Euacanthopterygii. Sequence data diverge on the question of 'beryciform' monophyly (grade: Miya *et al.* 2003; clade: Smith and Wheeler 2006), but they consistently recover a clade comprising holocentroids plus stephanoberycoids, with berycoids nested within the latter. Following these results, I conservatively consider trachichthyoids independently of all remaining 'beryciform' groups.

Trachichthyoidei.

Here I take Trachichthyoidei to comprise trachichthyids plus four other extant families: Monocentridae, Anomalopidae, Diretmidae and Anoplogastridae (Moore 1993a, b). Many Cretaceous acanthomorphs have been associated with trachichthyoids in general, and trachichthyids in particular: †*Lissoberyx*, †*Libanoberyx*, †*Stichopteryx*, †*Acrogaster*, †*Gnathoberyx*, †*Hoplopteryx*, †*Cryptoberyx*, †*Pattersonoberyx,* †*Plesioberyx*, †*Antarctiberyx,* †*Hgulichthys* and †*Gigantokranion* (Gayet 1980, 1982; Grande and Chatterjee 1987; Patterson

1993; Otero *et al.* 1995; Taverne 2003a). The link between †*Cryptoberyx*, †*Pattersonoberyx,* †*Plesioberyx* and trachichthyids has been questioned by Patterson (1993), who also suggested that all other Mesozoic 'trachichthyoids' might fall outside the crown. The two analyses that have addressed the placement of fossil trachichthyoids have come to divergent conclusions: Moore (1993a), like Patterson (1993a), places these fossils along the trachichthyoid stem, whereas Otero *et al.* (1995) nest them within the crown, as stem trachichthyids. I am doubtful of this latter conclusion. The shortest network in Otero *et al.* (1995) is rooted on an imaginary outgroup, and unites fossil trachichthyoids with trachichthyids using a combination of unconvincing characters and plesiomorphies. Here I adopt a conservative approach, placing all Mesozoic fossils in a basal polytomy. The crown exemplar is the Oligocene (Rupelian) trachichthyid †*Gephyroberyx robustus* (Danil'chenko 1960), the only Cenozoic trachichthyoid represented by body fossil remains. Paleocene reports of †*Hoplopteryx* (Davis 1890) are in error (see 'Polymixiidae' above), but this genus does appear to occur in the type Maastrichtian (pers. obs.).

Topology used in analyses (Newick format; branch lengths given in Ma).

```
1 †Hoplopteryx,
2 †Gnathoberyx,
3 †Judeoberyx,
4 †Tubantia,
5 †Lissoberyx,
6 †Stichopteryx,
7 †Acrogaster,
8 †Libanoberyx,
9 Gephyroberyx;

(9:66.1,1:1.0,2:1.0,3:1.0,4:23.9,5:1.0,6:1.0,7:11.0,8:1.0);
```

Holocentroidei.

A series of Cretaceous taxa have been associated with extant holocentrids: †*Caproberyx*, †*Trachichthyoides*, †*Parospinus*, †*Alloberyx*, †*Adriacentrus*, †*Ctenocephalichthys*, †*Erugocentrus*, †*Pelotius,* †*Plesioberyx*, †*Pattersonoberyx*, †*Kansius*, †*Stichocentrus* and unnamed forms from the Niobrara Formation of North America (Patterson 1967; Gayet 1980, 1982; Stewart 1984; Patterson 1993a; Gallo-da-Silva and de Figueiredo 1999). All of these Cretaceous examples lack characters common to living holocentrids, and probably branch from the stem (Stewart 1984; Patterson 1993a). Here I place these Mesozoic taxa in a basal polytomy, and include †*Eoholocentrum* (Sorbini and Tirapelli 1975), †*Berybolcensis* (Sorbini 1984) and †*Tenuicentrum* (Sorbini 1975), all from the Ypresian of Bolca, as Paleogene representatives. Following Stewart (1984), these crown holocentroids (stem myripristines) branch as follows: †*Eoholocentrum* [†*Berybolcensis* + †*Tenuicentrum*].

Berycoidei.

The body fossil record of berycoids is scant, represented only by the Oligocene (Rupelian) †*Berycormus* (Arambourg 1967). Following molecular solutions, this fossil genus is placed as the sister taxon of the stephaoberycoid exemplar discussed below.

Stephanoberycoidei.

There are four reports of fossil stephanoberycoids, all from the Cenozoic: the melamphid †*Scopelogadus*? *capistranensis* from the upper Miocene of California, USA (Ebeling 1962); an unnamed species of *Scopelogadus* from the Miocene of Ravenna, Italy (Corsi *et al.* 1999); an indeterminate melamphid from the ?Miocene of Aichi Prefecture, Japan; a 'cetomimid' from the Eocene (Ypresian) of Denmark (Bonde 1997, 2008; Bonde *et al.* 2008). The first of these is the most reliable, and is used here as a stephanoberycoid exemplar. The mandible in available material is poorly preserved, so measurements are derived from extant *Scopelogadus*. The Italian material has not been formally described or figured, and I have been unable to find any additional details on the Japanese melamphid. I have briefly examined the putative Danish whalefish (MGUH DK 70); it is certainly not a cetomimid *sensu stricto*. The dorsal fin does seem to be posteriorly positioned, with an exenensive series of what appear to be supraneurals placed anterior to the first fin-ray bearing pterygiophore (these ossifications closely resemble the more posteriorly placed pterygiophores, but do appear to articulate with fin rays or spines); both of these apomorphic features are found in some stephanoberycoids (Paxton *et al.* 2001; however, many other stephanoberycoids lack supraneurals altogether: Merrett and Moore 2005). I have excluded this potentially important specimen from the analysis, pending a more exacting account of its anatomy.

Topology used in analyses (Newick format; branch lengths given in Ma).

