

The following supplement accompanies the article

Finding the way to the top: how the composition of oceanic mid-trophic micronekton groups determines apex predator biomass in the central North Pacific

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Table S1. Description of all 41 Ecopath functional groups, including key species and references for diet and biological parameters.

	Functional Group	Example Taxa	Group Description and Source(s)
1	Blue Sharks	<i>Prionace glauca</i>	Biological parameters and diet follow ‘blue sharks’ group in Howell et al. (2013), including some updated stock status information from the most recent blue shark assessment in the Pacific Ocean (Shark Working Group 2013).
2	Other Sharks	white sharks (<i>Carcharodon carcharias</i>), tiger sharks (<i>Galeocerdo cuvier</i>), shortfin Mako sharks (<i>Isurus oxyrinchus</i>), silky sharks (<i>Carcharhinus falciformis</i>), oceanic white tip (<i>Carcharhinus longimanus</i>), Galapagos shark (<i>Carcharhinus galapagensis</i>), bigeye thresher (<i>Alopias superciliosus</i>), common thresher (<i>Alopias vulpinus</i>), pelagic thresher (<i>Alopias pelagicus</i>), sandbar shark (<i>Carcharhinus plumbeus</i>), longfin mako (<i>Isurus paucus</i>), dogfish (<i>Squalus mitsukurii</i> , <i>Squalus blainville</i>), crocodile shark (<i>Pseudocarcharias kamoharai</i>)	Biological parameters and diet follow ‘other sharks’ group in Howell et al. (2013).
3	Broadbill Swordfish	<i>Xiphias gladius</i>	Biological parameters and diet follow ‘swordfish’ group in Howell et al. (2013). Diet information was updated to include Young et al. (2006).
4	Blue Marlin	<i>Makaira nigricans</i>	Biological parameters and diet follow ‘blue marlin’ group in Howell et al. (2013).
5	Striped Marlin	<i>Tetrapturus audax</i>	Biological parameters and diet follow

			‘striped marlin’ group in Howell et al. (2013).
6	Other Billfishes	sailfish (<i>Istiophorus platypterus</i>), black marlin (<i>Makaira indica</i>), shortbill spearfish (<i>Tetrapturus angustirostris</i>)	Biological parameters and diet follow ‘other billfishes’ group in Howell et al. (2013).
7	Small Billfishes	Juveniles of broadbill swordfish (<i>Xiphias gladius</i>), blue marlin (<i>Makaira nigricans</i>), striped marlin (<i>Tetrapturus audax</i>), sailfish (<i>Istiophorus platypterus</i>), black marlin (<i>Makaira indica</i>), shortbill spearfish (<i>Tetrapturus angustirostris</i>)	Biological parameters and diet follow ‘other billfishes’ group in Howell et al. (2013). Diet information was updated to include Shimose et al. (2010) and Young et al. (2006), mostly to downplay the importance of crustacean prey. Maximum sizes for billfishes in this group were 110 cm, or approximately 8 kg.
8	Baleen Whales	Bryde's whale (<i>Balaenoptera edeni</i>), sei whale (<i>Balaenoptera borealis</i>)	Biological parameters and diet follow Essington (2006) and Ramp et al. (2010, 2014), with some updated diet information from Pauly et al. (1998). Consists primarily of Bryde's whales (<i>Balaenoptera edeni</i>) and small numbers of sei whales (<i>Balaenoptera borealis</i>). Humpback whales (<i>Megaptera novaeangliae</i>) are not considered because they do not feed while residing in the CNP (Calambokidis et al. 1996).
9	Toothed Whales	false killer whale (<i>Pseudorca crassidens</i>), pantropical spotted dolphin (<i>Stenella attenuata</i>), rough-toothed dolphin (<i>Steno bredanensis</i>), common bottlenose dolphin (<i>Tursiops truncatus</i>); short-finned pilot whale (<i>Globicephala macrorhynchus</i>), sperm whale (<i>Physeter macrocephalus</i>), Blainville's beaked whale (<i>Mesoplodon densirostris</i>), Cuvier's beaked whale (<i>Ziphius cavirostris</i>)	Group consists of false killer whales, the most-frequently encountered dolphin species in offshore Hawaiian waters (pantropical spotted dolphin (<i>Stenella attenuata</i>)), rough-toothed dolphin (<i>Steno bredanensis</i>), and common bottlenose dolphin (<i>Tursiops truncates</i>); R. Baird, pers. comm.), and other large toothed whale species common to offshore Hawaiian waters (sperm whale (<i>Physeter catodon</i>)), short-finned pilot whale (<i>Globicephala macrorhynchus</i>), Blainville's beaked whale (<i>Mesoploden densirostris</i>), and Cuvier's beaked whale (<i>Ziphius cavirostris</i>)). Biomass information comes from NMFS marine mammal stock assessment reports and Barlow (2006). Biological parameters follow ‘sperm whales’ group in Essington (2006) and ‘toothed whales’ group in Griffiths et al. (2010). Consumption rates were also taken from Oleson et al. (2010) and Barlow et al. (2008), and compared to ‘sperm whale’ and ‘toothed whales’ groups from Essington (2006) and Griffiths et al. (2010), respectively. Diet information for false killer whales comes from Oleson et al. (2010, and references therein) and Baird et al. (2008), as well as from Pauly et al. (1998) and Jefferson et al. (1993) for the dolphin, sperm, pilot and beaked whale species. Diet information was weighted according to

