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3.1.7 *In situ* and *ex situ* trophic consequences of fishing

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Managing fishery harvests for ecosystem sustainability requires conservation of ecological processes. Energy transfer among trophic levels is one of the central organising themes in ecology (Polis *et al.* 2004), and underpins patterns in populations and assemblages of organisms (biodiversity). Harvesting of marine animals might alter energy pathways either in the immediate vicinity (*in situ* consequences) or in adjacent habitats (*ex situ* consequences).

Stable isotope analysis has proven to be a useful method of tracing energy and nutrient pathways in aquatic systems. One advantage that isotope analysis has over traditional methods such as stomach content analysis is that it provides information about the ultimate autotrophic source of nutrition for animals at any trophic level. The method relies on different autotrophs (e.g. macroalgae and seagrass) having different isotope signatures, that are then propagated through the trophic levels of a food web. Analysis of carbon isotopes is particularly useful since: (1) carbon isotope signatures of autotrophs are predictably different because of known differences in photosynthetic pathways and carbon sources, and (2) signatures remain essentially constant even after multiple trophic interactions. It is a relatively straightforward exercise to collect representative samples of potential autotrophic sources and of the animals being studied, and to analyse their carbon isotope signature (ratio of $^{13}C/^{12}C$). The contribution of different sources to the consumer signature can then be analysed using mixing model algorithms.

Carbon isotope analysis has been used to trace energy pathways for animals associated with temperate rocky reefs (e.g. Jennings *et al.* 1997). In future, it could be used to measure predictable trophic consequences of harvesting invertebrates from temperate reefs in conservation areas. Harvesting of lobsters, for example, might increase sea urchin densities, resulting in decreased kelp and foliose red algae and subsequent increased cover of crustose and filamentous algae (Edgar and Barrett 1999). For animals such as urchins and abalone, *in situ* on reefs and relying at least partly on drifting vegetation, increased consumption of drift seagrass from adjacent meadows can be expected. Since seagrass has a signature more enriched in ^{13}C than algae, this would be detectable as enrichment in the carbon isotope signature of animal tissue (e.g. a shift in the carbon isotope signature from -20‰ to -15‰).

Ecosystem sustainability also requires that ecological processes are conserved in habitats adjacent to where animals are harvested, and this is particularly important for energy pathways. Since the ultimate autotrophic source at the base of marine food webs can come from a different habitat to that where animals occur (Lepoint *et al.* 2000), harvesting of reef animals may affect habitats adjacent to reefs that rely on organic material exported from reefs. Carbon isotope analysis has been used to determine trophic pathways in these soft-sediment habitats, including pathways involving important Australian fisheries species (Loneragan *et al.* 1997, Connolly *et al.* 2005). Using lobster harvesting as an example of the potential effects of harvesting reef animals, a shift in the dominant autotrophic support from algae to seagrass would be expected for fish and invertebrates in sand areas adjacent to reefs. This shift would potentially also be important for animals on distant intertidal mudflats and beaches relying on allochthonous material from deeper waters. Again, the altered energy flow would be detectable as a shift toward enriched carbon isotope signatures of animal tissue.

Any effects of harvesting on trophic pathways would interact with existing trophic influences of landscape features such as reef size and distance from river mouths. Even without any harvesting, for example, animals such as urchins and abalone on small patch reefs surrounded by seagrass would be more reliant on drift seagrass than their counterparts on larger reefs.

Where the carbon isotope signatures of two or more autotroph sources are similar and unable to be distinguished, isotopes of other elements able to separate the sources can be employed. