

Abundance estimation using distance sampling

The Northeast Fisheries Science Center (NEFSC) Protected Species Branch (PSB) started conducting line-transect abundance surveys in 1990. Since then, NEFSC/PSB conducted about 23 shipboard and 16 aerial line-transect surveys (Table 1). The surveyed covered waters from South Carolina to Nova Scotia, where the aerial surveys were over waters closer to shore (less than the 2000 m isobath) and the shipboard surveys were either in the Gulf of Maine/Scotian Shelf or in the deeper offshore waters (greater than the 100 m isobaths to the EEZ or beyond to the Gulf Stream). Up until 2010, nearly all of the surveys were in the summer (June – August), which is the best weather time to cover the most track lines and see the most numbers of groups of a wide variety of species. Since 2010, survey effort has been expanded to also cover non-summer months.

Surveys for abundance estimates: These surveys targeted all marine mammals and sea turtles and a few large fish – ocean sunfish and basking sharks. Most of the abundance surveys followed a two team protocol to estimate $g(0)$, the probability of detecting a group on the track line, where aerial surveys used either the two team procedure (**Palka 2012¹**) or the circle-back procedure (**Palka 2006**), and the ships used a two-team procedure. Analytical methods involved mark-recapture distance sampling, specifically the mark-recapture direct duplicate method (Palka 1996a) and circle-back method in earlier years and the two-team mark-recapture distance sampling (MRDS) point independence method more recently. These surveys have resulted in abundance estimates for 18 stocks (Palka 2012).

Currently, the 2010 – 2014 shipboard and aerial survey data are being analyzed by a combination of MRDS with point independence and habitat spatial modeling that also account for availability bias to result in seasonal spatially-explicit models. These models are built using both a Bayesian hierarchical and generalized additive model framework.

Other goals: In addition to deriving abundance estimates, data collected on these surveys have been used in other research projects, such as:

- improving the line transect methodology (Palka and Hammond 2001; Palka and Pollard 1999; Pollard et al. 2002)
- determining factors influencing abundance estimates (Palka 1995; Palka 1996b; Palka 2005; Palka and Smith 2005)
- describing marine mammal distributions relative to the biotic and abiotic environment (Hamazaki 2002; Waring et al. 1993; Waring et al. 2001; 1996 canyon survey; 2002 Bear Seamount survey,),
- describing marine mammal distributions during non-summer months (1996 and 1997 surveys conducted during the spring in the mid-Atlantic; AMAPPS aerial surveys conducted since 2010),
- focusing on sperm whale dive patterns (Palka et al. 2007)
- focusing on beaked whale acoustics and dive patterns (the 2014 summer survey)
- focusing on sei whale or beaked whale acoustics (2015 summer survey)
- incorporating into ecosystem models (Link 2008a, b).

A complete list of abundance/distribution related papers is in Appendix 1.

¹ References in bold are core background documents

Future work: The seasonal spatially-explicit modeled data have a great potential for future investigations. The projects planned for the near future include:

- investigating trends over years and seasons
- overlaying abundance distributions with distributions of potential/actual threats
- investigating changes in distribution and abundance as related to environmental changes

In the slightly longer term, the plans are to use these data to inform ecosystem models, such as those being developed by the NEFSC EcoAp program and to predict future distribution patterns under changing environments and risk profiles.

Reviews: Over the years, the abundance data have been reviewed in various forums. For example, in 1992 the initial 1991 survey data and analytical methods were extensively reviewed during a two-day meeting hosted by the NEFSC where abundance estimation experts were invited. Over the years, the abundance papers have also been reviewed during International Whaling Commission Scientific Committee meetings, focused review meetings, and by a variety of abundance estimation experts. Since the development of the MMPA Scientific Review Groups (SRGs), the Atlantic SRG has also reviewed the estimation methods and estimated abundance estimates that are reported in the Stock Assessment Reports. The Stock Assessment Reports have also been vetted by the public, who has provided comments on the abundance estimates. There was a recent focused reviews held on 26 February 2015, which was a webinar with 22 participants reviewing the Bayesian Hierarchical and Generalized Additive modeling methods currently being developed.