			biomass of the different toothed whale species.
10	Bigeye Tuna	<i>Thunnus obesus</i>	Biological parameters and diet follow ‘bigeye tuna’ group in Howell et al. (2013). Diet information was updated to include King and Ikehara (1956). The importance of crustacean prey to juvenile bigeye tuna was reduced. Maximum sizes for juvenile bigeye tuna in this group were 100 cm, or approximately 16 kg.
11	Juvenile Bigeye Tuna	<i>Thunnus obesus</i>	See above, group 10
12	Yellowfin Tuna	<i>Thunnus albacares</i>	Biological parameters and diet follow ‘yellowfin tuna’ group in Howell et al. (2013). Diet information was updated to include Olson et al. (2014), King and Ikehara (1956), Reintjes and King (1953), and Alverson (1963). Maximum sizes for juvenile yellowfin tuna in this group were 120 cm, or approximately 29 kg.
13	Juvenile Yellowfin Tuna	<i>Thunnus albacares</i>	See above, group 12
14	Albacore Tuna	<i>Thunnus alalunga</i>	Biological parameters and diet follow ‘bigeye tuna’ group in Howell et al. (2013). Diet information was updated to include Pinkas et al. (1971). Maximum sizes for juvenile albacore tuna in this group were 90 cm, or approximately 10 kg.
15	Juvenile Albacore Tuna	<i>Thunnus alalunga</i>	See above, group 14
16	Skipjack Tuna	<i>Katsuwonus pelamis</i>	Biological parameters and diet follow ‘skipjack tuna’ group in Howell et al. (2013). Diet information was updated to include Alverson (1963), transferring some of the importance of epipelagic fish prey to crustacean and mesozooplankton prey. Maximum sizes for juvenile skipjack tuna in this group were 30 cm, or approximately 0.5 kg.
17	Juvenile Skipjack Tuna	<i>Katsuwonus pelamis</i>	See above, group 16
18	Mahi-mahi	<i>Coryphaena hippurus</i>	Biological parameters and diet follow ‘mahimahi’ group in Howell et al. (2013).
19	Lancetfish	<i>Alepisaurus ferox</i>	Biological parameters and diet follow ‘lancetfish’ group in Howell et al. (2013). Diet information was updated using Choy et al. (2013) and Moteki et al. (1993).
20	Opah	<i>Lampris guttatus</i>	Diet information comes from Choy et al. (2013). Consumption rates follow ‘opah’ group in Griffiths et al. (2010). Very little biological data is available for opah, thus P:B is estimated from FishBase (at a temperature of 18°C).
21	Snake Mackerel & Escolars	snake mackerel (<i>Gempylus serpens</i>), Smith’s escolar (<i>Lepidocybium flavobrunneum</i>), oilfish (<i>Ruvettus pretiosus</i>), longfin escolar (<i>Scombrolabrax heterolepis</i>), Roudi escolar (<i>Promethichthys prometheus</i>)	Snake mackerel (<i>Gempylus serpens</i>) and escolar (<i>Lepidocybium flavobrunneum</i> , <i>Ruvettus pretiosus</i> , <i>Scombrolabrax heterolepis</i>) diet information comes from Choy et al. (2013) and Nakamura and Parin (1993). Specific biological parameters are taken from the ‘mid-trophic level fish’ group from Howell et al. (2013), as well as from FishBase (at a temperature of 18°C) and Polovina et al.

			(2009).
22	Other Large Pelagic Fishes	wahoo (<i>Acanthocybium solandri</i>), pomfrets (<i>Brama japonica</i> , <i>Taractichthys steindachneri</i> , <i>Taractes rubescens</i> , <i>Eumegistus illustris</i>), mola (<i>Mola mola</i> , <i>Ranzania laevis</i> , <i>Masturus lanceolatus</i>)	Follows ‘mid-trophic level fish’ group in Howell et al. (2013). However, diet information was re-balanced to remove snake mackerel (<i>Gempylus serpens</i>), opah (<i>Lampris guttatus</i>), and escolars (<i>Lepidocybium flavobrunneum</i> , <i>Ruvettus pretiosus</i> , <i>Scombrolabrax heterolepis</i>) into their own groups. Wahoo (<i>Acanthocybium solandri</i>) diet information was updated to include Zischke (2012, and references therein). Diet information for fishes from the family Molidae was updated to include Pope et al. (2010, and references therein).
23	Sea Birds	albatrosses (<i>Phoebastria immutabilis</i> , <i>Phoebastria nigripes</i>), sooty tern (<i>Onychoprion fuscatus</i>), Bulwer’s petrel (<i>Bulweria bulwerii</i>), brown noddy (<i>Anous stolidus</i>), black noddy (<i>Anous tenuirostris</i>), wedge-tailed shearwater (<i>Puffinus pacificus</i>)	This group is comprised of representative common tropical sea birds with known oceanic feeding habits: black-footed albatross (<i>Phoebastria nigripes</i>), Laysan albatross (<i>Phoebastria immutabilis</i>), sooty tern (<i>Onychoprion fuscatus</i>), wedge-tailed shearwater (<i>Puffinus pacificus</i>), and Bulwer’s petrel (<i>Bulweria bulwerii</i>). Diet information comes primarily from Harrison et al. (1983) and Shealer (2002) and was weighted according to biomass of the different sea bird species. Biomass was estimated using numbers of breeding pairs for the Hawaiian Archipelago from Harrison and Seki (1987) and Harrison et al. (1984). Other biological parameters follow ‘seabirds’ group in Griffiths et al. (2010).
24	Sea Turtles	loggerhead (<i>Caretta caretta</i>), leatherback (<i>Dermochelys coriacea</i>), olive ridley (<i>Lepidochelys olivacea</i>), green (<i>Chelonia mydas</i>)	Diet information is based primarily on sea turtle species known to feed in oceanic central North Pacific waters: green (<i>Chelonia mydas</i> ; Arthur and Balazs 2008; Parker et al. 2011), leatherback (<i>Dermochelys coriacea</i> ; Jones & Seminoff 2013; Bjorndal 1997), loggerhead (<i>Caretta caretta</i> ; Parker et al. 2005), and olive ridley (<i>Lepidochelys olivacea</i> ; Jones & Seminoff 2013; Bjorndal 1997). Biomass estimates were taken from Jones et al. (2012) for leatherback turtles, and from National Marine Fisheries Service biological opinions and 5-year reviews. Other biological parameters were estimated using growth and mortality data in Jones et al. (2012) and Jones et al. (2011) for leatherback turtles, Wabnitz et al. (2010) for green turtles, and Swimmer et al. (2014) for loggerhead turtles. P:B and Q:B were variable between leatherback turtles and the other hard-shelled species, and were thus weighted according to biomass estimates of the different turtle species.
25	Small Epipelagic Fishes	beloniformes (Exocoetidae)	Follows ‘epipelagic fish’ group in Howell

		Hemiramphidae, Belonidae, and Scomberesocidae families), jacks (Family Carangidae), rainbow runner (<i>Elagatis bipinnulata</i>), small tunas (<i>Auxis</i> spp., <i>Euthynnus affinis</i>), clupeiformes (Clupeidae and Engraulidae families)	et al. (2013). Diet information was updated to include Van Noord et al. (2013).
26	Zooplanktivorous Micronekton Fishes	Myctophidae, Gonostomatidae, Sternopychidae, Bathylagidae, Bregmacerotidae, and Phosichthyidae families (among others)	Biological parameters follow ‘mesopelagic fish’ group in Howell et al. (2013), and has been further informed by Torres et al. (1979) and Childress et al. (1980). Diet information was re-balanced to remove the families belonging to the carnivorous micronekton group. Diet information comes primarily from Clarke (1980), Clarke (1982), and Hopkins et al. (1996). Biomass estimates were derived in the same way as the ‘carnivorous micronekton fish’ group.
27	Carnivorous Micronekton Fishes	Stomiidae, Melamphaidae, Chiasmodontidae, and Paralepididae fish families, and Anguilliformes	Biomass was estimated from best available trawling studies conducted in offshore waters surrounding the Hawaiian Islands: Drazen et al. (2011), Pahkomov and Yamamura (2010), and Maynard et al. (1975). Due to the mobility of midwater fishes, trawls are known underestimates of mesopelagic fish biomass by at least an order of magnitude (Koslow et al. 1997; Kaartvedt et al. 2012). Thus, the highest biomass estimate of the three trawling studies was selected, and a correction factor of 3 was used to account for trawl capture inefficiency. This correction factor was chosen to keep biomass estimates comparable to the ‘mesopelagic fish’ group in Howell et al. (2013). Diet information comes primarily from Clarke (1980), Clarke (1978), Clarke (1973), DeWitt and Cailliet (1972), and Lancraft et al. (1988). Biological parameters are drawn from the ‘mesopelagic fish’ group in Howell et al. (2013), and from Davison et al. (2013). Additionally, Torres et al. (1979) and Childress et al. (1980) who showed that the metabolic rate decreases with depth and that non-migratory mesopelagic fishes have an even lower metabolic rate compared to the migratory (e.g. the ‘zooplanktivorous micronekton fishes’ group) species. Metabolic rates (respiration/biomass ratio in Ecopath) decreased with depth indicating that the input parameters follow this thermodynamic rule well.
28	Decapod Crustaceans	Ophlophoridae, Pandalidae, Pasaphaeidae, Penaeidae,	Diet information from this group comes primarily from Podeswa (2012), Hopkins

