

that the advantages of flightlessness on islands came with modifications of bone structure. This concept is also applied to the trade-off between growth rate and functional maturity, to explain the spectrum of bird development (altricial-precocial).

Those of us who love to study birds inevitably want to conserve them. We now have tools and techniques that the pioneers of conservation would only have dreamed of. The final chapter of this book is dedicated to these developments in conservation science. For example, climate change will affect bird phenology, distribution, and behavior, while species distribution models help us to foresee how. These models have revolutionized our knowledge of habitat use and habitat selection; which are very valuable for conservation.

If we want to know what our birds eat, we do not need to open their stomachs; isotopic analysis of their feathers and sequencing of DNA from their feces will give us this information. By checking feather structure and chemistry, we can address questions about the physiology, ecology, and conservation of birds. Furthermore, with video technology, we can see details of foraging behavior that were previously hidden.

To verify the status of bird populations, we can carry out a population viability analysis and use molecular genetic techniques to estimate population diversity. A small population is more prone to inbreeding and could be at risk. If we cannot see where our bird nests, because, for example, they live in inaccessible colonies, we can send in a drone and then analyze the photographs or video recording. If the bird migrates to an unknown location, we can put bands on it, but it will be more effective to use a small GPS device or satellite transmitter that allows us to track it live. If we need a lot of data on records

of individuals to trace survival or migratory routes, we can use the datasets collated by citizen science online platforms, such as eBird.

Readers of this book will delight in the breadth of topics covered, which will not just increase their knowledge, but allow them to see the application of new techniques to solve research and conservation issues. The only topic that I regret not seeing in this book was the application of network theory to bird-plant interactions as a tool for community ecology [5]. Network theory is increasingly being applied to understand functional issues of ecosystems, such as mutualism, and also for applications in conservation. It is a field of study that is growing fast, so budding ornithologists should learn about it [6].

With such a wealth of accumulated knowledge in ornithology, this book provides a detailed resource for understanding how birds came to be and how they interact with their environment. This book represents a milestone; reviewing the breadth of the science so far, highlighting new discoveries and technical developments which will continue to advance our knowledge of birds into the future.

Ornithology, Foundation, Analysis, and Application
by Michael L. Morrison, Amanda D. Rodewald, Gary Voelker, Melanie R. Colón, and Jonathan F. Prather (eds), Johns Hopkins University Press, 2018. US\$ 110.00, hbk (1016 pp.) ISBN-13: 978-1421424712.

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References

1. Titley, M.A. *et al.* (2017) Scientific research on animal biodiversity is systematically biased towards vertebrates and temperate regions. *PLoS One* 12
2. Benton, M.J. *et al.* (2019) The early origin of feathers. *Trends Ecol. Evol.* Published online June 1, 2019. <https://doi.org/10.1016/j.tree.2019.04.018>

3. Feduccia, A. (1999) *The Origin and Evolution of Birds*, Yale University Press
4. Olofson, H. *et al.* (2009) Bet-hedging as an evolutionary game: the trade-off between egg size and number. *Proc. R. Soc. B* 276, 2963–2969
5. Garcia, D. (2016) Birds in ecological networks: insights from bird-plant mutualistic interactions. *Ardea* 63, 151–180
6. Bascompte, J. and Jordano, P. (2013) *Mutualistic Networks*, Princeton University Press

Letter

Aquatic Predators Influence Flux of Essential Micronutrients

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A recent review summarised the key position occupied by aquatic predators in ecosystems [1] and their importance for the adaptive management of aquatic ecosystem functions and services. This review highlighted that more research is needed to understand the mechanisms and extent to which aquatic predators influence micronutrient and trace element fluxes within ecosystems. While this field deserves more attention, a large body of evidence already exists to suggest that aquatic predators play a crucial role for the flux of essential micronutrients not only within marine and freshwater food webs, but also as a vital source of dietary micronutrients for terrestrial animals including humans [2–4]. We suggest that extending the social and ecological framework proposed by Hammerschlag *et al.* [1] to the known effects of aquatic predators on flux of essential micronutrients can improve the

management of aquatic predators and aquatic ecosystem functioning and services.