References

- Hamazaki, T. 2002. Spatiotemporal prediction models of cetacean habitats in the mid-western North Atlantic Ocean (from Cape Hatteras, NC to Nova Scotia). *Marine Mammal Science* 18(4):920-939.
- Link, J.S., O'Reilly, J., Dow, D., Fogarty, M., Vitaliano, J., Legault, C., Overholtz, W., Green, J., Palka, D., Guida, V. & Brodziak, J. 2008. Comparisons of the Georges Bank Ecological Network: EMAX in Historical Context. *J. Northwest Atl. Fish. Sci.* 39:83-101.
- Link, J., Overholtz, W., O'Reilly, J., Green, J., Dow, D., Palka, D., Legault, C., Vitaliano, J., Guida, V., Fogarty, M., Brodziak, J., Methratta, L., Stockhausen, W., Col, L., Griswold, C. 2008. The Northeast U.S. continental shelf Energy Modeling and Analysis exercise (EMAX): Ecological network model development and basic ecosystem metrics. *J. of Marine System* 74: 453-474.
- Palka, D., 1995. Influences on spatial patterns of Gulf of Maine harbor porpoises, in: Blix, A.S., L. Walløe, and Ø. Ulltang (eds.) *Whales, Seals, Fish and Man*. Elsevier Science, Amsterdam, pp. 69–75.
- Palka, D.L., 1996a. Update on abundance of Gulf of Maine/Bay of Fundy harbor porpoises. NEFSC Reference Document 96-04.
- Palka, D. 1996b. Effects of Beaufort sea state on the sightability of harbor porpoises in the Gulf of Maine. *Rep. Int. Whal. Commn* 46: 575-582.
- Palka, D., 2005. Evaluating assumptions underlying a line transect analysis of a 2004 Northwest Atlantic shipboard abundance survey for cetaceans. ICES [Int. Council. Explor. Sea] C.M. 2005/R:07, 37.
- Palka, D.L., 2006. Summer abundance estimates of cetaceans in the US North Atlantic Navy Operating Areas (NEFSC Reference Document 06-03 No. 06-03). Northeast Fisheries Science Center, Woods Hole, MA.
- Palka, D. 2012. Cetacean abundance estimates in US Northwestern Atlantic Ocean waters from summer 2011 line transect survey. NEFSC Reference Document 12-29.
- Palka, D., Johnson, M., Palka, D., 2007. Cooperative research to study dive patterns of sperm whales in the Atlantic Ocean. U. S. Department of the Interior, Minerals Management Service Gulf of Mexico OCS Regional Office New Orleans LA USA.
- Palka, D.L., Hammond, P.S., 2001. Accounting for responsive movement in line transect estimates of abundance. *Canadian Journal of Fisheries and Aquatic Sciences* 58, 777–787.

- Palka, D. and Pollard, J. 1999. Adaptive line transect survey for harbor porpoises. In: *Marine mammal survey and assessment methods*. A.A. Balkema Publishers, Rotterdam, Netherland. Pp 3-12.
- Palka, D.L., Smith., D.W., 2005. Description of 2005 simulations of the IWC/SOWER Southern Hemisphere minke whale abundance survey. IWC [Int. Whal. Comm.] Sci. Counc. Work. Pap. SC/57/IA2, 8.
- Pollard JH, Palka DL and Buckland ST. 2002. Adaptive line transect sampling. *Biometrics* 58:862-870
- Waring, G.T., Fairfield, C.P., Ruhsam, C.M., Sano, M., 1993. Sperm whales associated with Gulf Stream features off the north-eastern USA shelf. *Fisheries Oceanography* 2, 101–105.
- Waring, G.T., Fairfield, C.P., Ruhsam, C.M., Sano, M., 1993. Sperm whales associated with Gulf Stream features off the north-eastern USA shelf. *Fisheries Oceanography* 2, 101–105.
- Waring, G.T., Hamazaki, T., Sheehan, D., Wood, G., Baker, S., 2001. Characterization of beaked whale (*Ziphiidae*) and sperm whale (*Physeter macrocephalus*) summer habitat in shelf-edge and deeper waters off the northeast U.S. *Marine Mammal Science* 17, 703–717.