		Sergestidae, Pandalidae, Benthesicymidae families	et al. (1994), and Flock and Hopkins (1992). Biological parameters follow those of the ‘invertebrates’ group in Howell et al. (2013) and the ‘mesopelagic crustaceans’ group in Griffiths et al. (2010).
29	Other Crustaceans	mysids (Eucopeidae, Lophogastridae families), hyperiid amphipods, isopods, lobster phyllosoma, stomatopods, scyllarids	Diet information from this group comes primarily from Podeswa (2012) and Hopkins et al. (1994). Biological parameters follow those of the ‘invertebrates’ group in Howell et al. (2013) and the ‘mesopelagic crustaceans’ group in Griffiths et al. (2010).
30	Predatory Gelatinous	pelagic cnidarians (Siphonophora, Ctenophora, Scyphozoa, hydromedusae)	Diet information is summarized from Purcell (1980), Purcell (1991), and Purcell and Arai (2001). Biomass was estimated using average biomass of pelagic cnidarians (Siphonophora, Ctenophora, Scyphozoa) for the North Pacific Tropical Gyre biome in Lucas et al. (2014). Proximal and elemental compositions from Lucas et al. (2011) were used to convert from carbon to wet weight biomass. Other biological parameters are summarized from a meta-analysis by Pauly et al. (2009).
31	Filter-feeding Gelatinous	Pyrosomatidae and Salpidae families, pelagic tunicates (Class Appendicularia)	Diet information is summarized from Madin et al. (2006), Bone et al. (2003), Purcell and Madin (1991), and Alldredge and Madin (1982). Salps, pyrosomes, and appendicularians were considered generalist feeders across particle size classes ranging from approximately < 1 µm (appendicularians) to upwards of 4 µm (salps and pyrosomes). Biomass was estimated in the same way as was done for the ‘predatory gelatinous animals’ group, but using biomass for chordates (pyrosomes and salps). Other biological parameters are summarized from a meta-analysis by Pauly et al. (2009) for the central North Pacific.
32	Epipelagic Mollusks	Ommastrephidae (<i>Ommastrephes bartramii</i> , <i>Sthenoteuthis oualaniensis</i> , <i>Eucleoteuthis luminosa</i> , <i>Hyaloteuthis pelagica</i>), Onychoteuthidae (<i>Onykia</i> spp., <i>Onychoteuthis</i> spp.), Argonautidae, Carinariidae, Davoliniidae, Loliginidae, Sepiolidae, and Thysanoteuthidae families	Follows ‘epipelagic mollusks’ group in Howell et al. (2013). Diet information was updated to include Parry (2006) and Watanabe et al. (2004).
33	Mesopelagic Mollusks	Enoploteuthidae, Pyroteuthidae, Amphitretidae, Histioteuthidae, Gonatidae (<i>Gonatopsis</i> spp., <i>Gonatus</i> spp.), Cranchiidae, and Chiroteuthidae (<i>Chiroteuthis</i>	Follows ‘mesopelagic mollusks’ group in Howell et al. (2013). Diet information was updated to include Passarella and Hopkins (1991).

		spp.) families	
34	Bathypelagic Fishes	Anoplogastridae, Ceratiidae, Himantolophidae, Oneirodidae, Melamphaidae, Sternoptychidae, Omosudidae, Chiasmodontidae, Cyematidae, and Eurypharyngidae families	Biological parameters follow ‘bathypelagic fish’ group in Howell et al. (2013). Based on the low metabolic rate of bathypelagic fishes (Torres et al. 1979, Childress et al. 1980) we decreased the Q/B value to 2.4. Diet information was drawn from existing literature: Hopkins et al. (1996), Gordon et al. (1985), Clarke (1978), Clarke (1982).
35	Mesozooplankton	copepods (<i>Neocalanus robustior</i> , <i>Pleuromamma xiphias</i> , <i>Euchaeta rimana</i> , <i>Oithona</i> spp.), chaetognaths, pteropods, euphausiids, amphipods	Biological parameters and diet follow ‘mesozooplankton’ group in Howell et al. (2013).
36	Microzooplankton	ciliates, copepod nauplii, heterotrophic dinoflagellates, protozoa, tintinnids	Biological parameters and diet follow ‘microzooplankton’ group in Howell et al. (2013).
37	Diatoms	diatoms (Class Bacillariophyceae)	Biological parameters follow ‘large phytoplankton >5µm’ and ‘small phytoplankton <5µm’ groups in Howell et al. (2013). Large phytoplankton were further divided into diatoms, diazotrophs, and other types of >5µm phytoplankton, using 1991 biomass output from ESM2.1 (see Methods).
38	Diazotrophs	<i>Trichodesmium</i> , <i>Richelia</i> , other small cyanobacterial diazotrophs	See above, group 37
39	Other Large Phytoplankton	some prymnesiophytes, pelagophytes, and cryptophytes	See above, group 37
40	Small Phytoplankton	<i>Prochlorococcus</i> , <i>Synechococcus</i> , picoeukaryotes, other cyanobacteria	See above, group 37
41	Detritus	particulate organic matter	Parameters follow ‘detritus’ group in Howell et al. (2013).

