40a. & 40b. Forage fish

Sensitivity Assessments

No existing MarESA sensitivity assessment was available for forage fish. An updated FeAST assessment was available for sandeel from August 2023, which was used as the basis of the separate sensitivity assessment for sandeel only. As such no individual resistance or resilience scores are available for sandeel. A separate full MarESA assessment for sprat, anchovy, and pilchard was conducted, including the literature search documented below. As this assessment relates to a species assemblage the sensitivity score for the most sensitive species was used in each pressure.

Table A11.40a. Sensitivity assessment forage fish: sprat, anchovy, and pilchard. Associated sectors include activities related to offshore renewable energy (O), Fishing (F), or shipping (S). NR = not relevant, NA = not assessed, NEv = no evidence, H = high, M = medium, L = low, NS = not sensitive.

Pressures		**Associated sector(s)**	**Resistance**				**Resilience**				**Sensitivity**			
Classification	**Pressure type**		**Score**	**QoE**	**AoE**	**DoC**	**Score**	**QoE**	**AoE**	**DoC**	**Score**	**QoE**	**AoE**	**DoC**
Physical	Physical loss (to land or freshwater habitat)	O	L	H	H	H	H	H	H	H	L	H	H	H
	Physical change (to another seabed type)	O, F									NEv			

Pressures		Associated sector(s)	Resistance				Resilience				Sensitivity			
Classification	**Pressure type**		**Score**	**QoE**	**AoE**	**DoC**	**Score**	**QoE**	**AoE**	**DoC**	**Score**	**QoE**	**AoE**	**DoC**
	Physical change (to another sediment type)	O, F									NEv			
	Habitat structure change-removal of substratum (extraction)	O									NR			
	Abrasion/disturbance of substratum surface or seabed	O, F									NR			
	Penetration or disturbance of substratum subsurface	O, F									NR			
Physical	Changes in suspended solids (water clarity)	O, F									NEv			

Pressures		Associated sector(s)	Resistance				Resilience				Sensitivity			
Classification	**Pressure type**		**Score**	**QoE**	**AoE**	**DoC**	**Score**	**QoE**	**AoE**	**DoC**	**Score**	**QoE**	**AoE**	**DoC**
	Smothering and siltation changes (light)	O									NEv			
	Smothering and siltation changes (heavy)	O									NEv			
	Underwater noise	O, F, S	M	H	H	H	M	H	H	H	M	H	H	H
	Electromagnetic energy	O									NEv			
	Barrier to species movement	O, F									NR			
	Death or injury by collision	O, F, S									NR			
Hydrological	Water flow changes	O	M	M	M	M	H	M	M	M	L	M	M	M

Pressures		Associated sector(s)	Resistance				Resilience				Sensitivity			
Classification	**Pressure type**		**Score**	**QoE**	**AoE**	**DoC**	**Score**	**QoE**	**AoE**	**DoC**	**Score**	**QoE**	**AoE**	**DoC**
Chemical	Transition elements & organo-metal contamination	O, F, S									NA			
	Hydrocarbon & PAH contamination	O, F, S									NA			
	Synthetic compound contamination	O, F, S									NA			
	Introduction of other substances	O, F, S									NA			
	Deoxygenation	O									NEv			
Biological	Introduction or spread of invasive non-indigenous species	O, F, S									NEv			

Pressures		Associated sector(s)	Resistance				Resilience				Sensitivity			
Classification	**Pressure type**		**Score**	**QoE**	**AoE**	**DoC**	**Score**	**QoE**	**AoE**	**DoC**	**Score**	**QoE**	**AoE**	**DoC**
	Removal of target species	F	L	H	H	H	M	H	H	H	M	H	H	H
	Removal of non-target species	F	L	H	H	H	M	H	H	H	M	H	H	H

Table A11.40b. Sensitivity assessment forage fish: sandeel. Associated sectors include activities related to offshore renewable energy (O), Fishing (F), or shipping (S). NR = not relevant, NA = not assessed, NEv = no evidence, H = high, M = medium, L = low, NS = not sensitive.