1 †Niobrara holocentroid,
2 †*Kansius*,
3 †*Pelotius*,
4 †*Caproberyx*,
5 †*Adriacentrus*,
6 †*Ctenocephalichthys*,
7 †*Eurogocentrus*,
8 †*Plesioberyx*,
9 †*Stichocentrus*,
10 †*Eoholocentrum*,

11 †*Berybolcensis*,
12 †*Tenuicentrum*,
13 †*Berycormus*,
14 *Scopelogadus*;

```
((13:1.0,14:24.068):66.1,(1:11.0,2:11.0,3:8.7,4:8.7,5:8.7,6:11.0,
7:8.7,8:1.0,9:1.0,(10:2.0,(11:1.0,12:1.0):1.0):43.9):1.0);
```

Syngnathoidei.

Syngnathoids are traditionally placed with gasterosteoids in Gasterosteiformes (Johnson and Patterson 1993; Orr 1995; Keivany and Nelson 2006). Mitochondrial (Kawahara *et al.* 2008) and nuclear (Smith and Wheeler 2006) sequence data widely separate these two groups, casting doubt on the coherence of a 'classical' gasterosteiform radiation; I only consider fossil syngnathoids (inclusive of pegasids) here. †*Gasterorhamphosus*, from the Campanian-Maastrichtian of Nardò, Italy, is the only Cretaceous syngnathoid known to date (Sorbini 1981). Sorbini (1981) described this genus as a macrorhamphosid, but Patterson (1993a) suggested that it might be a stem gasterosteiform (in the traditional sense of that group). More recently, Orr (1995) has argued convincingly that †*Gasterorhamphosus* branches from the common stem of Macrorhamphosidae + Centriscidae; this placement is accepted here. Three sister-family pairs are consistently recovered by both molecular and anatomical analyses: Centriscidae + Macrorphamphosidae (Centriscoidea); Aulostomidae + Fistularidae (Aulostomoidea); Syngnathidae + Solenostomidae (Syngnathoidea). Each of the three possible arrangements of these three groups has found support (Aulostomoidea [Syngnathoidea + Centriscoidea]: Pietsch 1978; Orr 1995; Syngnathoidea [Aulostomoidea + Centriscoidea]: Keivany and Nelson 2006; Centriscoidea [Aulostomoidea + Syngnathoidea]: Kawahara *et al.* 2008). There is considerable disagreement concering the position of pegasids (here considered to include †*Rhamphosus*; Pietsch 1978; Orr 1995) within Syngnathoidei. They are placed as the sister-group of: all remaining syngnathoids (Keivany and Nelson 2006); Syngnathoidea (Pietsch 1978; Orr 1995;

Kawahara *et al.* 2008); Centriscoidea (Smith and Wheeler 2006). To accommodate this uncertainty, I have placed Centriscoidea, Syngnathoidea, Aulostomoidea, and Pegasidae in a polytomy. †Aulorhamphidae (Tyler 2004), a nominal family known exclusively from fossils, is also included here. Members of this group are characterized by a suite of plesiomorphies that suggest they branch from the syngnathiform stem (Tyler 2004).

Topology used in analyses (Newick format; branch lengths given in Ma).

1 †*Aulorhamphus*,
2 †*Veronarhamphus*,
3 †*Rhamphosus*,
4 †*Gasterorhamphosus*,
5 †*Protorhamphosus*,
6 †*Paraeoliscus*,
7 †*Aeoliscoides*,
8 †*Urosphenopsis*,
9 †Fur aulostomid,
10 †*Urosphen*,
11 †*Eoaulostomus*,
12 †*Synhypuralis*,
13 †*Jungersenichthys*,
14 †*Solenorhynchus*,
15 †*Calamostoma*,
16 †*Proselenostomus*,
17 ‘*Syngnathus*’;

```
((1:1.0,2:1.0):18.9,(3:18.9,(4:1.0,(5:1.0,6:8.2,7:8.2):9.7):1.0,(14:1.0
,15:1.0,16:1.0,17:1.0):17.9,(8:1.0,9:8.2,10:8.2,11:8.2,12:8.2,13:8.2):1
0.7):1.0):1.0;
```

Tetraodontiformes

Fossil and living tetraodontiforms have been the subject of considerable systematic work (Tyler and Santini 2003, and references therin). The scheme of interrelationships among tetraodontiforms adopted here derives from Tyler and Santini (2003). Stem tetraodontiforms are said to be represented by three Cretaceous genera: †*Protriacanthus* (Cenomanian), †*Plectocretacius* (Cenomanian), and †*Cretatriacanthus* (Campanian-Maastrichtian) (Tyler and Sorbini 1996). These taxa form a clade to the exclusion of all post-Cretaceous tetraodontiforms, all of which appear to be nested within the crown radiation (Tyler and Santini 2003); this topology only invokes a single lineage crossing the Cretaceous/Paleogene boundary for which trait values must be inferred.

This analysis considers all three putative members of the stem, which are placed in the nominal group †Plectocretacioidea, as well as fossil representatives of nine out of the remaining ten suprafamilial clades recognized by Tyler and Santini (2003): Triacanthodoidea (†*Prohollardia*, †*Carpathospinosus*), Triacanthoidea (†*Protacanthodes*, †*Acanthopleurus*), †Moclaybalistoidea (†*Moclaybalistes*), †Bolcabalistoidea (†*Bolcabalistes*), Balistoidea (†*Oligobalistes*, †*Balistomorphus*), Ostracioidea (†*Proaracana*), †Eoplectoidea (†*Eoplectus*), Triodontoidea (†*Eotetraodon*), Tetraodontoidea (†*Archaeotetraodon*). The final suprafamily, Moloidea (ocean sunfishes), is not represented in the fossil record by complete material.