Appendix 1

List of distribution and abundance related papers produced by NEFSC Protected Species Branch staff

- Best, B., Halpin, P., Read, A., Fujioka, E., Good, C., LaBrecque, E., Schick, R., Roberts, J., Hazen, L., Qian, S., Palka, D., Garrison, L., McLellan, W., 2012. Online cetacean habitat modeling system for the US east coast and Gulf of Mexico. *Endangered Species Research* 18, 1–15. doi:10.3354/esr00430
- Barlow, J., Ferguson, M.C., Perrin, W.F., Ballance, L., Gerrodette, T., Joyce, G., MacLeod, C.D., Mullin, K., Palka, D.L. and Waring, G. 2006. Abundance and densities of beaked and bottlenose whales (family Ziphiidae). *J. Cetacean Res. Manage.* 7(3): 263-270.
- Clapham, P., Barlow, J., Bessinger, M., Cole, T., Mattila, D., Pace, R., Palka, D., Robbins, J., Seton, R., 2003. Abundance and demographic parameters of humpback whales from the Gulf of Maine, and stock definition relative to the Scotian Shelf. *Journal of Cetacean Research and Management* 5, 13–22.
- Friday, N., Smith, T.D., Stevick, P.T., Allen, J., 2000. Measurement of photographic quality and individual distinctiveness for the photographic identification of humpback whales, *Megaptera novaeangliae*. *Marine Mammal Science* 16, 355–374.
- Hamazaki, T. 2002. Spatiotemporal prediction models of cetacean habitats in the mid-western North Atlantic Ocean (from Cape Hatteras, NC to Nova Scotia). *Marine Mammal Science* 18(4):920-939.
- Link, J.S., O'Reilly, J., Dow, D., Fogarty, M., Vitaliano, J., Legault, C., Overholtz, W., Green, J., Palka, D., Guida, V. & Brodziak, J. 2008. Comparisons of the Georges Bank Ecological Network: EMAX in Historical Context. *J. Northwest Atl. Fish. Sci.* 39:83-101.
- Link, J., Overholtz, W., O'Reilly, J., Green, J., Dow, D., Palka, D., Legault, C., Vitaliano, J., Guida, V., Fogarty, M., Brodziak, J., Methratta, L., Stockhausen, W., Col, L., Griswold, C. 2008. The Northeast U.S. continental shelf Energy Modeling and Analysis exercise (EMAX): Ecological network model development and basic ecosystem metrics. *J. of Marine System* 74: 453-474.
- Link, J., Col, L., Guida, V., Dow, D., O'Reilly, J., Green, J., Overholtz, W., Palka, D., Legault, C., Vitaliano, J., Griswold, C., Fogarty, M., Friedland, K. 2009. Response of balanced network models to large-scale perturbation: Implications for evaluating the role of small pelagics in the Gulf of Maine. *Ecological Modelling* 220: 351-369.
- Macleod, C.D., Perrin, W.F., Pitman, R., Barlow, J., Ballance, L., D Amico, A., Gerrodette, T., Joyce, G., Mullin, K.D., Palka, D.L., Waring, G.T., 2006. Known and inferred distributions of beaked whale species (Cetacea: Ziphiidae). *Journal of Cetacean Research and Management* 7, 271–286.
- Palka, D., 1995a. Abundance estimate of the Gulf of Maine harbor porpoise. *Reports of the International Whaling Commission (special issue)* 16, 27–50.
- Palka, D., 1995b. Influences on spatial patterns of Gulf of Maine harbor porpoises, in: Blix, A.S., L. Walløe, and Ø. Ulltang (eds.) *Whales, Seals, Fish and Man*. Elsevier Science, Amsterdam, pp. 69–75.
- Palka, D.L., 1996a. Update on abundance of Gulf of Maine/Bay of Fundy harbor porpoises. NEFSC Reference Document 96-04.
- Palka, D. 1996b. Effects of Beaufort sea state on the sightability of harbor porpoises in the Gulf of Maine. *Rep. Int. Whal. Commn* 46: 575-582.
- Palka, D.L. 2001. Density estimates of cetaceans and turtles in two strata on the Scotian shelf, version 2. Appendix 3 in Bundy, A. 2004. Mass balance models of the eastern Scotian Shelf before and after the cod collapse and other ecosystem changes. *Canadian Technical Report of Fisheries and Aquatic Sciences* No. 2520.
- Palka, D., 2005a. Evaluating assumptions underlying a line transect analysis of a 2004 Northwest Atlantic shipboard abundance survey for cetaceans. ICES [Int. Coun. Explor. Sea] C.M. 2005/R:07, 37.
- Palka, D. 2005b. Shipboard surveys in the northwest Atlantic: estimation of $g(0)$. In *Proceedings of the workshop on Estimation of $g(0)$ in line-transect surveys of cetaceans*, ed. F. Thomsen, F. Ugarte, and P.G.H. Evans. ECS Newsletter No. 44 – Special Issue. April 2005. Pgs 32-7.
- Palka, D.L., 2005c. Aerial surveys in the northwest Atlantic: estimation of $g(0)$, in: Thomsen, F., Ugarte, F., Evans, P.G.H. (Eds.), *Proceedings of a Workshop on Estimation of $g(0)$ in Line-Transect Surveys of Cetaceans*, European Cetacean Society's 18th Annual Conference; Kolmården, Sweden; Mar. 28, 2004. pp. 12–17.
- Palka, D.L., 2006. Summer abundance estimates of cetaceans in the US North Atlantic Navy Operating Areas (NEFSC Reference Document 06-03 No. 06-03). Northeast Fisheries Science Center, Woods Hole, MA.
- Palka, D. 2012. Cetacean abundance estimates in US Northwestern Atlantic Ocean waters from summer 2011 line transect survey. NEFSC Reference Document 12-29.
- Palka, D., Johnson, M., Palka, D., 2007. Cooperative research to study dive patterns of sperm whales in the Atlantic Ocean. U. S. Department of the Interior, Minerals Management Service Gulf of Mexico OCS Regional Office New Orleans LA USA.

