

Ecosystem models clarify the trophic role of whales off Northwest Africa

Lyne Morissette^{1,2,*}, Kristin Kaschner³, Leah R. Gerber²

¹Institut des sciences de la mer de Rimouski, 310, Allée des Ursulines, C.P. 3300, Rimouski, Quebec G5L 2Y9, Canada

²School of Life Sciences, Arizona State University, Box 874501 Tempe, Arizona 85287-4501, USA

³Evolutionary Biology & Ecology Lab, Institute of Biology I (Zoology), Albert-Ludwigs-University Freiburg, Germany

*Email: lyne.morissette@globetrotter.net

Marine Ecology Progress Series 404: 289–302 (2010)

Table S1. Description of functional groups and parameters used for the construction of the *Ecopath with Ecosim* (*EwE*) model of Northwest Africa. P/B: production to biomass ratio, Q/B: consumption to biomass ratio

Group	Key species	Biomass (t km ⁻²)	P/B (yr ⁻¹)	Q/B (yr ⁻¹)	Diet information source
Minke whales	<i>Balaenoptera acutorostrata</i>	0.00844 ^a	0.0099 (Heymans 2005, Guénette et al. 2006)	8.42 ^a	Lydersen et al. (1991), Nordøy & Blix (1992), Haug et al. (1995, 1996), Olsen & Holst (2001), Sivertsen (2006), Smout & Lindstrom (2007)
Fin whales	<i>Balaenoptera physalus</i>	0.012 ^a	0.099 (Heymans 2005, Guénette et al. 2006)	4.16 ^a	Sigurjónsson & Víkingsson (1997)
Humpback whales	<i>Megaptera novaeangliae</i>	0.0030 ^a	0.0099 (Heymans 2005, Guénette et al. 2006)	5.07 ^a	Mitchell (1973), Sigurjónsson & Víkingsson (1997)
Bryde's whales	<i>Balaenoptera brydei</i>	0.00785 ^a	0.0099 (Heymans 2005, Guénette et al. 2006)	6.26 ^a	Best (2001)
Sei whales	<i>Balaenoptera borealis</i>	0.0016 ^a	0.020 (Pauly et al. 1996)	6.18 ^a	Sigurjónsson & Víkingsson (1997)
Sperm whales	<i>Physeter macrocephalus</i>	0.020 ^a	0.05 (Perry et al. 1999)	5.03 ^a	Kawakami (1980), Clarke et al. (1993), González et al. (1994), Best (1999), Roberts (2003)
Killer whales	<i>Orcinus orca</i>	0.00026	0.02 (Trites & Heise 1996)	7.76 ^a	Pauly et al. (1996), Sidi & Guénette (2004)
Blue whales	<i>Balaenoptera musculus</i>	0.00276	0.04 (Pauly et al. 1996, Okey 2004, Guénette & Christensen 2005)	3.40 ^a	Sigurjónsson & Víkingsson (1997)
Beaked whales	<i>Mesoplodon densirostris</i> , <i>M. europaeus</i> , <i>Ziphius cavirostris</i>	0.0001 ^a	0.036 (Heymans 2005)	9.92 ^a	Santos et al. (2007)
Dolphins	<i>Delphinus delphis</i> , <i>Feresa attenuata</i> , <i>Globicephala macrorhynchus</i> , <i>Grampus griseus</i> , <i>Kogia breviceps</i> , <i>K. simus</i> , <i>Lagenodelphis hosei</i> , <i>Peponocephala electra</i> , <i>Pseudorca crassidens</i> , <i>Sousa teuszii</i> , <i>Stenella attenuata</i> , <i>S. clymene</i> , <i>S. coeruleoalba</i> , <i>S. frontalis</i> , <i>S. longirostris</i> , <i>Steno bredanensis</i> , <i>Tursiops truncatus</i>	0.0055 ^a	0.047 (Samb & Mendy 2004)	13.74 ^a	Northridge (1984), Samb & Mendy (2004)
Seabirds	All marine pelagic and coastal marine birds listed in Samb & Mendy (2004)	0.118	0.12 (Crawford et al. 1991, Samb & Mendy 2004)	118 (Crawford et al. 1991, Samb & Mendy 2004)	Jarre-Teichmann et al. (1998), Samb & Mendy (2004)
Large pelagics	<i>Thunnus albacares</i> , <i>T. obesus</i> , <i>Katsuwonus pelamis</i>	2.54 (Samb & Mendy 2004)	0.3 – 1.9 ^b (ICCAT 1999a,b)	3.0 – 11.6 ^b	Cayré et al. (1988)
Mesopelagic predators	<i>Aphanopus carbo</i> , <i>Micromesistius poutassou</i>	0.735 (Amorim et al. 2004)	3.99 – 5.11 ^b	28.75 – 37.51 ^b	Amorim et al. (2004)
Bathymersal predators	<i>Lophius budegassa</i> , <i>Merluccius senegalensis</i> , <i>M. merluccius</i>	0.255 (Stobberup et al. 2004)	0.38 – 2.71 ^b	3.84 – 17.43 ^b	Stobberup et al. (2004)
Sharks	<i>Prionace glauca</i> and other Carcharhinidae	0.290 (Samb & Mendy 2004)	0.30 – 1.34 ^b (Branstetter 1987)	1.02 – 11.48 ^b	Samb & Mendy (2004)
Rays	<i>Rhinobatos rhinobatos</i>	0.112 (Samb & Mendy 2004)	0.51 – 1.00 ^b	3.91 – 6.30 ^b	Samb & Mendy (2004)
Coastal tunas	<i>Auxis thazard</i> , <i>Euthynnus alletteratus</i> , <i>Sarda sarda</i> , <i>Scomberomorus tritor</i>	2.89 (Samb & Mendy 2004)	0.62 – 0.82 ^b (Pauly 1978, 1979, Diouf 1980, Pauly & Munro 1984)	3.77 – 9.50 ^b	Postel (1955), Samb & Mendy (2004)