Topology used in analyses (Newick format; branch lengths given in Ma).

```
†Protriacanthus,
†Plectocretacius,
†Cretatriacanthus,
†Prohollardia,
†Carpathospinosus,
†Protoacanthodes,
†Acanthopleurus,
†Cryptobalistes,
```

9 †*Moclaybalistes*,
10 †*Bolcabalistes*,
11 †*Oligobalistes*,
12 †*Balistomorphus*,
13 †*Proaracana*,
14 †*Eoplectus*,
15 †*Eotetraodon*,
16 †*Archaeotetraodon*;

```
((3:30.0,(1:1.0,2:1.0):1.0):1.0,((4:1.0,5:1.0):25.2,((14:2.0,(15:1.0,16
:21.2):1.0):3.0,((6:3.0,(7:1.0,8:1.0):22.2):1.0,(9:3.0,(10:2.0,(13:1.0,
(11:1.0,12:1.0):20.2):1.0):1.0):1.0):1.0):1.0):41.9):1.0;
```

III. Maastrichtian fishes (observed plus implied): trait values.

Supporting table 1. ‘Raw’ (phylogenetically) uncorrected trait values for observed and implied taxa present in the Maastrichtian.

				Gradual model		**Punctuated model**	
Taxon or clade	**E**	**N**	**R**	**MA**	**Body size (ln[mm^2])**	**MA**	**Body size (ln[mm^2])**
*[†_Oropycnodus_ + †_Pycnodus_]				0.819722	9.448557	0.535552	9.903729
*†_Nursallia_				0.669618	10.36527	0.708333	10.50807
*†_Abdobalistum_				0.476232	10.01563	0.434829	9.96136
*†_Palaeobalistum_				0.504616	11.03736	0.682077	9.770636
†_Anomeodus_				0.551425	9.508355	0.551425	9.508355
†_Protosphyraena_	X			0.236985	13.17689	0.236985	13.17689
†_Belonostomus_	X			0.109343	9.885555	0.109343	9.885555
†_Xiphactinus_	X			0.358566	14.6274	0.358566	14.6274
†_Saurodon_	X			0.239034	12.66322	0.239034	12.66322
†_Saurocephalus_	X			0.292023	12.95888	0.292023	12.95888
†_Apsopelix_	X			0.502488	9.97621	0.502488	9.97621
*_Elops_			X	0.357725	9.804182	0.36272	9.903115
*[†_Protarpon_ + †_Promegalops_]				0.321844	11.932	0.304573	11.32415
*_Albula_				0.36093	11.43392	0.349807	12.54476
Isteus				0.48666	10.73182	0.48666	10.73182
*†_Laytonia_				0.496518	7.767609	0.372316	7.4808
*†_Mylomyrus_				0.271224	8.199944	0.260906	8.505817
*_Anguilla_				0.266815	9.207772	0.257203	10.10532
*†_Eoanguilla_				0.28771	8.027368	0.291765	8.182928
*†_Proteomyrus_				0.331026	7.546314	0.35546	7.523281
*[†_Bolycyrus_+†_Anguilloides_]				0.258127	8.473007	0.286315	8.851255
*_Simenchelys_			X	0.347845	8.04305	0.5	8.949366
*[_Conger_+_Serrivomer_]			X	0.237038	7.994677	0.253681	9.079588
*_Coloconger_			X	0.227738	8.125915	0.208589	9.521287
*_Derichthys_			X	0.259994	7.431959	0.315217	7.806566
*[†_Milanangulla_+_Ophichthus_]				0.28245	7.530983	0.263871	8.172096
*_Chilorhinus_			X	0.200429	6.80903	0.185185	6.480964
*†_Patavichthys_				0.191508	6.223254	0.188679	5.89976
*_Muraena_			X	0.204663	7.124016	0.243094	7.890246
*†_Paranguilla_				0.244345	8.576722	0.282609	9.636516
*_Nemichthys_			X	0.116956	7.082866	0.022624	8.45794
*[_Cyema_ + _Eurypharynx_]			X	0.109596	6.534716	0.048793	7.12967
†_Pentanogmius_	X			0.274949	13.33781	0.274949	13.33781
†_Diplomystus_				0.584396	10.18048	0.584396	10.18048
†_Gasteroclupea_				0.59589	5.816992	0.59589	5.816992
*_Engraulis_				0.596774	7.447563	0.18018	6.898169
*†_Palaeodenticeps_				0.63134	7.047843	0.655914	5.164957
*[_Clupea_ + _Alosa_]				0.646842	7.825799	0.65571	8.026549