References for Table S1

- Alldredge AL, Madin LP (1982) Pelagic tunicates: unique herbivores in the marine plankton. Bioscience 32:655–663 doi:10.2307/1308815
- Alverson FG (1963) The food of yellowfin and skipjack tunas in the eastern tropical Pacific Ocean. Inter-American Tropical Tuna Comm Bull 7:295–367. <http://aquaticcommons.org/2610>
- Arthur KE, Balazs GH (2008) A comparison of immature green turtles (*Chelonia mydas*) diets among seven sites in the main Hawaiian islands’. Pac Sci 62:205–217 doi:10.2984/1534-6188(2008)62[205:ACOIGT]2.0.CO;2
- Baird RW, Gorgone AM, McSweeney DJ, Salden DR and others (2008) False killer whales (*Pseudorca crassidens*) around the main Hawaiian Islands: Long-term site fidelity, inter-island movements, and association patterns. Mar Mamm Sci 24:591–612 doi:10.1111/j.1748-7692.2008.00200.x
- Barlow J (2006) Cetacean abundance in Hawaiian waters estimated from a summer/fall survey in 2002. Mar Mamm Sci 22:446–464 doi:10.1111/j.1748-7692.2006.00032.x

- Barlow J, Kahru M, Mitchell BG (2008) Cetacean biomass, prey consumption, and primary production requirements in the California Current ecosystem. *Mar Ecol Prog Ser* 371:285–295 doi:10.3354/meps07695
- Bjorndal KA 1997. Foraging ecology and nutrition of sea turtles. In *The biology of sea turtles*. eds. PL Lutz and JA Musick. CRC Press, London. pp. 199–231
- Bone Q, Carre C, Chang P (2003) Tunicate feeding filters. *J Mar Biol Assoc UK* 83:907–919 doi:10.1017/S002531540300804Xh
- Calambokidis J, Steiger GH, Evenson JR, Flynn KR and others (1996) Interchange and isolation of humpback whales off California and other North Pacific feeding grounds. *Mar Mamm Sci* 12:215–226 doi:10.1111/j.1748-7692.1996.tb00572.x
- Childress JJ, Taylor SM, Cailliet GM, Price MH (1980) Patterns of growth, energy utilization and reproduction in some meso-and bathypelagic fishes off southern California. *Mar Biol* 61:27–40 doi:10.1007/BF00410339
- Choy CA, Portner E, Iwane M, Drazen JC (2013) Diets of five important predatory mesopelagic fishes of the central North Pacific. *Mar Ecol Prog Ser* 492:169–184 doi:10.3354/meps10518
- Clarke TA (1973) Some aspects of the ecology of lanternfishes (Myctophidae) in the Pacific Ocean near Hawaii. *Fish Bull* 71:401–434
- Clarke TA (1978) Diel feeding patterns of 16 species of mesopelagic fishes from Hawaiian waters. *Fish Bull* 76:495–513
- Clarke TA (1980) Diets of fourteen species of vertically migrating mesopelagic fishes in Hawaiian waters. *Fish Bull* 78:619–640
- Clarke TA (1982) Feeding habits of stomiatoid fishes from Hawaiian waters. *Fish Bull* 80:287–304
- Davison PC, Checkley DM Jr, Koslow JA, Barlow J (2013) Carbon export mediated by mesopelagic fishes in the northeast Pacific Ocean. *Prog Oceanogr* 116: 14–30
- DeWitt FA, Cailliet GM (1972) Feeding habits of two bristlemouth fishes, *Cyclothona acclinidens* and *C. signata* (Gonostomatidae). *Copeia* 1972:868–871 doi:10.2307/1442749
- Drazen JC, De Forest LG, Domokos R (2011) Micronekton abundance and biomass in Hawaiian waters as influenced by seamounts, eddies, and the moon. *Deep Sea Res Part I Oceanogr Res Pap* 58: 557–566
- Essington TE 2006. Pelagic ecosystem response to a century of commercial whaling and fishing. In *Whales, whaling and ocean ecosystems*. eds JA Estes, DP DeMaster, DF Doak, TM Williams, RF Brownell. University of California Press, Berkeley and Los Angeles, CA. pp. 38–49
- Flock ME, Hopkins TL (1992) Species composition, vertical distribution, and food habits of the Sergestid shrimp assemblage in the eastern Gulf of Mexico. *J Crustac Biol* 12:210–223 doi:10.2307/1549076
- Gordon, J. D. M., S. Nishida and T. Nemoto (1985) The diet of mesopelagic fish from the Pacific coast of Hokkaido, Japan. *J. Oceanogr. Soc. Japan*, **41**, 89–97
- Griffiths SP, Young JW, Lansdell MJ, Campbell RA and others (2010) Ecological effects of longline fishing and climate change on the pelagic ecosystem off eastern Australia. *Rev Fish Biol Fish* 20: 239–272
- Harrison CS, Seki MP 1987. Trophic relationships among tropical seabirds at the Hawaiian Islands. In *Seabirds: feeding ecology and role in marine ecosystems*. ed JP Croxall. Cambridge University Press, England. pp 305–326
- Harrison CS, Hida TS, Seki MP (1983) Hawaiian seabird feeding ecology. *Wildl Monogr* 85:1–71

- Harrison CS, Naughton MB, Fefer SI 1984. The status and conservation of seabirds in the Hawaiian Archipelago and Johnston Atoll. In Status and conservation of the world's seabirds. eds JP Croxall, PGH Evans, RW Schreiber. ICBP, Cambridge. pp. 513-526.
- Hopkins TL, Flock ME, Gartner JV Jr, Torres JJ (1994) Structure and trophic ecology of a low latitude midwater decapod and mysid assemblage. Mar Ecol Prog Ser 109:143–156 doi:10.3354/meps109143
- Hopkins TL, Sutton TT, Lancraft TM (1996) The trophic structure and predation impact of a low latitude midwater fish assemblage. Prog Oceanogr 38:205–239 doi:10.1016/S0079-6611(97)00003-7
- Howell EA, Wabnitz CCC, Dunne JP, Polovina JJ (2013) Climate-induced primary productivity change and fishing impacts on the Central North Pacific ecosystem and Hawaii-based pelagic longline fishery. Clim Change 119:79–93 doi:10.1007/s10584-012-0597-z
- Jefferson TA, Leatherwood S, Webber MA 1993. Marine mammals of the world. FAO Species Identification Guide. Food and Agriculture Organization, Rome. 320 pp.
- Jones TT, Bostrom BL, Hastings MD, Van Houtan KS, Pauly D, Jones DR (2012) Resource requirements of the Pacific leatherback turtle population. PLoS ONE 7: e45447. doi:10.1371/journal.pone.0045447
- Jones TT, Seminoff JA 2013. Feeding Biology: advances from field-based observations, physiological studies, and molecular techniques. In The biology of sea turtles, volume III. eds. J Wyneken, KL Lohmann, JA Musick. CRC Press, London. pp. 211-247
- Kaartvedt S, Staby A, Aksnes DL (2012) Efficient trawl avoidance by mesopelagic fishes causes large underestimation of their biomass. Mar Ecol Prog Ser 456: 1–6
- King JE, Ikebara II (1956) Comparative study of food of bigeye and yellowfin tuna in the central Pacific. Fish Bull 57:61–81
- Koslow JA, Kloser RJ, Williams A (1997) Pelagic biomass and community structure over the mid-continent slope off southeastern Australia based upon acoustic and midwater trawl sampling. Mar Ecol Prog Ser 146: 21–35
- Lancraft TM, Hopkin TL, Torres JJ (1988) Aspects of the ecology of the mesopelagic fish *Gonostoma elongatum* (Gonostomatidae, Stomiiformes) in the eastern Gulf of Mexico. Mar Ecol Prog Ser 49: 27–40
- Lucas CH, Pitt KA, Purcell JE, Lebrato M, Condon RH (2011) What's in a jellyfish? Proximate and elemental composition and biometric relationships for use in biogeochemical studies. Ecology 92:1704 doi:10.1890/11-0302.1
- Lucas CH, Jones DOB, Hollyhead CJ, Condon RH and others (2014) Gelatinous zooplankton biomass in the global oceans: geographic variation and environmental drivers. Glob Ecol Biogeogr. 23: 701-714 doi:10.1111/geb.12169
- Madin LP, Kremer P, Wiebe PH, Purcell JE, Horgan EH, Nemazie DA (2006) Periodic swarms of the salp *Salpa aspera* in the slope water off the NE United States: biovolume, vertical migration, grazing and vertical flux. Deep-Sea Res I 53:804–819 doi:10.1016/j.dsr.2005.12.018
- Maynard SD, Riggs FV, Walters J (1975) Mesopelagic micronekton in Hawaiian waters: faunal composition, standing stock, and diel vertical migration. Fish Bull 73: 726–736
- Moteki M, Fujita K, Kohno H (1993) Stomach contents of longnose lancetfish, *Alepisaurus ferox*, in Hawaiian and central equatorial Pacific waters. J Tokyo Univ Fish 80:121–137
- Nakamura, I. and N. V. Parin (1993) FAO species catalogue. Vol. 15. Snake mackerels and cutlassfishes of the world (Families Gempylidae and Trichiuridae). An annotated and illustrated catalogue of the snake mackerels, snoeks, escolars, gemfishes, sackfishes, domine, oilfish, cut-