- Palka, D.L., Hammond, P.S., 2001. Accounting for responsive movement in line transect estimates of abundance. *Canadian Journal of Fisheries and Aquatic Sciences* 58, 777–787.
- Palka, D.L., Polacheck, T., 1997a. Comparison of several analytical methods that estimate $g(0)$ and account for covariates in density estimates using double-team line transect data. *Reports of the International Whaling Commission SC/49/O18*, 24.
- Palka, D. and Pollard, J. 1999. Adaptive line transect survey for harbor porpoises. In: *Marine mammal survey and assessment methods*. A.A. Balkema Publishers, Rotterdam, Netherland. Pp 3-12.
- Palka, D., Read, A. and Potter, C. 1997b. Summary of knowledge of white-sided dolphins (*Lagenorhynchus acutus*) from the U.S. and Canadian North Atlantic waters. *Rep. Int. Whal. Commn.* 47: 729-34.
- Palka, D.L., Read, A.J., Westgate, A.J., Johnston, D.W., 1996c. Summary of current knowledge of harbour porpoises in US and Canadian Atlantic waters. *Reports of the International Whaling Commission* 46, 559–565.
- Palka, D.L., Smith, D.W., 2005. Description of 2005 simulations of the IWC/SOWER Southern Hemisphere minke whale abundance survey. IWC [Int. Whal. Comm.] Sci. Counc. Work. Pap. SC/57/IA2, 8.
- Palka, D.L., Thompsen, F., Ugarte, F., Evans, P.G.H., 2005. Shipboard surveys in the northwest Atlantic: estimation of $g(0)$, in: *Proceedings of a Workshop on Estimation of $g(0)$ in Line-Transect Surveys of Cetaceans*, European Cetacean Society's 18th Annual Conference; Kolmården, Sweden; Mar. 28, 2004. pp. 32–37.
- Palka, D.L. and Waring, G.T. 2006. 16. Pinnipeds pgs 87-92 in L.S. Link, Griswold, C.A., Methratta, E.T., and Gunnard, J.G. (eds). *Documentation for the Energy Modeling and Analysis eXercise (EMAX)*. *US Dep. Commer., Northeast Fish. Sci. Cent. Ref. Doc.* 06-15; 166p.
- Palka, D.L., Waring G.T. 2006. 17. Baleen whales and odontocets. pgs 93-103 in L.S. Link, Griswold, C.A., Methratta, E.T., and Gunnard, J.G. (eds). *Documentation for the Energy Modeling and Analysis eXercise (EMAX)*. *US Dep. Commer., Northeast Fish. Sci. Cent. Ref. Doc.* 06-15; 166p.
- Pollard JH, Palka DL and Buckland ST. 2002. Adaptive line transect sampling. *Biometrics* 58:862-870.
- Rone, B.K., Pace III, R.M., 2012. A simple photograph-based approach for discriminating between free-ranging long-finned (*Globicephala melas*) and short-finned (*G. macrorhynchus*) pilot whales off the east coast of the United States. *Marine Mammal Science* 28, 254–275. doi:10.1111/j.1748-7692.2011.00488.x