Pressures		**Associated sector(s)**	**Resistance**				**Resilience**				**Sensitivity**			
Classification	**Pressure type**		**Score**	**QoE**	**AoE**	**DoC**	**Score**	**QoE**	**AoE**	**DoC**	**Score**	**QoE**	**AoE**	**DoC**
Physical	Physical loss (to land or freshwater habitat)	O									M	M	M	M
	Physical change (to another seabed type)	O, F									H	M	M	M
	Physical change (to another sediment type)	O, F									NA			
	Habitat structure change-removal of substratum (extraction)	O									H	M	M	M

Pressures		Associated sector(s)	Resistance				Resilience				Sensitivity			
Classification	**Pressure type**		**Score**	**QoE**	**AoE**	**DoC**	**Score**	**QoE**	**AoE**	**DoC**	**Score**	**QoE**	**AoE**	**DoC**
	Abrasion/disturbance of substratum surface or seabed	O, F									M	M	M	M
	Penetration or disturbance of substratum subsurface	O, F									H	M	M	M
	Changes in suspended solids (water clarity)	O, F									NA			
	Smothering and siltation changes (light)	O									M	M	M	M
	Smothering and siltation changes (heavy)	O									H	M	M	M
Physical	Underwater noise	O, F, S									NA			

Pressures		Associated sector(s)	Resistance				Resilience				Sensitivity			
Classification	**Pressure type**		**Score**	**QoE**	**AoE**	**DoC**	**Score**	**QoE**	**AoE**	**DoC**	**Score**	**QoE**	**AoE**	**DoC**
	Electromagnetic energy	O									NA			
	Barrier to species movement	O, F									NA			
	Death or injury by collision	O, F, S									L	M	M	M
Hydrological	Water flow changes	O									NA			
Chemical	Transition elements & organo-metal contamination	O, F, S									Sensitive	L	M	M
	Hydrocarbon & PAH contamination	O, F, S									L	M	M	L
	Synthetic compound contamination	O, F, S									Sensitive	M	M	L

Pressures		Associated sector(s)	Resistance				Resilience				Sensitivity			
Classification	**Pressure type**		**Score**	**QoE**	**AoE**	**DoC**	**Score**	**QoE**	**AoE**	**DoC**	**Score**	**QoE**	**AoE**	**DoC**
	Introduction of other substances	O, F, S									NEv			
	Deoxygenation	O									NA			
Biological	Introduction or spread of invasive non-indigenous species	O, F, S									NA			
	Removal of target species	F									H	H	H	H
Biological	Removal of non-target species	F									NA			

References for forage fish sensitivity assessment

1. Behrens, J.H.& Steffensen, J.F. (2007). The effect of hypoxia on behavioural and physiological aspects of lesser sandeel, *Ammodytes tobianus*. *Marine Biology* 150, 1365-1377. https://doi.org/10.1007/s00227-006-0456-4

2. Behrens, J.H., Stahl, H.J., Steffensen, J.F. & Glud, R.N. (2007). Oxygen dynamics around buried lesser sandeels *Ammodytes tobianus* (Linnaeus 1785): mode of ventilation and oxygen requirements. *The Journal of Experimental Biology* 210, 1006-1014. https://doi.org/10.1242/jeb.000570

3. Behrens, J.W., Petersen, J.K., Ærtebjerg, G, & Steffensen, J.F. (2010). Influence of moderate and severe hypoxia on the diurnal activity pattern of lesser sandeel *Ammodytes tobianus. Journal of Fish Biology* 77, 538-551. https://doi.org/10.1111/j.1095-8649.2010.02697.x

4. Binion-Rock, S.M., Christian, R.R., & Buckel, J.A. (2023). Identification of important forage fish and implications of increased predator demand through Ecopath modelling. *Estuarine Coastal and Shelf Science*, 280, 108164. https://doi.org/10.1016/j.ecss.2022.108164

5. Bolle, L.J., de Jong, C.A.F., Bierman, S.M., van Beek, P.J.G., Wessels, P.W., Blom, E., van Damme, C.J.G., Winter, H.V., & Dekeling, R.P.A. (2016). Effect of Pile-Driving Sounds on the Survival of Larval Fish. In Popper A.N. & Hawkins A. (eds) *Effects of Noise on Aquatic Life II*, Advances in Experimental Medicine and Biology, vol 875. Springer, New York, NY, 91-100. https://doi.org/10.1007/978-1-4939-2981-8_11

6. Clausen, L.W., Rindorf, A., van Deurs, M., Dickey-Collas, M., & Hintzen, N.T. (2018). Shifts in North Sea forage fish productivity and potential fisheries yield. *Journal of Applied Ecology*, 55, 1092 - 1101. https://doi.org/10.1111/1365-2664.13038

7. Cresci, A., Perrichon, P., Durif, C.M.F., Sorhus, E., Johnsen, E., Bjelland, R., Larsen, T., Skiftesvik, A.B., & Browman, H.I. (2022). Magnetic fields generated by the DC cables of offshore wind farms have no effect on spatial distribution or swimming behaviour of lesser sandeel larvae (*Ammodytes marinus*). *Marine Environment Research*, 176, 105609. https://doi.org/10.1016/j.marenvres.2022.105609

8. Danhardt, A. & Becker, P.H. (2011). Herring and Sprat Abundance Indices Predict Chick Growth and Reproductive Performance of Common Terns Breeding in the Wadden Sea. *Ecosystems*, 14, 791-803. https://doi.org/10.1007/s10021-011-9445-7

9. Day, L., Le Bris, H., Saulnier, E., Pinsivy, L., & Brind'Amour, A. (2020). Benthic prey production index estimated from trawl survey supports the food limitation hypothesis in coastal fish nurseries. *Estuarine Coastal and Shelf Science*, 235, 106594. https://doi.org/10.1016/j.ecss.2020.106594

10. DePasquale, E., Baumann, H., & Gobler, C.J. (2015). Vulnerability of early life stage Northwest Atlantic forage fish to ocean acidification and low oxygen. *Marine Ecology Progress Series*, 523, 145-156. https://doi.org/10.3354/meps11142

11. Dickey-Collas, M., Brown, J., Fernand, L., Hill, A.E., Horsburgh, K.J., & Garvine, R.W. (1997). Does the western Irish Sea gyre influence the distribution of pelagic juvenile fish? *Journal of Fish Biology*, 51A, 206-209. https://doi.org/10.1111/j.1095-8649.1997.tb06100.x

12. Eggleton, J.D., Depestele, J., Kenny, A.J., Bolam, S.G., & Garcia, C. (2018). How benthic habitats and bottom trawling affect trait composition in the diet of seven demersal and benthivorous fish species in the North Sea. *Journal of Sea Research*, 142, 132-146. https://doi.org/10.1016/j.seares.2018.09.013

13. Eleftheriou, A. & Robertson, M.R. (1992). The effects of experimental scallop dredging on the fauna and Physical environment of a shallow sandy community. *Netherlands Journal of Sea Research* 30, 289-299. https://doi.org/10.1016/0077-7579(92)90067-O

14. Engelhard, G.H., Peck, M.A., Rindorf, A., Smout, S., van Deurs, M., Raab, K., Andersen, K.H., Garthe, S., Lauerburg, R.A.M., Scott, F., Brunel, T., Aarts, G., van Kooten, T., & Dickey-Collas, M. (2014). Forage fish, their fisheries, and their predators: who drives whom? *ICES Journal of Marine Science*, 71(1), 90-104. https://doi.org/10.1093/icesjms/fst087

15. Essington, T.E., Moriarty, P.E., Froehlich, H.E., Hodgson, E.E., Koehn, L.E., Oken, K.L., Siple, M.C., & Stawitz, C.C. (2015). Fishing amplifies forage fish population collapses. *Proceedings of the National Academy of Sciences of the United States of America*, 112, 6648–6652. https://doi.org/10.1073/pnas.1422020112