While the transfer of dietary energy across trophic levels is usually defined in terms of macronutrients (e.g., C, N, P), it is increasingly recognised that the transfer of trophic energy is limited by the availability of essential dietary micronutrients [5]. For example, bioactive essential fatty acids (EFAs) such as docosahexaenoic acid (DHA) (22:6 ω 3) and eicosapentaenoic acid (EPA) (20:5 ω 3) are micronutrients necessary for the functioning of many consumers [3,4] and have been shown to play an especially important role in the development of neural tissues of animals [2,4]. Most animals, including humans, have a limited capacity to synthesise these EFAs *de novo* in quantities required for their physiological demand, so these micronutrients must be supplied through the diet [4,6]. EFAs are produced by some marine and freshwater algae (e.g., diatoms) [5,6]. However, aquatic predators bioaccumulate these micronutrients in their tissues at disproportionately higher quantities than consumers at lower trophic levels [6]. Consequently, carcasses and also eggs of aquatic predators are important sources of these essential micronutrients for consumers, generating fluxes of EFAs within and between marine, freshwater, and terrestrial food webs [3]. For instance, in marine food webs the exceptionally high biomass of eggs produced during spawning by the predatory twin-spot red snapper *Lutjanus bohar* is utilised by a range of aquatic consumers and facilitates the counter-gradient transfer of energy and micronutrients from higher to lower trophic levels [7]. In coastal British Columbia, bears and wolves consume lipid-rich heads of spawning Pacific salmon *Oncorhynchus* spp. during seasonal salmon runs, behaviour that can be explained by targeting EFAs in the tissues of the aquatic predators [8]. In humans, the consumption of EFA-rich seabird nestlings and eggs has been identified as a key element in the evolution of neural tissue and cognitive capacity in early *Homo sapiens*

[2]. Therefore, decline or increase of abundance of aquatic predators can affect the flux of EFAs throughout the food webs.

The key role of EFAs for the development of neural tissues of animals [2,6] also implies that cognition and behaviour of aquatic predators depend on EFA supply to their neural tissues. Hindered cognition of aquatic predators caused by EFA deficiency can reduce their capacity to forage across macrohabitats and flexibly utilise different prey types, which can decrease the stability of aquatic food webs [9]. Several factors directly related to anthropogenic effects on aquatic ecosystems can reduce the supply of EFAs for neural tissues of aquatic predators. For instance, overfishing and climate regime shifts have been shown to change EFA composition of prey fish in marine ecosystems [10]. In addition, evidence suggests that rising water temperature and fisheries-induced selection can cause changes in physiological performance of some aquatic predators [6, 11], which might alter their capacity to accumulate and synthesise EFAs. Therefore, studying the variability of EFA profiles of aquatic predators might improve predictions about how they respond to anthropogenic environmental changes and help in understanding interactions and feedbacks between aquatic predators and ecosystems.

Aquatic predators are a significant component of the modern human diet, particularly in communities historically dependent on the harvest of marine and freshwater fish and mammals [1]. More importantly, aquatic predators are a major source of dietary EFAs for humans across the globe [3,4,12]. The requirement for dietary EFAs for human health calls for adaptive management balancing conservation of aquatic predators and supply of essential micronutrients for a growing human population [4]. Development of alternative production of EFAs for human consumers is therefore critical to ease the pressure on wild populations of aquatic predators.

Production of EFAs based on animals at lower trophic levels or primary producers [12] and bioinspiration of production technologies by the high capacity of some aquatic predators to accumulate and synthesise these micronutrients may be a promising direction in adaptive management of aquatic predators and ecosystems.

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References

- Hammerschlag, N. *et al.* (2019) Ecosystem function and services of aquatic predators in the Anthropocene. *Trends Ecol. Evol.* 34, 369–383
- Broadhurst, C.L. *et al.* (2002) Brain-specific lipids from marine, lacustrine, or terrestrial food resources: potential impact on early African *Homo sapiens*. *Comp. Biochem. Physiol. B Biochem. Mol. Biol.* 131, 653–673
- Gladyshev, M.I. *et al.* (2009) Preliminary estimates of the export of omega-3 highly unsaturated fatty acids (EPA +DHA) from aquatic to terrestrial ecosystems. In *Lipids in Aquatic Ecosystems* (Arts, M. *et al.*, eds), pp. 234–262. Springer
- Bogard, J.R. *et al.* (2017) Higher fish but lower micronutrient intakes: temporal changes in fish consumption from capture fisheries and aquaculture in Bangladesh. *PLoS One* 17, e0175098
- Müller-Navarra, D.C. *et al.* (2000) A highly unsaturated fatty acid predicts carbon transfer between primary producers and consumers. *Nature* 403, 74–77
- Colombo, S.M. *et al.* (2017) A fundamental dichotomy in long-chain polyunsaturated fatty acid abundance between and within marine and terrestrial ecosystems. *Environ. Rev.* 25, 163–174
- Fuiman, L.A. *et al.* (2015) Egg boons: central components of marine fatty acid food webs. *Ecology* 96, 362–372
- Darimont, C.T. *et al.* (2003) Foraging behaviour by gray wolves on salmon streams in coastal British Columbia. *Can. J. Zool.* 81, 349–353
- Edmunds, N.B. *et al.* (2016) A role for brain size and cognition in food webs. *Ecol. Lett.* 19, 948–955
- Litzow, M.A. *et al.* (2006) Climate regime shifts and reorganization of fish communities: the essential fatty acid limitation hypothesis. *Mar. Ecol. Prog. Ser.* 315, 1–11
- Hollins, J. *et al.* (2018) A physiological perspective on fisheries-induced evolution. *Evol. Appl.* 11, 561–576
- Naylor, R.L. *et al.* (2009) Feeding aquaculture in an era of finite resources. *Proc. Natl Acad. Sci. U. S. A.* 106, 15103–15110