*[*Spratelloides* + *Etrumeus*]				0.648731	8.787176	0.637676	6.93794
†*Italoclupea*	X	X		0.579125	6.822535	0.579125	6.822535
†*Pugliaclupea*	X	X		0.692414	7.754992	0.692414	7.754992
†*Nardoclupea*	X	X		0.658762	9.80641	0.658762	9.80641
†*Sorbininardus*	X	X		0.782051	6.028664	0.782051	6.028664
†*Auplichthys*	X	X		0.56196	7.794502	0.56196	7.794502
†*Lecceichthys*	X	X		0.779736	6.705272	0.779736	6.705272
**Chanos*			X	0.677905	9.852356	0.637478	9.727835
**Gonorhynchus*			X	0.78807	7.390831	0.972452	9.207961
†*Chanoides*				0.853165	9.46959	0.853165	9.46959
†*Sorbinicharax*	X	X		0.404635	6.231013	0.404635	6.231013
†*Pachyrhizodus*	X			0.111361	13.09715	0.111361	13.09715
*†*Platinx*				0.619899	10.81698	0.791866	11.3527
*[†*Sytchevskia* + †*Horbatshia*]				0.3149	5.826072	0.283364	5.947863
†*Ophidercetis*	X	X		0.231839	7.766464	0.231839	7.766464
†*Apuliadercetis*	X	X		0.198276	9.029125	0.198276	9.029125
†*Nardodercetis*	X	X		0.334641	9.885835	0.334641	9.885835
†*Caudadercetis*	X	X		0.129827	9.170035	0.129827	9.170035
†*Dercetis*	X			0.196078	7.802769	0.196078	7.802769
†*Rhynchodercetis*	X			0.15122	7.798769	0.15122	7.798769
†*Apateodus*	X			0.152641	11.53294	0.152641	11.53294
†*Nardorex*	X	X		0.135283	10.66655	0.135283	10.66655
*[†*Agrillichthys* + †*Labrophagus*]				0.297487	9.153859	0.241588	8.466604
**Chloropthalamus*			X	0.26298	7.532549	0.31457	8.412037
*[†*Holosteus*+*Paralepis*]				0.149169	9.789706	0.221842	9.963063
**Alepisaurus*				0.20931	8.969739	0.228137	9.87157
†*Cimolichthys*	X			0.221024	12.57673	0.221024	12.57673
†*Enchodus*	X			0.266241	12.23813	0.266241	12.23813
*[†*Neocassandra* + †*Oligophus*]				0.262477	7.479207	0.223013	6.152007
†*Nardovelifer*	X	X		0.340845	10.55096	0.340845	10.55096
*[†*Veronavelifer* + †*Analectis*]				0.500648	9.514047	0.578554	8.554756
*[†Danian polymixiid + †*Digoria*]				0.469615	8.736434	0.44419	8.042042
†Maastrichtian polymixiid	X			0.396636	7.587655	0.396636	7.587655
†*Nardoichthys*	X	X		0.42735	5.770662	0.42735	5.770662
*†*Asineops*				0.420654	6.080758	0.336617	9.972457
*†*Archaeozeus*				0.531042	4.982415	0.547537	3.018472
*†*Protozeus*				0.548279	5.200735	0.645853	3.17722
*[*Cyttus* + *Neocyttus*]			X	0.522244	6.092658	0.598194	9.065014
*[*Zeus* + *Zenopsis*]				0.512489	6.279295	0.55132	9.177554
**Cyttopsis*			X	0.501973	6.223905	0.540302	9.35473
†*Cretzeus*	X	X		0.491773	6.211864	0.491773	6.211864
**Gephyroberyx*				0.387495	7.675533	0.404412	8.210538
†*Hoplopteryx*	X			0.31746	10.36503	0.31746	10.36503
†*Lissoberyx*	X	X		0.340206	6.709841	0.340206	6.709841
*[†*Eoholocentrum* + †*Tenuicentrum*]				0.372552	8.337156	0.379461	8.240423
*[†*Berycormus* + *Scopelogadus*]				0.447107	8.215611	0.435672	7.310487
*[†*Aulorhamphus* + †*Veronarhamphus*]				0.562383	6.049444	0.402511	5.688785

*†*Rhamphosus*				0.633504	6.281812	0.808333	7.057373
*[†*Protorhamphosus* + †*Aeoliscoides*]				0.637322	5.948664	0.513746	5.402865
*[†*Solenorhynchus* + ‘*Syngnathus’*]				0.60016	6.102919	0.5164	5.580949
*[†*Urosphenopsis* + †*Jungersenichthys*]				0.572092	6.440108	0.536458	6.967403
†*Gasterorhamphosus*	X	X		0.675159	6.154709	0.675159	6.154709
*[†*Prohollardia* + †*Balistomorphus*]				0.617765	6.117125	0.514941	6.28702
†*Cretatriacanthus*	X	X		0.546729	5.286397	0.546729	5.286397
N = 92	33	18	14				

Names marked with asterisk (*) indicate estimated values for inferred boundary-crossing lineages leading to the taxon or set of taxa (which bracket a clade) listed. Column labeled ‘E’ indicates whether the taxon makes its last appearance in the Maastrichtian. Column labeled ‘N’ indicates whether the taxon makes its last appearance in the Nardò assemblage. Column labeled ‘R’ indicates whether the terminal taxon is based on Recent rather than post-Mesozoic fossil material. Final row gives counts for the number of taxa corresponding to each category.

IV. Complete logistic regression results.

Supporting table 2. Logistic regression results. Model: MA in isolation (extinction ~ MA)

excluded sets	***n***	**mode**	**AIC**	$p_{parameter}$	**odds ratio**
none	92(33)	G	121.14	0.0934	2.0088
		P	121.76	0.136	1.70265
Nardò	74(15)	G	64.488	0.00253	7.6906
		P	66.57	0.00448	6.6948
Recent	78(33)	G	104.68	0.0231	3.0288
		P	106.38	0.0559	2.4616
Nardò, Recent	60(15)	G	51.95	0.00101	10.272
		P	54.536	0.00224	9.8142

For sample sizes (*n*), the figure in parentheses indicates the number out of the total that are extinction victims. Mode refers to model of evolutionary change; gradual (G) or punctuated (P).

Supporting table 3. Logistic regression results. Model: body size in isolation (extinction ~ size).

excluded sets	***n***	**mode**	**AIC**	$p_{parameter}$	**odds ratio**
none	92(33)	G	116.16	0.0071	-0.2904
		P	119.1	0.03114	-0.2223
Nardò	74(15)	G	50.889	0.0000656	-0.8337
		P	54.18	0.000027	-0.8095
Recent	78(33)	G	104.98	0.0265	-0.2402
		P	105.40	0.0337	-0.2174
Nardò, Recent	60(15)	G	48.639	0.000235	-0.7665
		P	50.28	0.000393	-0.7217

For sample sizes (*n*), the figure in parentheses indicates the number out of the total that are extinction victims. Mode refers to model of evolutionary change; gradual (G) or punctuated (P).

Supporting table 4. Model: body size and MA in conjunction (extinction ~ MA + size).