- Schofield, D.T., Early, G., Wenzel, F.W., Matassa, K., Perry, C., Beekman, G., Whitaker, B., Gebhard, E., Walton, W., Swingle, M., 2008. Rehabilitation and homing behavior of a satellite-tracked harbor porpoise (*Phocoena phocoena*). *Aquatic Mammals* 34, 1–8. doi:10.1578/AM.34.1.2008.1
- Sears, R., Williamson, J.M., Wenzel, F.W., Bérubé, M., Gendron, D., Jones, P., 1990. Photographic identification of the blue whale (*Balaenoptera musculus*) in the Gulf of St. Lawrence, Canada. *Report of the International Whaling Commission (Special Issue 12)* 335–342.
- Steele, J.H., Collie, J.S., Bisagni, J.J., Gifford, D.J., Forgarty, M.J., Link, J.S., Sullivan, B.K., Sieracki, M.E., Beet, A.R., Mountain, D.G., Durbin, E.G., Palka, D., Stockhausen, W.T. 2007. Balancing end-to-end budgets of the Georges Bank ecosystem. *Progress in Oceanography*. 74: 423-448.
- Waring, G.T., Fairfield, C.P., Ruhsam, C.M., Sano, M., 1992. Cetaceans associated with Gulf Stream features off the northeastern USA shelf. (CM 1992/N:12). *ICES Marine Mammals Comm.*
- Waring, G.T., Fairfield, C.P., Ruhsam, C.M., Sano, M., 1993. Sperm whales associated with Gulf Stream features off the north-eastern USA shelf. *Fisheries Oceanography* 2, 101–105.
- Waring, G.T., Gilbert, J.R., Loftin, J., Cabana, N., 2006. Short-term movements of radio-tagged harbor seals in New England. *Northeastern Naturalist* 13, 1–14.
- Waring, G.T., Hamazaki, T., Sheehan, D., Wood, G., Baker, S., 2001. Characterization of beaked whale (*Ziphiidae*) and sperm whale (*Physeter macrocephalus*) summer habitat in shelf-edge and deeper waters off the northeast U.S. *Marine Mammal Science* 17, 703–717.
- Waring, G.T., Palka, D.L., P. G. H. Evans, 2009. North Atlantic Marine Mammals, in: W. Perrin, B. Wursig and J. G. M. Thewissen, (eds.) *Encyclopedia of Marine Mammals*, 2nd Ed. Academic Press, New York, pp. 773–780.
- Wenzel, F.W., Allen, J., Berrow, S., Hazevoet, C.J., Jann, B., Seton, R.E., Steiner, L., Stevick, P., Suárez, P.L., Whooley, P., 2009. Current knowledge on the distribution and relative abundance of humpback whales (*Megaptera novaeangliae*) off the Cape Verde Islands, eastern North Atlantic. *Aquatic Mammals* 35, 502–510. doi:10.1578/AM.35.4.2009.502
- Wood, S., Brault, S., Gilbert, J., 2002. Aerial survey of grey seals in the Northeastern United States. *Grey seals in the North Atlantic and Baltic*. NAMMCO Scientific Publications 6, 117–121.
- Wood, S., LaFond, S.A., 2009. Dynamics of recolonization: A study of the gray seal (*Halichoerus grypus*) in the northeast U.S. (Ph.D. thesis). University of Massachusetts, Boston.