16. Essington, T.E., Siple, M.C., Hodgson, E.E., Koehn, L.E., Moriarty, P.E., Oken, K.L., & Stawitz, C.C. (2015). Reply to Szuwalski and Hilborn: Forage fish require an ecosystem approach. *Proceedings of the National Academy of Sciences of the United States of America*, 112(26), E3316. https://doi.org/10.1073/pnas.1508822112

17. Fischer, J., Haedrich, R.L., & Sinclair, P.R. (1997). *Interecosystem impacts of forage fish fisheries*. In Forage Fishes in Marine Ecosystems. Proceedings of the International Symposium on the Role of Forage Fishes in Marine Ecosystems. Alaska Sea Grant College Program Report No. 97-01. University of Alaska Fairbanks, 311-321.

18. Frederiksen, M., Furness, R.W., & Wanless, S. (2007). Regional variation in the role of bottom-up and top-down processes in controlling sandeel abundance in the North Sea. *Marine Ecology Progress Series*, 56, 279-286. https://doi.org/10.3354/meps337279

19. Frederiksen. M., Edwards, M., Mavor, R.A., & Wanless, S. (2007). Regional and annual variation in black-legged kittiwake breeding productivity is related to sea surface temperature. *Marine Ecology Progress Series* 350, 137–143. https://doi.org/10.3354/meps07126

20. Free, C.M., Jensen, O.P., & Hilborn, R. (2021). Evaluating impacts of forage fish abundance on marine predators. *Conservation Biology*, 35, 5. https://doi.org/10.1111/cobi.13709

21. Froehlich, H.E., Jacobsen, N.S., Essington, T.E., Clavelle, T., & Halpern, B.S. (2018). Avoiding the ecological limits of forage fish for fed aquaculture. *Nature Sustainability*, 1(6), 298-303. https://doi.org/10.1038/s41893-018-0077-1

22. Gronczewska, J., Biegniewska, A., Zietara, M.S., & Skorkowski, E.F. (2004). Inhibition by tributyltin of herring skeletal muscle lactate dehydrogenase activity. *Comparative Biochemistry and Physiology C-Toxicology & Pharmacology*, 137(4), 307-311. https://doi.org/10.1016/j.cca.2004.02.005

23. Hannesson, R (2013). Strictly for the birds? On ecosystem services of forage fish. *Marine Policy*, 38, 109-115. https://doi.org/10.1016/j.marpol.2012.05.026

24. Jensen, H. (2001). Settlement dynamics in the lesser sandeel, *Ammodytes marinus* in the North sea. PhD thesis University of Aberdeen.

25. Keyl, F (2017). Inter-annual variability in distribution and spatial abundance of sprat, Norway pout and small herring in the North Sea. *Hydrobiologia*, 795(1) 239-256. https://doi.org/10.1007/s10750-017-3132-4

26. Koehn, L.E., Siple, M.C., & Essington, T.E. (2021). A structured seabird population model reveals how alternative forage fish control rules benefit seabirds and fisheries. *Ecological Applications*, 31(7), e02401. https://doi.org/10.1002/eap.2401

27. Lauerburg, R.A.M., Temming, A., Pinnegar, J.K., Kotterba, P., Sell, A.F., Kempf, A., & Floeter, J. (2018). Forage fish control population dynamics of North Sea whiting *Merlangius merlangus*. *Marine Ecology Progress Series*, 594, 213-230. https://doi.org/10.3354/meps12533

28. Laurel, B.J., Copeman, L.A., Iseri, P., Spencer, M.L., Hutchinson, G., Nordtug, T., Donald, C.E., Meier, S., Allan, S.E., Boyd, D.T., Ylitalo, G.M., Cameron, J.R., French, B.L., Linbo, T.L., Scholz, N.L., & Incardona, J.P. (2019). Embryonic crude oil exposure impairs growth and lipid allocation in a keystone Arctic forage fish. *iScience*, 19, 1101-1113. https://doi.org/10.1016/j.isci.2019.08.051

29. Lindholm, J.B., Auster, P.J., & Kaufman, L.S. (1999). Habitat-mediated survivorship of juvenile (0-year) Atlantic cod *Gadus morhua*. *Marine Ecology Progress Series*, 180, 247-255. https://doi.org/10.3354/meps180247