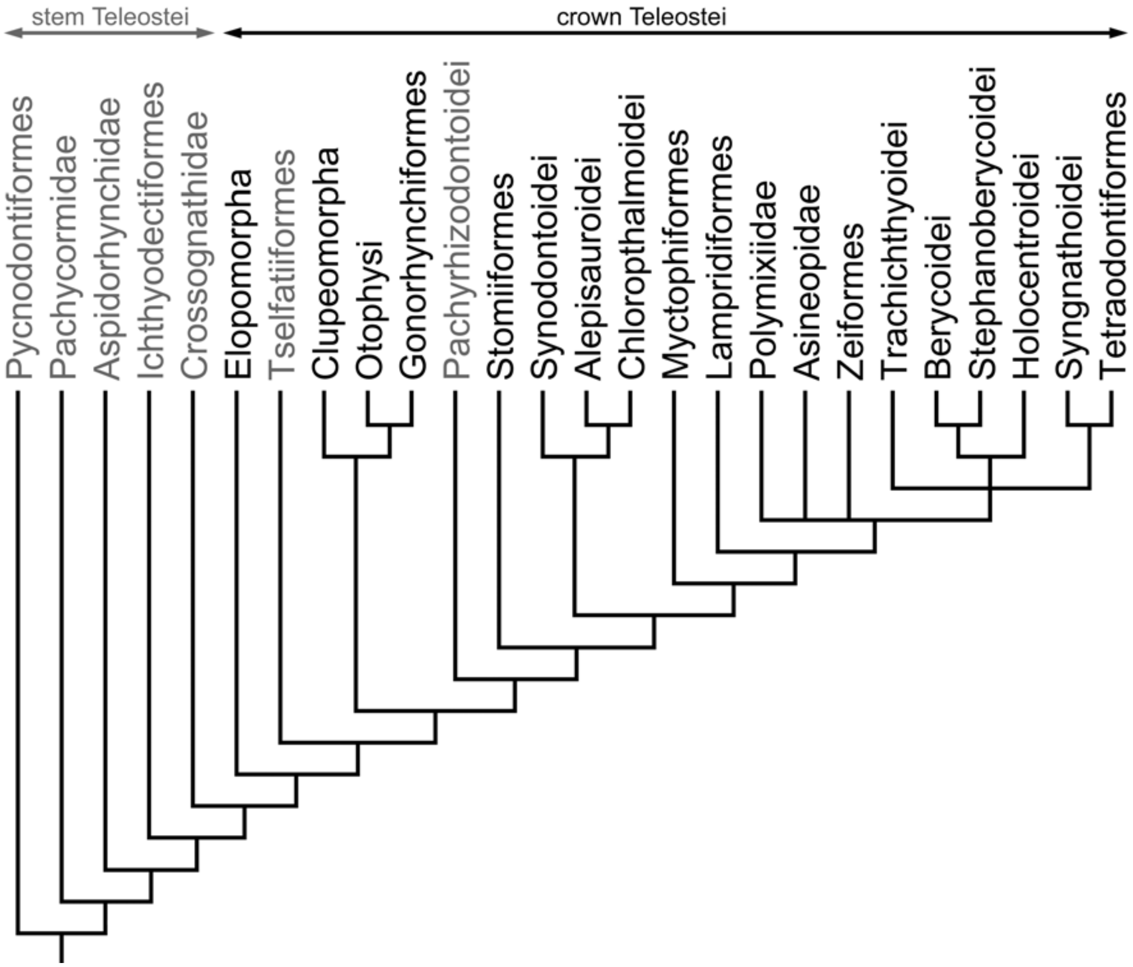
excluded sets	***n***	**mode**	**AIC**	$p_{parameter}$	**odds ratio**
none	92(33)	G	117.23	MA: 0.3370; size: 0.0187	MA: 1.2001; size: -0.2633
		P	120.09	MA: 0.3199; size: 0.0621	MA: 1.1637; size: -0.1984
Nardò	74(15)	G	43.101	MA: 0.014817; size: 0.000271	MA: 8.7568; size: -0.8382
		P	47.546	MA: 0.018717; size: 0.000358	MA: 7.1761; size: -0.7859
Recent	78(33)	G	104.38	MA: 0.115; size: 0.136	MA: 2.2302; size: -0.1740
		P	105.69	MA: 0.198; size: 0.109	MA: 1.7324; size: -0.1738
Nardò, Recent	60(15)	G	39.915	MA: 0.01118; size: 0.00247	MA: 9.5504; size: -0.6956
		P	41.957	MA: 0.02026; size: 0.00191	MA: 9.5135; size: -0.6588

For sample sizes (*n*), the figure in parentheses indicates the number out of the total that are extinction victims. Mode refers to model of evolutionary change; gradual (G) or punctuated (P).

VI. Global topology for independent contrasts analysis.

The relationships among the higher-level clades reviewed in the earlier section derives from several studies targeting different regions of teleost phylogeny. References, arranged by areas of the tree, are: Patterson and Rosen (1977), Patterson (1977), Nursall (1996), Hurley *et al.* (2006) (teleost stem); Patterson and Rosen (1977), Taverne (2000b), Hurley *et al.* (2006) (primitive' [i.e., non-clupeocephalan] teleosts); Lecointre and Nelson (1996) (Clupeomorpha + Ostariophysi); Rosen (1973), Johnson (1992), Johnson and Patterson (1996), Cavin (2001b) (Euteleostei); Johnson and Patterson (1993); Smith and Wheeler (2006) (Acanthomorpha). Following Taverne (2000b), I place tselfatiiforms on the clupeocephalan stem. Pachyrhizodontoids are placed as 'protoacanthopterygians', following Forey *et al.* (2003) and Cavin (2001b). Uncertainty surrounding the position of †*Chanoides* centers on its position within Otophysi (either within the crown or along the stem; Patterson 1984). Since no other members of this radiation are included in the analysis, this genus is simply placed as sister to gonorhynchiformes. †Dercetids are placed in an unresolved clade, and this group, along with †*Nardorex* and †*Apateodus*, is placed in a basal polytomy with the resolved clade uniting all remaining alepisauroids included in this analysis.

The independent contrasts analysis concerns only those taxa going extinct at or surviving the end of the Cretaceous. Therefore the dataset analyzed was limited to taxa observed in Maastrichtian deposits, or boundary-crossing individuals inferred on the basis of phylogeny.