Table S1 (continued)

Group	Key species	Biomass (t km ⁻²)	P/B (yr ⁻¹)	Q/B (yr ⁻¹)	Diet information source
Coastal demersals	<i>Cynoglossus</i> spp., <i>Dentex</i> spp., <i>Epinephelus</i> spp., <i>Galeoides</i> spp., <i>Pagellus</i> spp., <i>Pseudolithus</i> spp., <i>Pseudupeneus</i> spp., <i>Scuris</i> spp.	2.634 – 27.267 ^b	1.20 – 13.94 (Franqueville 1983)	6.00 – 57.28 ^b	Fischer et al. (1981), Franqueville (1983), Samb & Mendy (2004)
Clupeids	<i>Ethmalosa fimbriata</i> , <i>Sardinella aurita</i> , <i>S. maderensis</i>	22.130 (Saetersdal et al. 1995, Toresen 1996, 1997, 1998, Toresen & Kolding 1999, Samb & Pauly 2000)	1.10 – 3.10 ^b (Camarena 1986, Samb 1988, Fréon 1988)	9.01 – 28.39 ^b	Nieland (1982), Medina-Gaertner (1985)
Other coastal pelagics	<i>Brachydeuterus auritus</i> , <i>Chloroscombrus crysurus</i> , <i>Pomadasy jubelini</i> , <i>Scomber japonicus</i> , <i>Trachurus</i> spp., <i>Trichiurus lepturus</i>	13.12 (Samb & Mendy 2004)	0.62 – 4.38 ^b (Maxim 1995)	4.44 – 41.05 ^b	Samb & Mendy (2004)
Cephalopods	<i>Alloteuthis subalata</i> , <i>Illex coindetii</i> , <i>Loligo vulgaris</i> , <i>Octopus</i> spp., <i>Sepia</i> spp., <i>Todarodes sagittatus</i>	1.087 (Samb & Mendy 2004)	1.90 – 4.70 ^b	11.70 – 23.40 ^b	Diatta et al. (2001), Samb & Mendy (2004)
Crustaceans	<i>Parapenaeus longirostris</i> , <i>Penaeus</i> spp.	13.048 (Stobberup et al. 2004)	2.50 – 15.19 ^b	10.0 – 54.84 ^b	Stobberup et al. (2004)
Benthos	Macrobenthos and meiobenthos	112.6 (Samb & Mendy 2004)	1.69 – 108.30 ^b	13.48 – 243.10 ^b	Samb & Mendy (2004)
Benthic producers		10.50 (Samb & Mendy 2004)	15.00 (Jarre-Teichmann et al. 1998, Samb & Mendy 2004)	–	–
Zooplankton		20.636 (Touré 1983)	28.00 – 78.36 ^b	106.33 – 280.00 ^b	Samb & Mendy (2004)
Phytoplankton		82.00 (Voituriez & Herbland 1982)	138.19 (Samb & Mendy 2004)	–	–
Detritus	Benthic and pelagic detritus, benthic bacteria involved in the microbial loop	10.00 (Samb & Mendy 2004)	–	–	–