30. Lindholm, J.B., Auster, P.J., Ruth, M., & Kaufman, L. (2001). Modelling the effects of fishing and implications for the design of marine protected areas: Juvenile fish responses to variations in seafloor habitat. *Conservation Biology*, 15(2), 424-437. https://doi.org/10.1046/j.1523-1739.2001.015002424.x

31. Naidoo, T., & Glassom, D. (2019). Decreased growth and survival in small juvenile fish, after chronic exposure to environmentally relevant concentrations of microplastic. *Marine Pollution Bulletin*, 145, 254-259. https://doi.org/10.1016/j.marpolbul.2019.02.037

32. Nissar, S., Bakhtiyar, Y., Arafat, M.Y., Andrabi, S., Bhat, A.A., & Yousuf, T. (2023). A review of the ecosystem services provided by the marine forage fish. *Hydrobiologia*, 850(12), 2871-2902. https://doi.org/10.1007/s10750-022-05033-1

33. Perrow, M.R., Gilroy, J.J., Skeate, E.R., & Tomlinson, M.L. (2011). Effects of the construction of Scroby Sands offshore wind farm on the prey base of Little tern *Sternula albifrons* at its most important UK colony. *Marine Pollution Bulletin*, 62(8), 1661-1670. https://doi.org/10.1016/j.marpolbul.2011.06.010

34. Skov, H., Durinck, J., & Andell, P. (2000). Associations between wintering avian predators and schooling fish in the Skagerrak-Kattegat suggest reliance on predictable aggregations of herring *Clupea harengus*. *Journal of Avian Biology,* 31(2), 135-143. https://doi.org/10.1034/j.1600-048X.2000.310205.x

35. Spiga, I., Fox, J., & Benson, R. (2012). Potential Effects of long-term exposure to boat noise on the growth, survival, and nutrient retention in juvenile fish. *Effects of Noise on Aquatic Life*, 730, 255-257. https://doi.org/10.1007/978-1-4419-7311-5_56

36. Staudinger, M.D., Goyert, H., Suca, J.J., Coleman, K., Welch, L., Llopiz, J.K., Wiley, D., Altman, I., Applegate, A., Auster, P., Baumann, H., Beaty, J., Boelke, D., Kaufman, L., Loring, P., Moxley, J., Paton, S., Powers, K., Richardson, D., Robbins, J., Runge, J., Smith, B., Spiegel, C., & Steinmetz, H. (2020). The role of sand lances (*Ammodytes* sp.) in the Northwest Atlantic Ecosystem: A synthesis of current knowledge with implications for conservation and management. *Fish and Fisheries*, 21(3), 522-556. https://doi.org/10.1111/faf.12445

37. Stenberg, C; Stottrup, J.G., van Deurs, M., Berg, C.W., Dinesen, G.E., Mosegaard, H., Grome, T.M., & Leonhard, S.B. (2015). Long-term effects of an offshore wind farm in the North Sea on fish communities. *Marine Ecology Progress Series*, 528, 257-265. https://doi.org/10.3354/meps11261

38. Sullivan, M.C., Cowen, R.K., Able, K.W., & Fahay, M.P. (2003). Effects of anthropogenic and natural disturbance on a recently settled continental shelf flatfish. *Marine Ecology Progress Series*, 260, 237-253. https://doi.org/10.3354/meps260237

39. Tacon, A.G.J., & Metian, M. (2009). Fishing for feed or fishing for food: Increasing Global competition for small pelagic forage fish. *Ambio*, 38(6), 294-302. https://doi.org/10.1579/08-a-574.1

40. Trenkel, V.M., Pinnegar, J.K., Dawson, W.A., du Buit, M.H., Tidd, A.N. (2005). Spatial and temporal structure of predator-prey relationships in the Celtic Sea fish community. *Marine Ecology Progress Series*, 299, 257-268. https://doi.org/10.3354/meps299257