Supporting figure 1. Global phylogeny relating the clades reviewed in the above section. This ‘backbone’ was used in conjunction with the topologies discussed previously when deriving independent contrasts from raw genus-level trait values. Only observed Maastrichtian genera and inferred boundary-crossers were considered. Extinct groups shown in grey.

VI. Phylogenetically independent contrasts: values.

For details of the different approaches to estimating independent contrasts (i.e., the Brunch and Cruch algorithms), consult Materials and Methods in the main text and the manual accompanying CAIC (Purvis and Rambaut 1995)

Supporting table 5. Independent contrasts: BRUNCH algorithm applied to gradual 'raw' (phylogenetically uncorrected) dataset.

ΔMA	**ΔBody size ($\ln[mm^2]$)**
-0.0051	-0.00602
0.01892	0.10302
-0.03552	-0.41536
-0.00592	-0.28706
-0.03136	0.46071
0.00502	0.50962
-0.03649	-0.57439
0.00335	-0.15505
-0.00417	-0.34278
-0.08334	0.98546
-0.04308	1.39217
-0.22426	-1.61929
0.03793	-0.76273
-0.21407	1.81952
-0.03388	1.00321
-0.15231	1.09704

Phylogenetically independent contrasts for changes in mechanical advantage (ΔMA) and body size (ΔBody size) associated with the lineage leading to clades (either single genus or multi-genus) making their last appearance in the Maastrichtian. These values are derived from the dataset generated under a model of gradual trait change. Contrasts calculated using the BRUNCH algorithm as implemented in CAIC (Purvis and Rambaut 1995).

Supporting table 6. Independent contrasts: BRUNCH algorithm applied to punctuated 'raw' (phylogenetically uncorrected) dataset.

ΔMA	**ΔBody size (ln[mm^2])**
-0.02426	-1.57143
0.08071	0.37592
0.01589	-0.50031
-0.01066	-0.39436
-0.0404	0.17473
0.01054	1.43424
-0.02378	-0.22719
0.04537	-2.1009
-0.09636	-1.25134
-0.11391	1.47469
-0.06704	0.98372
-0.22426	-1.61929
0.03583	-0.60206
-0.26984	1.66839
-0.03068	0.9874
-0.12577	1.07731

Phylogenetically independent contrasts for changes in mechanical advantage (ΔMA) and body size (ΔBody size) associated with the lineage leading to clades (either single genus or multi-genus) making their last appearance in the Maastrichtian. These values are derived from the dataset generated under a model of punctuated trait change. Contrasts calculated using the BRUNCH algorithm as implemented in CAIC (Purvis and Rambaut 1995).

Supporting table 7. Independent contrasts: CRUNCH algorithm applied to gradual ‘raw’ (phylogenetically uncorrected) dataset.

‘Extinction value’	ΔMA	ΔBody size (ln[mm^2])
0	-0.00368	-0.27407
0.5	-0.0051	-0.00602
0.5	0.01892	0.10302
0.24019	0.0261	-0.10725
0.06934	0.02535	0.07067
0.5	-0.03552	-0.41536
0.53452	-0.00592	-0.28706
0	0.02261	-0.1693
0.16667	-0.01714	0.33905
0.53452	-0.03136	0.46071
0	0.03728	-0.06077
0.17588	-0.0012	-0.16538
0.44491	0.00191	0.11443
0.5	-0.03649	-0.57439
0.04714	0.00247	0.18852
0.5	0.00335	-0.15505
0.20059	0.01822	-0.47261
0.5	-0.00417	-0.34278
0	-0.01668	0.54272
0.16987	-0.02681	0.31223
0	0.02432	-0.04684
0.46468	-0.07555	1.01967
0.45262	-0.04615	1.39609
0.23236	0.07096	0.90584
0.14105	0.00587	0.56301
0.5	-0.22426	-1.61929
0.16667	-0.00062	-0.3398
0.15318	-0.01171	-0.30009
0.03599	0.02128	-1.17621
0.15189	0.05998	-0.623
0.06758	-0.01294	1.35252
0.24625	0.03682	-0.78668
0.51093	-0.21336	1.80241
0	0.06286	-0.35105
0.05026	-0.12217	1.1699
0	-0.01794	1.06391
0	-0.05175	-0.71235
0.2481	-0.08291	1.44966
0.33441	-0.00643	0.54859
0	0.01419	0.51087
0	0.02649	0.14783
0.29134	0.06428	-0.59511

0.11352	-0.05382	1.59213
0	-0.12446	0.40742
0.03776	-0.11451	-1.30162
0	0.07477	0.10652
0.01464	0.01149	0.9365
0.38731	-0.1525	1.08169

Phylogenetically independent contrasts for changes in mechanical advantage (ΔMA) and body size (ΔBody sizes), with extinction (considered a continuous variable, but scored only for two end member states: extinction [1] or survival [0]) treated as the predictor variable. These values are derived from the dataset generated under a model of gradual trait change. Contrasts calculated using the CRUNCH algorithm as implemented in CAIC (Purvis and Rambaut 1995).

Supporting table 8. Independent contrasts: CRUNCH algorithm applied to punctuated 'raw' (phylogenetically uncorrected) dataset.