lassfishes, scabbardfishes, hairtails, and frostfishes known to date. FAO Fisheries Synopsis. No. 125, Vol. 15. 136 p., 200 figs.

Oleson EM, Boggs CH, Forney KA, Hanson MB and others (2010) Status review of Hawaiian insular false killer whales (*Pseudorca crassidens*) under the Endangered Species Act. US Department of Commerce, NOAA Tech. Memo., NOAA-TM-NMFS-PIFSC-22, 140 p.

Olson RJ, Duffy LM, Kuhnert PM, Galván-Magaña F and others (2014) Decadal diet shift in yellowfin tuna *Thunnus albacares* suggests broad-scale food web changes in the eastern tropical Pacific Ocean. Mar Ecol Prog Ser 497:157–178 doi:10.3354/meps10609

Pahkomov E, O Yamamura (2010) Report of the Advisory Panel on Micronekton Sampling Inter-calibration Experiment. North Pacific Marine Science Organization, PICES Sci. Rep. No. 38

Parker DM, Cooke WJ, Balazs GH (2005) Diet of oceanic loggerhead sea turtles (*Caretta caretta*) in the central North Pacific. Fish Bull 103:142–152

Parker DM, Dutton PH, Balazs G (2011) Oceanic diet and distribution of haplotypes for the green turtle, *Chelonia mydas*, in the central North Pacific. Pac Sci 65:419–431 doi:10.2984/65.4.419

Parry M (2006) Feeding behavior of two ommastrephid squids *Ommastrephes bartramii* and *Sthenoteuthis oualaniensis* off Hawaii. Mar Ecol Prog Ser 318:229–235 doi:10.3354/meps318229

Passarella KC, Hopkins TL (1991) Species composition and food habits of the micronektonic cephalopod assemblage in the eastern Gulf of Mexico. Bull Mar Sci 49:638–659

Pauly D, Trites AW, Capuli E, Christensen V (1998) Diet composition and trophic levels of marine mammals. ICES J Mar Sci 55:467–481 doi:10.1006/jmsc.1997.0280

Pauly D, Graham W, Libralato S, Morissette L, Palomares MLD (2009) Jellyfish in ecosystems, online databases, and ecosystem models. Hydrobiologia 616:67–85 doi:10.1007/s10750-008-9583-x

Pinkas L, Oliphant MS, Iverson ILK (1971) Food habits of albacore, bluefin tuna, and bonito in California waters. Calif Dep Fish Game, Fish Bull 152, 105 pp.

Podeswa Y 2012. Active carbon transport and feeding ecology of pelagic decapods in the North Pacific Subtropical Gyre. MS thesis, Univ British Columbia, 119 pp.

Polovina JJ, Abecassis M, Howell EA, Woodworth P (2009) Increases in the relative abundance of mid-trophic level fishes concurrent with declines in apex predators in the subtropical North Pacific, 1996–2006. Fish Bull 107:523–531

Pope EC, Hays GC, Thys TM, Doyle TK and others (2010) The biology and ecology of the ocean sunfish *Mola mola*: a review of current knowledge and future research perspectives. Rev Fish Biol Fish 20:471–487 doi:10.1007/s11160-009-9155-9

Purcell JE (1980) Influence of siphonophore behavior upon their natural diets: evidence for aggressive mimicry. Science 209:1045–1047 PubMed doi:10.1126/science.209.4460.1045

Purcell JE (1991) A review of cnidarians and ctenophores feeding on competitors in the plankton. Hydrobiologia 216/217:335–342 doi:10.1007/BF00026483

Purcell JE, Arai MN (2001) Interactions of pelagic cnidarians and ctenophores with fish: a review. Hydrobiologia 451:27–44 doi:10.1023/A:1011883905394

Purcell JE, Madin LP (1991) Diel patterns of migration, feeding, and spawning by salps in the Subarctic Pacific. Mar Ecol Prog Ser 73:211–217 doi:10.3354/meps073211

Ramp C, Bérubé M, Palsbøll P, Hagen W, Sears R (2010) Sex-specific survival in the humpback whale *Megaptera novaeangliae* in the Gulf of St. Lawrence, Canada. Mar Ecol Prog Ser 400:267–276 doi:10.3354/meps08426

Ramp C, Delarue J, Bérubé M, Hammond PS, Sears R (2014) Fin whale survival and abundance in the Gulf of St. Lawrence, Canada. Endang Spec Res 23:125–132 doi:10.3354/esr00571