41. van Deurs, M., Grome, T.M., Kaspersen, M., Jensen, H., Stenberg, C., Sorensen, T.K., Stottrup, J., Warnar, T., & Mosegaard, H. (2012). Short- and long-term effects of an offshore wind farm on three species of sandeel and their sand habitat. *Marine Ecology Progress Series*, 458, 169-180. https://doi.org/10.3354/meps09736

42. van Hal, R., Griffioen, A.B., & van Keeken, O.A. (2017). Changes in fish communities on a small spatial scale, an effect of increased habitat complexity by an offshore wind farm. *Marine Environmental Research,* 126, 199-210. https://doi.org/10.1016/j.marenvres.2017.01.009

43. Volkenandt, M., O'Connor, I., Guarini, J.M., Berrow, S., & O'Donnell, C. (2016). Fine-scale spatial association between baleen whales and forage fish in the Celtic Sea. *Canadian Journal of Fisheries and Aquatic Sciences*, 73(2), 197-204. https://doi.org/10.1139/cjfas-2015-0073

44. Wright, P.J., Orpwood, J.E., & Scott, B.E. (2017). Impact of rising temperature on reproductive investment in a capital breeder: The lesser sandeel. *Journal of Experimental Marine Biology and Ecology*, 486, 52-58. https://doi.org/10.1016/j.jembe.2016.09.014

45. Wright, P.J., Jensen, H. & Tuck, I. (2000). The influence of sediment type on the distribution of the lesser sandeel, *Ammodytes marinus*. *Journal of Sea Research,* 44, 243-256. https://doi.org/10.1016/S1385-1101(00)00050-2

46. Wright, P. J., Stagg, R., & McIntosh, A. (1997). The impact of the Braer oil spill on sandeels around Shetland. In *Proceedings of the Royal Society of Edinburgh symposium on the Braer oil spill.* The Royal Society of Edinburgh, Edinburgh, 161-181.

Literature search

Note: including the full list of forage fish species in the Web of Science search resulted in tens of thousands of records. Reducing the search to “forage fish” resulted in 920 records. Therefore some specific papers may have been missed but as only the first 1000 search results can be exported, this number would be far higher if the full search terms were used.

Web of Science search terms

(“forage fish”)

AND (“angl*” OR “beam” OR “bottom trawl*” OR “by-catch” OR “dredge*” OR “fish*” OR “gear” OR “gillnet*” OR “hook*” OR “injury” OR “net*” OR “otter trawl*” OR “remov*” OR “aggregate*” OR “anchor*” OR “ballast” OR “barrier*” OR “beach*” OR “launch*” OR “moor*” OR “noise” OR “ship*” OR “steaming” OR “collision*” OR “construction” OR “electro*” OR “turbine*” OR “renewable*” OR “wave” OR “wind” OR “wind farm*” OR “anoxia” OR “copper” OR “current*” OR “deoxy*” OR “disease*” OR “disturbance” OR “endocrine disru*” OR “eutrophication” OR “exposure” OR “heavy metals” OR “hydrocarbon” OR “hypoxia OR litter*” OR “non-native*” OR “nitrate*” OR “nitrite*” OR “noise” OR “radionuclide” OR “nutrient*” OR “oil” OR “PAH*” OR “PCB*” OR “regime” OR “sedimentation” OR “silt*” OR “tributyltin” OR “turbid*”)

Database

ISI Web of Science

Search date

7th February 2024

Search output and screening process

https://www.webofscience.com/wos/woscc/summary/378eccd3-604b-468a-8cdb-b0d1ec490603-cb39319a/relevance/1

Search results were screened for relevance i.e. must describe forage fish and mention one of the listed sectors and/or pressures from MarESA. Workflow follows the Rapid Evidence Assessment approach. The title and all auxiliary information (including abstract) were downloaded from ISI Web of Science in a .ris and excel format. The title and all auxiliary information (including abstract) were downloaded from ISI Web of Science in a .ris and excel format. In Excel, abstracts were read and listed to either pass or fail the initial screening process with a reason provided.

Outcome from screening

64 abstracts passed initial screening. Of these, 24 did not pass secondary screening (i.e., on further reading were determined as not relevant).