'Extinction value'	ΔMA	ΔBody size (ln[mm^2])
0	0.01308	-0.66413
0.5	-0.02426	-1.57143
0.5	0.08071	0.37592
0.24019	-0.01246	-0.36339
0.06934	0.0946	0.27659
0.5	0.01589	-0.50031
0.53452	-0.01066	-0.39436
0	0.02261	-0.1693
0.16667	-0.04327	1.53536
0.53452	-0.0404	0.17473
0	0.02811	-0.46497
0.17588	0.01731	-0.06086
0.44491	0.00839	1.09812
0.5	-0.02378	-0.22719
0.04714	0.02947	0.50162
0.5	0.04537	-2.1009
0.20059	0.00728	-0.19907
0.5	-0.09636	-1.25134
0	-0.01668	0.54272
0.16987	-0.04567	1.15278
0	0.02432	-0.04684
0.46468	-0.10128	1.36005
0.45262	-0.0695	0.99802
0.23236	0.10089	1.34443
0.14105	-0.00286	0.88505
0.5	-0.22426	-1.61929
0.16667	-0.03135	-0.64265
0.15318	0.02039	-0.06182
0.03599	0.0294	-1.88734
0.15189	0.06798	-0.54414
0.06758	-0.00965	1.09663
0.24625	0.03779	-0.5237
0.51093	-0.27031	1.62785
0	0.06843	-0.90647
0.05026	-0.10228	1.34534
0	-0.02907	0.71052
0	-0.06375	-0.64075
0.2481	-0.09842	1.45668
0.33441	0.00249	0.52931
0	0.12362	-0.09536
0	0.02649	0.14783
0.29134	0.06399	-0.60414

0.11352	-0.05393	1.58861
0	0.00866	-0.01426
0.03776	-0.11455	-1.30279
0	-0.004	0.16507
0.01464	0.01148	0.93605
0.38731	-0.12596	1.06213

Phylogenetically independent contrasts for changes in mechanical advantage (ΔMA) and body size (ΔBody sizes), with extinction (considered a continuous variable, but scored only for two end member states: extinction [1] or survival [0]) treated as the predictor variable. These values are derived from the dataset generated under a model of punctuated trait change. Contrasts calculated using the CRUNCH algorithm as implemented in CAIC (Purvis and Rambaut 1995).

VII. Stratigraphic occurrences of extinction victims.

Below are listed references for stage-level stratigraphic occurrences of multistage extinction victims as shown in Supporting figures 2 and 3. Complete citations are found in the references section of this supplement.

†*Xiphactinus*: Bardack (1965); Gallagher *et al.* (1986); Gallagher (1993); Schwimmer *et al.* (1997); Carpenter (2003).

†*Pentanogmius*: Chalifa and Lewy (1992); Gallagher (2003); Taverne (2004).

†*Protosphyraena*: Dollo (1893); David (1946); Lambers (1992); Carpenter (2003).

†*Pachyrhizodus*: Forey (1977); Carpenter (2003).

†*Saurocephalus*: Bardack and Sprinkle (1969); Stewart (1999); Carpenter (2003).

†*Saurodon*: Bardack and Sprinkle (1969); Stewart (1999); Carpenter (2003).

†*Cimolichthys*: Goody (1969); Carpenter (2003); Ekrt *et al.* (2008).

†*Enchodus*: Goody (1969); McNaulty and Kienzlen (1970); Carpenter (2003); Shimada (2006).

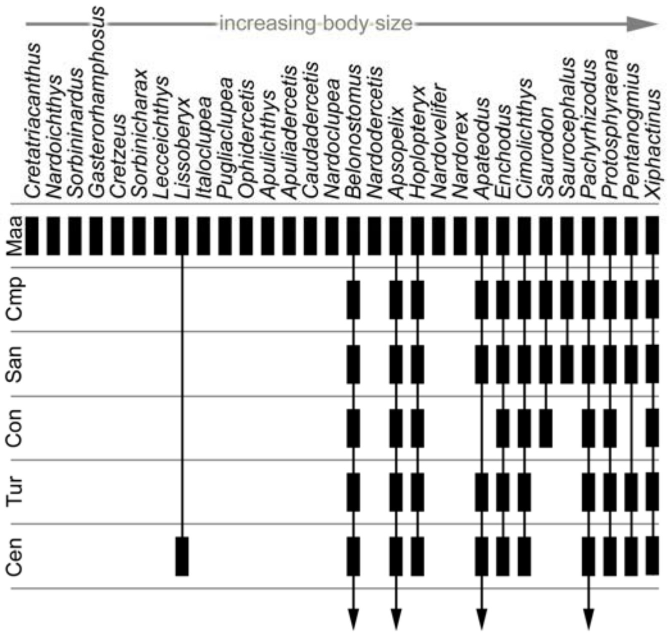
†*Apateodus*: Goody (1969); Carpenter (2003); Stewart and Hakel (2006).

†*Hoplopteryx*: Patterson (1964); Forey *et al.* (2003); Ekrt *et al*. (2008); pers. obs.

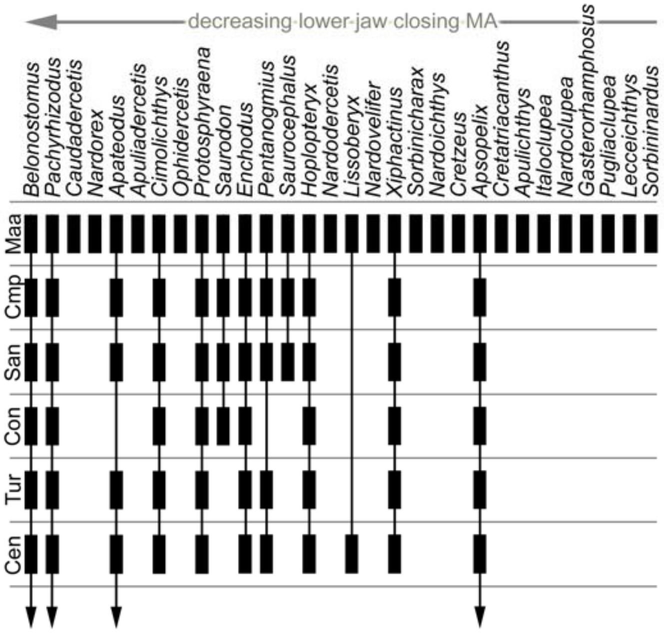
†*Apsopelix*: Dunkle (1960); Teller-Marshall and Bardack (1978).

†*Belonostomus*: Whetstone (1978); Brito (1997); Taverne (1998); Forey *et al.* (2003); Carpenter (2003).