- Reintjes JW, King JE (1953) Food of yellowfin tuna in the central Pacific. Fish Bull 81: 91-110
- Shark Working Group (2013) Stock assessment and future projections of blue shark in the North Pacific Ocean. Western and Central Pacific Fisheries Commission, Report WCPFC-SC9-2013/ SA-WP-11, 82pp
- Shealer DA 2002. Foraging behavior and food of seabirds. In Biology of marine birds. eds EA Schreiber, J Burger. CRC Press, Boca Raton, FL, pp 137–177
- Shimose T, Yokawa K, Saito H (2010) Habitat and food partitioning of billfishes (Xiphioidae). J Fish Biol 76:2418–2433 PubMed doi:10.1111/j.1095-8649.2010.02628.x
- Swimmer Y, Campora C, McNaughton L, Musyl M, Parga M (2014) Post-release mortality estimates of loggerhead sea turtles (*Caretta caretta*) caught in pelagic longline fisheries based on satellite data and hooking location. Aquatic Conserv: Mar Freshw Ecosyst 24: 498-510
- Torres JJ, Belman BW, Childress JJ (1979) Oxygen consumption rates of midwater fishes as a function of depth of occurrence. Deep Sea Res Part A Oceanogr Res Pap 26: 185–197
- Van Noord JE, Lewallen EA, Pitman RL (2013) Flyingfish feeding ecology in the eastern Pacific: prey partitioning within a speciose epipelagic community. J Fish Biol 83:326–342 PubMed doi:10.1111/jfb.12173
- Wabnitz CCC, Balazs G, Beavers S, Bjorndal KA, Bolten AB and others (2010) Ecosystem structure and processes at Kaloko Honokohau, focusing on the role of herbivores, including the green sea turtle *Chelonia mydas*, in reef resilience. Mar Ecol Prog Ser 420: 27-44.
- Watanabe H, Kubodera T, Ichii T, Kawahara S (2004) Feeding habits of neon flying squid *Ommastrephes bartramii* in the transitional region of the central North Pacific. Mar Ecol Prog Ser 266:173–184 doi:10.3354/meps266173
- Young J, Lansdell M, Riddoch S, Revill A (2006) Feeding ecology of broadbill swordfish, *Xiphias gladius*, off Eastern Australia in relation to physical and environmental variables. Bull Mar Sci 79:793–809

Table S2. Balanced Ecopath diet matrix showing percent diet composition (wet weight basis) of consumers (columns) and their prey items (rows). J. =Juvenile, L = Large, Pel = Pelagic, MN = micronekton, Crus. = Crustacean.

Prey \ Predator	Blue Sharks	Other Sharks	Broadbill Swordfish	Blue Marlin	Striped Marlin	Other Billfishes	Small Billfishes	Baleen Whales	Toothed Whales	Bigeye Tuna	J. Bigeye Tuna	Yellowfin Tuna	J. Yellowfin Tuna	Albacore Tuna	J. Albacore Tuna	Skipjack Tuna	J. Skipjack Tuna	Mahimahi	Lancetfish	Opah	Snake Mackerel & Escolars	Other Large Pelagic Fishes
Blue Sharks	0	0.01	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Other Sharks	0.02	0.01	0	0	0	0.01	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Broadbill Swordf	0.01	0.01	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Blue Marlin	0.01	0.01	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Striped Marlin	0.01	0.01	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Other Billfishes	0.01	0.01	0	0.02	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Small Billfishes	0.01	0.01	0	0.01	0	0	0.002	0	0	0	0	0	0	0.01	0	0	0	0	0	0	0	0.003333
Baleen Whales	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Toothed Whales	0	0.01	0	0	0	0	0	0	0.0002	0	0	0	0	0	0	0	0	0	0	0	0	0
Bigeye Tuna	0	0.05	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
J. Bigeye Tuna	0.01	0.03	0.002	0.02	0.005	0	0	0	0	0	0	0	0	0	0	0.002	0	0	0	0	0	0
Yellowfin Tuna	0.01	0.02	0	0.01	0.01	0	0	0	0.0004	0	0	0	0	0	0	0	0	0	0	0	0	0
J. Yellowfin Tuna	0.01	0.02	0.002	0.01	0.002	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Albacore Tuna	0	0.05	0	0.01	0	0	0	0	0.0003	0	0	0	0	0.001	0	0	0	0	0	0	0	0
J. Albacore Tuna	0.01	0.03	0.002	0.01	0.01	0.01	0	0	0	0.01	0	0.02	0	0	0	0	0	0	0	0	0	0
Skipjack Tuna	0.02	0.02	0.002	0.01	0.01	0	0	0	0.0003	0	0	0.02	0	0	0	0	0	0	0	0	0	0
J. Skipjack Tuna	0.01	0.05	0.002	0.1	0.1	0.125	0.01	0	0	0.005	0.005	0.02	0	0.02	0.005	0.02	0	0.02	0	0	0	0.0001
Mahimahi	0.025	0.05	0.014	0.03	0.01	0.01	0	0	0.0031	0.04	0	0.02	0	0.01	0	0	0	0.02	0	0	0	0.0033
Lancetfish	0.05	0.08	0.04	0.05	0.05	0	0	0	0	0.1	0	0.05	0	0.05	0	0	0	0	0.05	0.2774	0	0
Ophah	0	0.01	0	0	0	0	0.01	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Snake Mackerel	0	0.01	0.002	0.05	0.05	0	0.02	0	0	0.05	0	0.02	0	0.02	0	0	0	0.06	0	0	0.027	0
Other L. Pel. Fish	0.05	0.01	0.04	0.02	0.01	0.01	0	0.05	0.1567	0.05	0	0.09	0	0.02	0	0	0	0.014	0.0728	0.2060	0.1793	0.025
Sea Birds	0	0.01	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sea Turtles	0	0.01	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Small Epi. Fishes	0.1	0.16	0.1	0.3	0.35	0.525	0.35	0.125	0.0398	0.08	0.3	0.27	0.2	0.27	0.28	0.2	0.1	0.55	0.0186	0.0005	0.01	0.05
Zoopl. MN Fishes	0.1	0.02	0.003	0	0	0	0	0.1438	0.1230	0.025	0.01	0.02	0	0.03	0.01	0.1	0	0.03	0.0014	0.0151	0.05	0
Carniv. MN	0.1	0.08	0.04	0.02	0.05	0	0.2	0.0188	0	0.2	0.15	0.05	0.1	0.17	0.04	0.01	0.05	0.01	0.2	0.1033	0.08	0.08
Fishes																						
Decapod Crust.	0	0	0.0005	0.02	0.01	0	0	0	0.035	0.1	0.03	0.125	0.05	0.05	0.01	0.05	0.001	0.0014	0.0066	0.1	0.0819	
Other Crustaceans	0.05	0.02	0.0005	0.01	0.043	0.01	0.108	0.0188	0	0.035	0.215	0.2	0.405	0.074	0.403	0.1	0.465	0.05	0.22	0.0728	0.0827	0.1
Pred. Gelatinous	0	0	0	0	0	0	0	0	0.02	0.01	0	0.01	0	0	0	0	0	0	0	0.0053	0	0.18
Filter-feed. Gelat.	0	0	0	0	0	0	0	0	0.02	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0	0.097	0.0481	0	0.15	
Epi. Molluscs	0.37	0.17	0.1	0.3	0.28	0.3	0.2	0	0.3807	0.13	0.075	0.15	0	0.18	0	0.3	0	0.2	0.056	0.0137	0.208	0.0333
Mesopel.	0.015	0	0.6	0	0	0	0	0.025	0.2953	0.1	0.075	0	0.05	0.055	0.05	0	0.075	0.03	0.1	0.1993	0.09	0.09
Molluscs																						
Bathypel. Fishes	0	0.02	0.05	0	0	0	0	0	0	0.1	0	0.01	0	0.01	0	0	0	0.01	0.0827	0.0291	0	0
Mesozooplankton	0	0	0	0	0.01	0	0.1	0.5	0	0	0.05	0.02	0.1	0.01	0.15	0.25	0.2	0	0.0998	0.0228	0.17	0.2
Microzooplankton	0	0	0	0	0	0	0	0.1188	0	0	0	0	0	0	0	0	0.05	0	0	0	0.003	0
Diatoms	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Diazotrophs	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Other L. Phytopl.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Small Phytopl.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.003
Detritus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.005	0	0	0	0	0

