# A Renewable Engineer's Essential Guide to Marine Ecology

**Beth E. Scott,** School of Biological Sciences, University of Aberdeen

*Abstract*—**The environmental impacts of tidal stream energy extraction are not yet understood. What is known is that the ecological effects of tidal mixing are both direct and indirect. The direct effects of changes in mixing affect the location and timing of foraging of a range of marine animals. The indirect effects of changes in mixing influence the amount and location of primary production. The complexity of the possible effects due to the placement of tidal devices needs to be understood by both ecologist and engineers. Designing and implementing collaborative field studies will improve the decision making process for the environmentally sound deployment of tidal energy devices.**

***Index Terms*— environmental impacts, marine predators, primary production, tidal mixing**

## I. Introduction

The potential environmental impacts of marine renewables are considerable; or are they? The simple answer is that we don't know. It is calculated that 34% of the UK's electricity demand could be generated from tidal currents alone. However, a major stumbling block to achieving these targets is that the environmental impacts of tidal stream energy extraction are not yet understood. The placement of any marine structural development may affect the ecology of the marine environment in both positive and negative ways. In particular the placement of tidal devices may have possible direct and indirect ecological effects on the entire food chain, ranging from phytoplankton to large mobile predators. The direct effects are those that impinge on the success of foraging by top marine predators (such as seabirds, seals and cetaceans) as they have been seen to use strong tidal steams to help corral fish or simply to pick fish off the surface in locations with strong upward tidal motions. The indirect effects are possible changes to mixing properties of the water column which can strongly affect the primary producers at the bottom of the food chain. These indirect effects can be felt many kilometers away from the actual device placement and may have knock-on effects to a wide array of animals ranging from zooplankton to whales. It is essential that marine engineers appreciate the important ecological factors that their devices may influence, even in the early planning stages of development. By working together, the subsequent interactive flow of knowledge both ways between ecologist and engineer, will beneficially influence and ease the implementation of marine renewable energy devices. To meet these aims the paper presents an overview of how marine animals and plant species use the direct and indirect effects of tidal mixing to make their day-to-day living in the sea.

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B.E. Scott is from the University of Aberdeen, School of Biological Sciences, Tillydrone Ave., Aberdeen, AB24 2TZ . Tel: 44 (0) 1224 273257 fax: 44 (0) 1224 272396; e-mail: b.e.scott@ abdn.ac.uk

## II. Direct Effects of Tidal Mixing

What do we mean by direct effects? Tidal mixing, especially areas of strong tidal mixing that are of the most interest for the extraction of tidal energy, create regions with a high degree of turbulent upwelling properties that many marine animals rely on to capture their prey. The direct effects of changes in mixing have been shown to change the foraging behaviour of a range of marine animals from fish to birds and marine mammals (Irons 1998, Russell et al. 1999, Simard et al. 2002, Zammon 2001,& 2003, Johnston et al. 2005). At a temporal scale of hours, changes in mixing and the presence of areas of turbulent water flow change the aggregation patterns of lower trophic levels. They displace zooplankton and trigger more active foraging of fish species. In turn, this makes fishes more available as prey, for very limited time periods, to a range of larger marine predators. The different highly mobile (and visible) larger species such as birds and marine mammals use these changes in mixing properties to obtain food.

Continuing work lead by Y. Simard in the St. Lawrence Estuary (Cotté & Simard 2005, Sourisseau *et al.* 2006) shows what an complex interplay the topography, tidal currents and behaviour of both predators (whales) and prey (zooplankton and pelagic fish) play in providing eating opportunities for the range of predators in the food chain. In Alaska (Hunt *et al.* 1998) and along the west coast of North America (Holm & Burger, 2002) there have been numerous studies showing that seabirds use strong currents to forage within. Different species show preferences for different speeds and upwelling characteristics. Even here in the North Sea (Camphuysen *et al.* 2006) we have found that indeed seabirds are very limited in the amount of time that they will actually forage for prey. As there is a consensus that a reduction or change to tidal mixing characteristics following full scale deployment of renewable devices might affect the mixing characteristics that marine predators use, the complexity of the possible direct effects due to the placement of tidal devices therefore needs to be understood under field conditions.

## III. Indirect effects of tidal mixing

The indirect effects of changes in tidal mixing can influence the entire food chain as levels of tidal mixing will ultimately determine the amount and location of primary production. Primary production being the marine ecological equivalent of grass as the bottom of the food chain in terrestrial systems. By the very nature of the mixing properties of water columns, frontal areas, the regions of highest primary production, will exist in proximity to tidally energetic areas (Pingree et al 1975, Simpson 1981). Frontal areas exist in areas where the water depths have increased enough that the frictional effects of tidal mixing will no longer be felt throughout the water column and the upper section of the water column is subject to stratification. Frontal areas, especially tidal fronts, have been shown to be spatially and temporally predictable foraging locations for a wide range of marine animals (Decker & Hunt, 1996, Polovina et al. 2001, Mendes et al. 2002, Ladd et al. 2005).