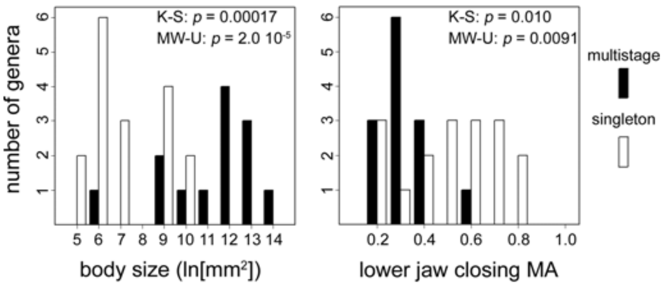
†*Lissoberyx*: Patterson (1993a); Taverne (2003).



Supporting figure 2. Stratigraphic distribution of fossils assigned to genera making their last appearance in the Maastrichtian, sorted by body size (increasing from left to right; taxonomically uncertain Maastrichtian forms cf. †*Omosoma*, cf. †*Rhynchodercetis* and cf. †*Dercetis* are excluded). Solid blocks indicate that the genus is known from that stage. Arrows extending from bottom of figure indicate that the genus is recorded prior to the Cenomanian. The distribution of body sizes between genera occurring in more than one stage and that of singletons differ significantly (Kolmogorov-Smirnov test, p = 0.00017; Mann-Whitney U-test, $p = 2.0 \cdot 10^{-5}$). MA demonstrates the opposite trend (multistage victims have lower MA values than singletons); this pattern is also statistically significant (see main text and Supporting figures 3-4).



Supporting figure 3. Stratigraphic distribution of fossils assigned to genera making their last appearance in the Maastrichtian, sorted by jaw closing MA (decreasing from right to left; taxonomically uncertain Maastrichtian forms cf. †*Omosoma*, cf. †*Rhynchodercetis* and cf. †*Dercetis* are excluded). Solid blocks indicate that the genus is known from that stage. Arrows extending from bottom of figure indicate that the genus is recorded prior to the Cenomanian. The distribution of MA values between genera occurring in more than one stage and that of singletons differ significantly (Kolmogorov-Smirnov test, p = 0.010; Mann-Whitney U-test, p = 0.0091). Body size demonstrates the opposite trend (multistage victims are larger than than singletons); this pattern is also statistically significant (see main text and Supporting figures 2, 4).



Supporting figure 4. Relationships between anatomical trait values (left, MA; right, body size) and stage-level distribution of fossil occurrences. Hollow bars indicate victims known only from a single stage, while those known from multiple stages are indicated by filled bars (taxonomically uncertain Maastrichtian forms cf. †*Omosoma*, cf. †*Rhynchodercetis* and cf. †*Dercetis* are excluded). For both traits, distributions of singletons and multistage victims differ significantly (body size: Kolmogorov-Smirnov test, $p = 0.00017$; Mann-Whitney U-test, $p = 2.0 \cdot 10^{-5}$; MA: Kolmogorov-Smirnov test, $p = 0.010$; Mann-Whitney U-test, $p = 0.0091$).

IX. Dietary evidence for select extinction victims.

Supporting table 9. Preserved gut contents for select taxa making their last appearance in the final stage of the Cretaceous.

Higher taxon	Genus	Stomach contents	Reference
†Aspidorhynchidae	†***Belonostomus*** (J^U)	†*Homeosaurus* (sphenodontid); †*Notagogus* (†macrosemiid)	Eastman (1911); de Saint Seine (1949); Viohl (1990)
	†*Aspidorhynchus* (J^U)	? †*Anaethalion* (teleost); †*Eichstaettia* (teleost); †*Pholidophorus* (teleost); indeterminate fishes	Viohl (1990)
†Pachycormidae	†*Asthenocormus* (J^U)	†*Tharsis* (teleost)	Viohl (1990)
	†*Hypsocormus* (J^U)	indeterminate fishes	Viohl (1990)
†Ichthyodectiformes	†*Thrissops* (J^U)	†*Leptolepides* (teleost)	Viohl (1990)
	†*Allothrissops* (J^U)	†*Leptolepides* (teleost)	Viohl (1990)
	†*Eulibodectes* (K^U)	†*Gaudryella* (teleost); †*Armigatus* (teleost)	Forey *et al.* (2003)
	†*Cladocyclus* (K_L)	†*Rhacoelpis* (teleost)	Patterson and Rosen (1977); Maisey (1994)
	†***Xiphactinus*** (K^U)	†*Gillicus* (teleost); †Tselfatiiformes (teleost)	Bardack (1965); Viohl (1990); Everhart (2005)
†Pachyrhizodontoidei	†*Rhacolepis* (K_L)	†*Rhacolepis* (teleost); †*Santanichthys* (teleost); cf. †*Dastilbe* (teleost)	Wilby and Martill (1992); Maisey (1994)
	†*Goulmimichthys* (K^U)	†*Enchodus* (teleost)	Cavin (1999)
†Alepisauroidei	†***Enchodus*** (K^U)	indeterminate fishes; †Enchodontidae (teleost)	Viohl (1990); Gayet *et al.* (2003)
	†*Eurypholis* (K^U)	indeterminate fishes	Viohl (1990); Gayet *et al.* (2003)
	†***Cimolichthys*** (K^U)	†*Tusoteuthis* (squid); †*Enchodus* (teleost)	Kauffman (1990); Everhart (2005)

Stomach contents of extinction victims and their immediate relatives. Victims considered here are limited to those that fall outside the envelope of survivors in all data partitions (see Figure 2 in the main text). Ages of specific fossils with stomach contents are given in parentheses (J^U: Upper Jurassic; K_L: Lower Cretaceous; K^U: Upper Cretaceous); genera making their last appearance in the Maastrichtian appear in boldface. Victims for which direct evidence of diet is unknown but have close relatives with preserved stomach contents include: †*Protosphyraena* (†Pachycormidae); †*Saurodon* (†Ichthyodectiformes); †*Saurocephalus* (†Ichthyodectiformes); †*Pachyrhizodus* (†Pachyrhizodontoidei).

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