Continuation Table S2

Prey \ predator	Sea Birds	Sea Turtles	Small Epi. Fishes	Zooplanktiv. MN Fishes	Carniv. MN Fishes	Decapod Crustaceans	Other Crustaceans	Predatory Gelatinous	Filter-feeding Gelatinous	Epipelagic Molluscs	Mesopelagic Molluscs	Bathypelagic Fishes	Mesozooplank-ton	Microzooplank-ton
Blue Sharks	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Other Sharks	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Broadbill Swordfish	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Blue Marlin	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Striped Marlin	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Other Billfishes	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Small Billfishes	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Baleen Whales	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Toothed Whales	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bigeye Tuna	0	0	0	0	0	0	0	0	0	0	0	0	0	0
J. Bigeye Tuna	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Yellowfin Tuna	0	0	0	0	0	0	0	0	0	0	0	0	0	0
J. Yellowfin Tuna	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Albacore Tuna	0	0	0	0	0	0	0	0	0	0	0	0	0	0
J. Albacore Tuna	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Skipjack Tuna	0	0	0	0	0	0	0	0	0	0	0	0	0	0
J. Skipjack Tuna	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mahimahi	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lancetfish	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Opah	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Snake Mackerel	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Other L. Pelagic Fish	0	0	0	0	0	0	0	0	0	0.001	0	0	0	0
Sea Birds	0.0003	0	0	0	0	0	0	0	0	0	0	0	0	0
Sea Turtles	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Small Epi. Fishes	0.1631	0	0.054	0	0	0	0	0.012	0	0.05	0.01	0	0	0
Zoopl. MN Fishes	0.0057	0.0003	0	0	0.4	0.005	0.007	0	0	0.05	0.01	0.07	0	0
Carniv. MN Fishes	0.0187	0.0003	0.05	0	0.02	0.01	0.005	0.01	0	0.08	0.02	0.05	0	0
Decapod Crustaceans	0.0146	0	0.15	0	0.1337	0.03	0.0148	0	0	0.039	0.01	0.002	0	0
Other Crustaceans	0.0562	0.0013	0.3	0	0.0965	0.02	0.01	0.009	0	0.38	0.37	0.016	0	0
Pred. Gelatinous	0.0021	0.412	0	0	0	0.0233	0.0055	0.035	0	0	0.01	0.1057	0	0
Filter-feed. Gelat.	0.0239	0.25	0.02	0	0	0	0.007	0.03	0	0	0	0.02	0	0
Epipelagic Molluscs	0.5796	0	0.025	0	0	0	0	0	0	0.05	0	0	0	0
Mesopelagic Molluscs	0.0399	0	0.017	0	0.0686	0.008	0.0025	0	0	0.09	0.025	0.05	0	0
Bathypelagic Fishes	0	0	0.009	0	0.1112	0	0	0	0	0.04	0.02	0.02	0	0
Mesozooplankton	0.0957	0.2575	0.105	0.7281	0.17	0.46	0.51	0.763	0.02	0.22	0.125	0.316	0.05	0
Microzooplankton	0	0	0.055	0.1486	0	0.0434	0.0933	0.141	0.08	0	0.1	0.35	0.37	0
Diatoms	0	0	0.0083	0	0	0	0	0	0.175	0	0.033	0	0.05	0
Diazotrophs	0	0.0025	0.0083	0	0	0	0	0	0.175	0	0.033	0	0.05	0
Other L. Phytopl.	0	0.0763	0.0083	0.0333	0	0.15	0.005	0	0.1	0	0.033	0	0.05	0
Small Phytoplankton	0	0	0	0.0067	0	0	0	0	0.3	0	0	0	0	1
Detritus	0	0	0.19	0.0833	0	0.2503	0.34	0	0.15	0	0.2	0	0.43	0