^aFrom the database of K. Kaschner (described by Kaschner 2004)

^bThe range comes from 6 *EwE* models of the Northwest African region: Cape Verde (Stobberup et al. 2004), Gambia (Mendy 2004), Guinea (Diallo et al. 2004), Guinea-Bissau (Amorim et al. 2004), Mauritania (Sidi & Guénette 2004), and Morocco (Stanford et al. 2001). Other sources are added, when appropriate

LITERATURE CITED

- Amorim P, Duarte G, Guerra M, Morato T, Stobberup KA (2004) Preliminary Ecopath model of the Guinea-Bissau continental shelf ecosystem (NW Africa). In: Palomares MLD, Pauly D (eds) West African marine ecosystems: models and fisheries impacts. Fish Cent Res Rep 12:95–112
- Best PB (1999) Food and feeding of sperm whales *Physeter macrocephalus* off the west coast of South Africa. S Afr J Mar Sci 21:393–413
- Best PB (2001) Distribution and population separation of Bryde's whale *Balaenoptera edeni* off southern Africa. Mar Ecol Prog Ser 220:277–289
- Branstetter S (1987) Age and growth validation of newborn sharks in laboratory aquaria with comments on the life history of the Atlantic sharpnose shark, *Rhizoprionodon terraenovae*. Copeia 1987:291–299
- Camarena TL (1986) Les principales espèces de poissons pélagiques côtiers au Sénégal: biologie et évaluation des ressources. PhD dissertation, Université de Bretagne Occidentale, Brest
- Cayré P, Kothias JM, Stretta M, Diouf T (1988) La biologie des thonidés de l'Atlantique tropical Est. In: Fonteneau A, Marcille J (eds) Ressources, pêche et biologie des thonidés tropicaux de l'Atlantique tropicale Centre Est. Document Technique des Pêches No. 292. FAO, Rome, p 157–264
- Clarke MR, Martins HR, Pascoe P (1993) The diet of sperm whale (*Physeter macrocephalus* Linnaeus 1758) off the Azores. Philos Trans R Soc Lond B Biol Sci 339:67–82
- Crawford RJM, Ryan PG, Williams AJ (1991) Seabird consumption and production in the Benguela and Western Agulhas ecosystems. S Afr J Mar Sci 11:357–375
- Diallo I, Cissé I, Bah A (2004) Modèle trophique du système côtier du plateau continental Guinéen. In: Palomares MLD, Pauly D (eds) West African marine ecosystems: models and fisheries impacts. Fish Cent Res Rep 12(7), p 113–123
- Diatta Y, Ba FL, Capape C (2001) Rôle trophique du poulpe commun, *Octopus vulgaris*, chez les élaémobranches de la côte du Sénégal (Atlantique oriental tropical); comparaison avec les espèces des côtes Tunisiennes (Méditerranée centrale). Acta Adriat 42:77–88
- Diouf T (1980) Pêche et biologie de trois scombridae exploités au Sénégal: *Euthynnus alletteratus*, *Sarda sarda* et *Scomberomorus tritor*. PhD dissertation, Université de Bretagne Occidentale, Brest
- Fischer W, Bianchi G, Scott WB (1981) Fiches FAO d'identification des espèces pour les besoins de la pêche. Atlantique centre-est; zones de pêches 34, 47 (en partie), Vol 1–7. Canada Fonds de dépôts. Ministère des Pêcheries et Océans, Ottawa, en accord avec la FAO
- Franqueville C (1983) Biologie et dynamique de population des daurades (*Pagellus bellottii*, Steindacher, 1982) le long des côtes Sénégalaises. PhD dissertation, Université d'Aix-Marseille II
- Fréon P (1988) Réponses et adaptation des stocks de clupéidés d'Afrique de l'Ouest à la variabilité du milieu; analyse et réflexion à partir de l'exemple du Sénégal. Études et thèses. ORSTOM, Paris