The mechanisms behind this high occurrence of marine animals are firstly, driven by the contrasting changes in biweekly mixing (neap to spring tides). This change in mixing strength moves the location of the frontal region from closer to shore to much farther off (neap to spring) and as that occurs there is an increased availability of nutrients from the mixed areas of water into the stratified areas, which allows for high levels of primary production on a predicable biweekly basis. Secondly, the mixing and current characteristics at the front also provide the physical retention of phyto- and zoo-plankton, causing predictable aggregations of smaller prey items. These, in turn, attract the predatory attention of larger predators. Recent evidence suggests that even small differences in the amount of mixing may have profound effects on the suitability of these areas as foraging habitats.

In a recent study in the Firth of Forth for instance, 85% of a range of marine predators (3 species of seabirds, dolphins, porpoises and whales) were found foraging in only 20% of the available region and at limited times related to tidal current strength (Scott et al. 2005, Camphuysen et al. 2006, Scott et al. *in prep*). The indications from that study are that the key foraging locations (hotspots) are those with higher levels of sub-surface primary productivity. Indeed, primary production seems to play a profound role as we found that primary production can even affect the breeding success of seabirds (Scott et al. 2006).

As yet, the spatial range and scale of the potential impact of tidal stream energy extraction is unknown in the field, with modelled effects predicted to occur up to 7 km from the devices (Couch & Bryden, 2004). By implication, the foraging success of mobile marine predators within both the actual location of the deployment of tidal devices and nearby frontal regions may be affected by the extraction of energy from the tidal stream. Identifying and understanding the physical mechanisms behind the locations of key foraging hotspots which are in proximity to tidal energy extraction sites should be a key research priority**.** It will greatly increase the certainty in the decision-making process for the environmentally sound deployment of tidal energy devices.

## IV. Engineers and Ecologists working together

We advocate that the best approach is for engineers and ecologists to work together in tackling these unknowns. We recently (March 2007) ran a workshop, co-hosted by The University of Aberdeen and the Robert Gordon University, that brought together academics, regulators, tidal device developers, the DTI and utility companies. The principal aim of the workshop was the facilitation of knowledge dialogue between the different parties and the development of a coherent set of generic questions applicable to any proposed site. The workshop concluded that a substantial range of data acquisition and monitoring before deployment of devices is fundamental to understanding any subsequent change. Physical observation of species-specific activity above and immediately within the vicinity of device placement is required to establish relationships between flow characteristics and seasonal animal behaviour. At present, concerns are hypothetical and it is possible that the level of energy extracted is irrelevant to the marine environment, but without sufficient evidence to underpin existing postulates, there can be little confidence gained from supposition.

It was proposed that working group be formed to identify a clear, issue-focussed scope of the monitoring work required which actively encourages an increase in joint ecological and development studies at specific locations which are identify as highly likely sites of tidal energy extraction. By combining multiple trophic level sampling of the environment with continuous long-term collection of tidal stream data, the research will lay the foundations for understanding the potential environmental consequences of tidal stream energy extraction. Much theoretical and laboratory model testing work has been done with tidal energy devices, but this has yet to be translated into actual field-testing. At present, there are only two studies sites in the UK (Orkney and Strangford Narrows) where there are attempts to collect long-term continuous tidal stream data in highly energetic near-shore areas and that are also accompanied by simultaneously acquired environmental event data. The use of the data within both studies can be enhanced by the application of a wider range of marine ecological disciplines as well as commencing collaborative studies in areas with a wider range of tidal stream characteristics around the UK.

## V. Conclusions

The environmental impacts of tidal stream energy extraction are not yet understood. What is known is that the ecological effects of tidal mixing are both direct and indirect. The direct effects of changes in mixing affect the location and timing of foraging of a range of marine animals. The indirect effects of changes in mixing influence the amount and location of primary production. The complexity of the possible effects due to the placement of tidal devices therefore needs to be understood under field conditions. The specific objectives of ecological focus need to

1) Identify and understand the physical mechanisms behind the locations of key foraging hotspots for large marine predators (seabirds and marine mammals) which are in proximity to tidal energy extraction sites,

2) To understand the links between changes in tidal mixing and multi-trophic affects on the foraging behaviour of top marine predators.

3) Improve the decision making process for the environmentally sound deployment of tidal energy devices, and thereby reduce the uncertainty for stakeholders and investors

All of these objects can be achieved and achieved rapidly by developing collaborative studies with the engineering and ecological communities with novel methodologies data acquisition, field studies and analysis.

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