Table 1. Summary of abundance/distribution shipboard or aerial surveys conducted by the Northeast Fisheries Science Center's Protected Species Branch staff.

Year	Season	Platform	Name	Track line length(km)	Area	Analysis method*/Reference
1990	Aug	ship	Chapman	2067	Cape Hatteras, NC to Southern New England, north wall of Gulf Stream	1, NMFS 1990
1991	Jul-Aug	ship	Abel-J	1962	Gulf of Maine, lower Bay of Fundy, southern Scotian shelf	2, Palka 1995
1991	Aug	ship	Sneak Attack	640	inshore bays of Maine	1, Palka 1995
1991	Aug-Sep	planes	AT-11 and Twin Otter	9663	Cape Hatteras, NC to Nova Scotia, continental shelf and shelf edge waters	1, NMFS 1991
1991	Jun-Jul	ship	Chapman	4032	Cape Hatteras, NC to Georges Bank, between 200 and 2000m isobaths	1, Waring et al 1992; Waring 1998
1992	Jul-Sep	ship	Abel-J	3710	Gulf of Maine, lower Bay of Fundy, southern Scotian shelf	2, Smith et al 1993
1993	Jun-Jul	ship	Delaware II	1874	S. edge of Georges Bank to SE edge of the Scotian Shelf	1, NMFS 1993
1993	Aug	Ship	Abel-J	2249	Gulf of Maine, lower Bay of Fundy, southern Scotian shelf	2
1994	Aug-Sep	ship	Relentless	534	shelf edge and slope waters of Georges Bank	1, NMFS 1994
1995	Jul-Sep	ships and plane	Abel-J, Pelican, NOAA Twin Otter	32,600	Virginia to mouth of Gulf of St. Lawrence	2, 1, Palka 1996
1996	June	Ship	Abel-J	712	Shelf-edge from Veatch Canyon to Cosair Canyon	2
1997	March	Ship	Delaware	1930	New York to North Carolina	1
1997	Aug-Sep	Ship	Abel-J	1450	New England seamounts	2
1998	March	Ship	Delaware	2566	New York to North Carolina	1
1998	Jul-Sep	ship and plane	Abel-J and NOAA	15,900	Maryland to Scotian Shelf; to	2, 1

Year	Season	Platform	Name	Track line length	Area	Reference
1999	Jul-Aug	ship and plane	Abel-J and NOAA Twin Otter	6123	New York to mouth of Gulf of St. Lawrence	2, 3
2002	Jul-Aug	Ship	Delaware	806	Southern Georges Bank to Bear Seamount	1
2002	Jul-Aug	plane	NOAA Twin Otter	7465	Georges Bank to Maine	3, Palka 2006
2004	Jun-Aug	ship and plane	Endeavor and NOAA Twin Otter	10,761	Maryland to Bay of Fundy	2, 3, Palka 2006
2006	Aug	plane	NOAA Twin Otter	10,676	Georges Bank to Bay of Fundy	3
2007	Aug	ship and plane	Bigelow and Twin Otter	8,195	Georges Bank to Bay of Fundy	2, 3
2008	Aug	plane	NOAA Twin Otter	6,267	New York to Maine, US waters	3
2010	Aug-Sep	plane	Twin Otter	9,210	New Jersey to Nova Scotia	3
2011	Jan-Mar	plane	NOAA Twin Otter	5,850	New Jersey to Nova Scotia	3, 5
2011	Jun-Aug	ship	Bigelow	3,107	Virginia to Massachusetts	4, 5, Palka 2012
2011	Aug	plane	NOAA Twin Otter	5,313	New York to Bay of Fundy	4, 5, Palka 2012
2012	Mar-Apr	plane	NOAA Twin Otter	6,806	New Jersey to Nova Scotia	4, 5
2012	Oct-Nov	plane	NOAA Twin Otter	7,134	New Jersey to Nova Scotia	4, 5
2013	Jul-Aug	ship	Bigelow	5021	North Carolina to Massachusetts on shelf break	4, 5
2014	Feb-Mar	plane	NOAA Twin Otter	4905	New Jersey to Nova Scotia	4, 5
2014	Mar-Apr	ship	Gordon Gunter	4014	North Carolina to Massachusetts on shelf break	4, 5
2014	Jul	ship	Bigelow	740	Southern flank of Georges Bank on shelf break	4, 5
2014-2015	Dec-Jan	plane	NOAA Twin Otter		New Jersey to Nova Scotia	4, 5

- *1 = single team Distance analysis methods
- 2 = two team direct duplicate analysis method
- 3 = two team circle-back analysis method
- 4 = two team MRDS point independent analysis method

5 = habitat modeling (either Bayesian hierarchical or Generalized Additive model)