- González AF, Lopez A Guerra A, Barreiro A (1994) Diets of marine mammals on the northwestern Spanish Atlantic coast with special reference to Cephalopoda. *Fish Res* 21:179–191
- Guénette S, Christensen V (2005) Food web models and data for studying fisheries and environmental impacts in Eastern Pacific ecosystems. *Fish Cent Res Rep* 13(1)
- Guénette S, Heymans SJJ, Christensen V, Trites AW (2006) Ecosystem models show combined effects of fishing, predation, competition, and ocean productivity on Steller sea lions (*Eumetopias jubatus*) in Alaska. *Can J Fish Aquat Sci* 63:2495–2517
- Haug T, Gjøsæter H, Lindstrøm U, Nilssen KT (1995) Diet and food availability for Northeast Atlantic minke whales (*Balaenoptera acutorostrata*), during the summer of 1992. *ICES J Mar Sci* 52:77–86
- Haug T, Lindstrøm U, Nilssen KT, Røttingen I, Skaug HJ (1996) Diet and food availability for Northeast Atlantic minke whales, *Balaenoptera acutorostrata*. *Rep Int Whaling Comm* 46:371–382
- Heymans JJ (2005) Ecosystem model of the Eastern Aleutians and the Gulf of Alaska in 1963. In: Guénette S, Christensen V (eds) Food web models and data for studying fisheries and environmental impacts on Eastern Pacific ecosystems. *Fish Cent Res Rep* 13:83–105
- ICCAT (International Commission for the Conservation of Atlantic Tunas) (1999a) Rapport de la période biennale 1998–1999. 1ère partie (1998), Vol 1. Version Française. Madrid
- ICCAT (1999b) Rapport de la période biennale 1998–1999. 1ère partie (1998), Vol 2. Version Française. Madrid
- Jarre-Teichmann A, Shannon LJ, Moloney CL, Wickens PA (1998) Comparing trophic flows in the Southern Benguela to those in other upwelling ecosystems. *S Afr J Mar Sci* 19:391–414
- Kaschner K (2004) Modelling and mapping of resource overlap between marine mammals and fisheries on a global scale. PhD thesis, University of British Columbia, Vancouver, BC
- Kawakami T (1980) A review of sperm whale food. *Sci Rep Whale Res Inst Tokyo* 32:199–218
- Lydersen C, Weslawski JM, Oritsland NA (1991) Stomach content analysis of minke whales *Balaenoptera acutorostrata* from the Lofoten and Vesteralen areas, Norway. *Holarct Ecol* 14:219–222
- Maxim C (1995) Horse mackerel and false scad stock assessment and catch projections, CECAF Division 34.1.3 and 34.3.1. *Sci Mar* 59:611–627
- Medina-Gaertner M (1985) Étude du zooplancton côtier de la Baie de Dakar et de son utilisation par les poissons comme source de nourriture. PhD dissertation, Université de Bretagne Occidentale, Brest
- Mendy AN (2004) A trophic model of the Gambian continental shelf system in 1986. In: Palomares MLD, Pauly D (eds) West African marine ecosystems: models and fisheries impacts. *Fish Cent Res Rep* 12(7), p 81–94
- Mitchell E (1973) Draft report on humpback whales taken under specific scientific permit by eastern Canadian land stations, 1969–1971. *Rep Int Whaling Comm* 23:138–154
- Nieland H (1982) The food of *Sardinella aurita* (Val.) and *Sardinella eba* (Val.) off the coast of Senegal. *ICES Council Meet Pap* 180:369–373
- Nordøy ES, Blix AS (1992) Diet of minke whales in the north-eastern Atlantic. *Rep Int Whaling Comm* 43:393–399
- Northridge SP (1984) World review of interactions between marine mammals and fisheries. *FAO Fish Tech Pap* 251
- Okey TA (2004) Shifted community states in four marine ecosystems: some potential mechanisms. PhD thesis, Zoology, University of British Columbia, Vancouver, BC
- Olsen E, Holst JC (2001) A note on common minke whale (*Balaenoptera acutorostrata*) diets in the Norwegian Sea and the North Sea. *J Cetacean Res Manag* 3:179–183
- Pauly D (1978) A preliminary compilation of fish length growth parameters. *Ber Inst Meereskd Christian-Albrechts-Univ Kiel* 55
- Pauly D (1979) Gill size and temperature as governing factors in fish growth: a generalization of von Bertalanffy's growth formula. *Ber Inst Meereskd Christian-Albrechts Univ Kiel* 63
- Pauly D, Munro J (1984) Once more on growth comparison in fish and invertebrates. *Fishbyte* 2:21
- Pauly D, Christensen V, Haggan N (eds) (1996) Mass-balance model of Alaska Gyre. *Fish Cent Res Rep* 4
- Perry SL, DeMaster DP, Silber GK (1999) The great whales: history and status of six species listed as endangered under the U.S. Endangered Species Act of 1973. *Mar Fish Rev* 61:1–74
- Postel E (1955) Résumé des connaissances acquises sur les Clupéidés de l'Ouest Africain. *ICES Rep* 137:14–17
- Roberts SM (2003) Examination of the stomach contents from a Mediterranean sperm whale found south of Crete, Greece. *J Mar Biol Assoc UK* 83:667–670
- Saetersdal G, Ofstad A, Nore A, Olsen S, Moore GKF (1995) Survey of the pelagic fish resources off North West Africa. Senegal-Gambia. 7–16 November 1995. NORAD/FAO/UNDP GLO 82/001
- Samb B (1988) Seasonal growth, mortality, recruitment pattern of *Sardinella maderensis* off Senegal. In: Venema SC, Christensen JM, Pauly D (eds) Contributions to tropical fisheries biology. *FAO/DANIDA Follow-up training course on fish stock assessment in the tropics*, Denmark 1986, Philippines, 1987. *FAO Fish Rep* 389:257–271
- Samb B, Mendy AN (2004) Dynamique du réseau trophique de l'écosystème Sénégalais en 1990. In: Palomares MLD, Pauly D (eds) West African marine ecosystems: models and fisheries impacts. *Fish Cent Res Rep* 12:57–70
- Samb B, Pauly D (2000) On 'variability' as a sampling artifact: the case of *Sardinella* in north-western Africa. *Fish Fish* 1:206–210
- Santos MB, Martin V, Arbelo M, Fernandez A Pierce GJ (2007) Insights into the diet of beaked whales from the atypical mass stranding in the Canary Islands in September 2002. *J Mar Biol Assoc U K* 87:243–251
- Sidi TM, Guénette S (2004) Modèle trophique de la ZEE mauritanienne: comparaison de deux périodes (1987 et 1998). In: Palomares MLD, Pauly D (eds) West African marine ecosystems: models and fisheries impacts. *Fish Cent Res Rep* 12:12–38
- Sigurjónsson J, Víkingsson GA (1997) Seasonal abundance of and estimated food consumption by cetaceans in Icelandic and adjacent waters. *J Northwest Atl Fish Sci* 22:271–287
- Sivertsen K (2006) Overgrazing of kelp beds along the coast of Norway. *J Appl Phycol* 18:599–610
- Smout S, Lindstrom U (2007) Multispecies functional response of the minke whale *Balaenoptera acutorostrata* based on small-scale foraging studies. *Mar Ecol Prog Ser* 341:277–291
- Stobberup KA, Ramos VDM, Coelho ML (2004) Ecopath model of the Cape Verde coastal ecosystem. In: Palomares MLD, Pauly D (eds) West African marine ecosystems: models and fisheries impacts. *Fish Cent Res Rep* 12(7), p 39–56
- Stanford R, Lunn K, Guénette S (2001) A preliminary ecosystem model for the Atlantic coast of Morocco in the mid-