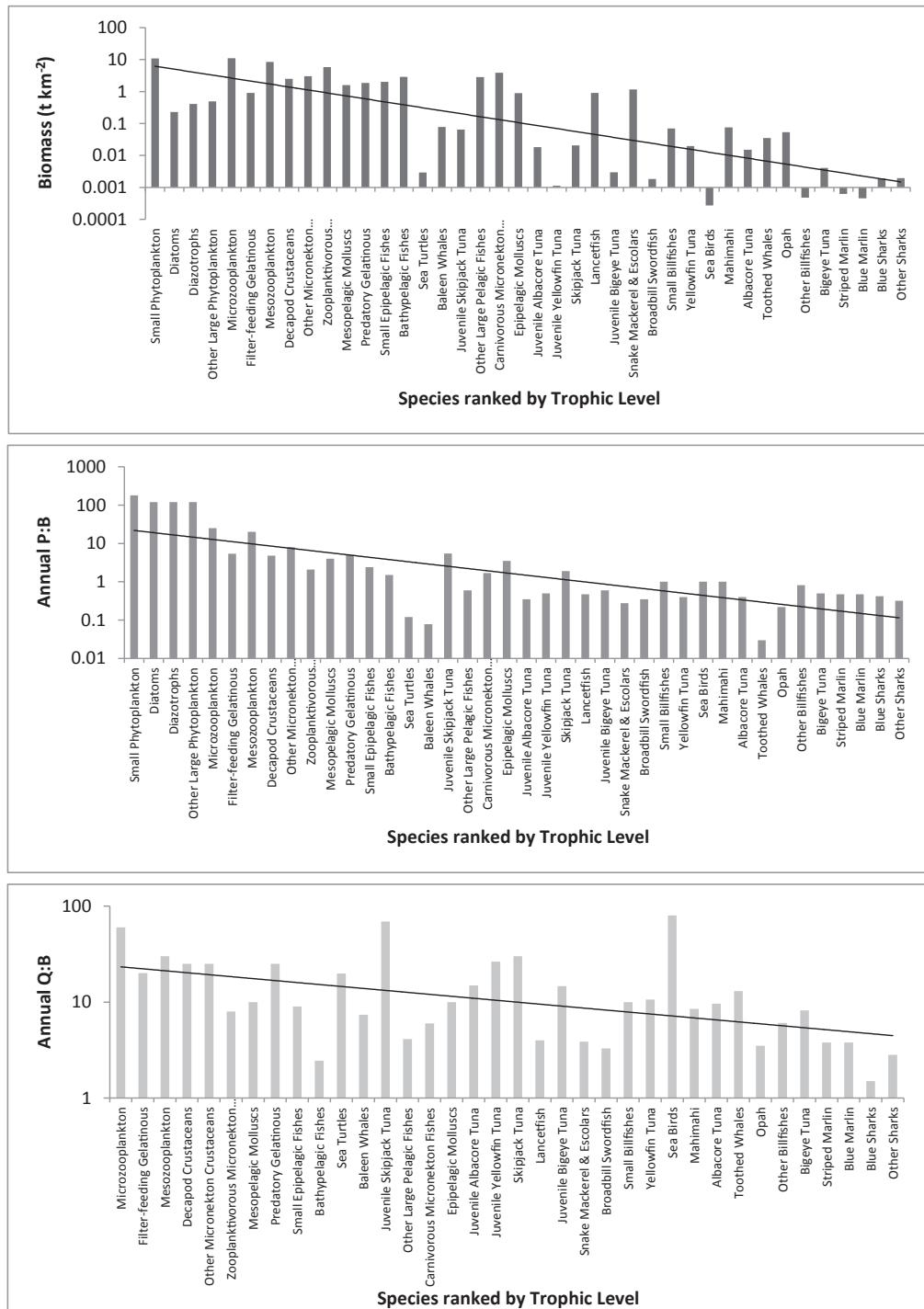


Figure S1. Pre-balance check of Ecopath input parameters. *After evaluation, we halved the Q:B of juvenile skipjack tuna, which also led to a reduction in the adult skipjack tuna Q:B ratio, and we almost doubled the Q:B for lancetfish. The other parameters that are outliers (e.g., low biomass of some phytoplankton groups, sea birds and sea turtles, high Q:B ratio for seabirds) were double-checked but we maintained confidence that they are correct based on the best available literature and expert opinion. For the phytoplankton groups in particular, the ecosystem in consideration is a highly oligotrophic, open ocean system and so low phytoplankton biomass is expected. On a per group basis, in line with available literature information phytoplankton biomass is dominated by small cells. Biomass estimates presented here fit directly with ESM outputs, as outlined in the Methods section.

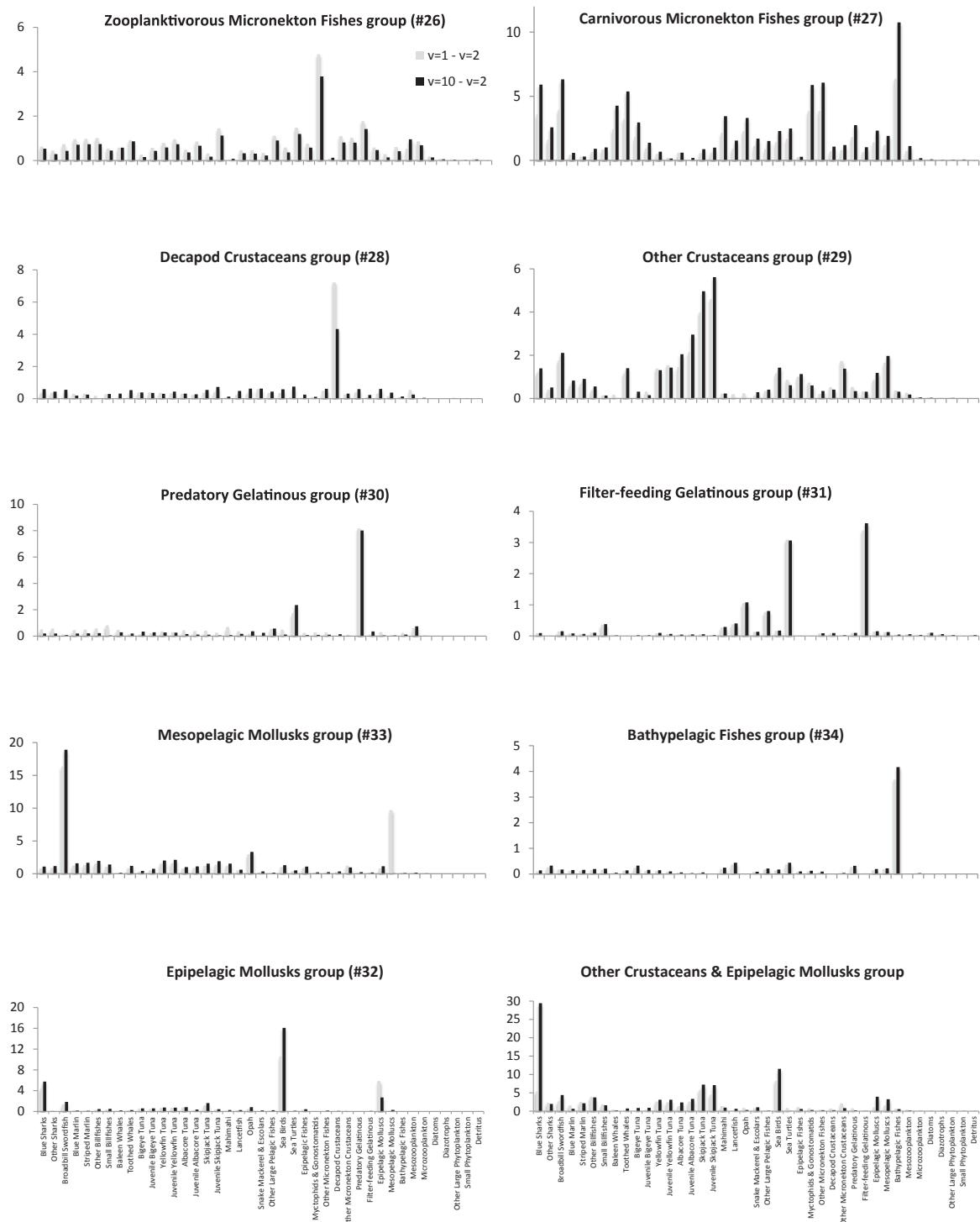


Figure S2. Vulnerability analyses of each micronekton functional group. Results show the absolute change in biomass (y-axis) per functional group (x-axis) between using a vulnerability value of 1 and 2 (grey), and 10 and 2 (black). Titles at the top of each graph indicate the micronekton group that underwent a 30% reduction in biomass.