- 1980s. In: Guénette S, Christensen V, Pauly D (eds) Fisheries impacts on North Atlantic Ecosystems: models and analyses. Fish Cent Res Rep 9(4), p 314-344
- Toresen R (1996) Survey of the pelagic fish resources off North West Africa. Part 3, Senegal-Gambia. 1–9 November 1996. NORAD/FAO/UNDP GLO 92/013. Cruise report 9/96
- Toresen R (1997) Survey of the pelagic fish resources off North West Africa. Cruise report No. 11/97. 4–12 November 1997. Part I, Senegal-Gambia. NORAD/FAO/UNDP GLO 92/013. Cruise report 9/96
- Toresen R (1998) Survey of the pelagic fish resources off North West Africa. Cruise report No. 11/98. 30 October – 9 November 1998. Part I, Senegal-Gambia. NORAD/FAO/UNDP. Cruise report 9/96
- Toresen R, Kolding J (1999) Survey of the pelagic fish resources off North West Africa. Cruise report No. 11/98. 30 October – 9 November 1999. Part I, Senegal-Gambia. NORAD/FAO/UNDP. Cruise report 9/96
- Touré D (1983) Contribution à l'étude de l'upwelling de la baie de Gorée (Dakar Sénégal) et de ses conséquences sur le développement de la biomasse phytoplanctonique. Doc. Sci. Centre du Recherche Océanographique de Dakar Tiaroye (CRODT 93), Dakar
- Trites AW, Heise K (1996) Marine mammals: southern BC shelf model. In: Pauly D, Christensen V, Haggan N (eds) Mass balance models of the north-eastern Pacific ecosystems. Fish Cent Res Rep 4:51–55
- Voituriez B, Herbland A (1982) Comparaison des systèmes productifs de l'Atlantique Tropical Est: dômes thermiques, upwellings côtiers et upwellings équatorial. ICES Annu Rep 180:114–130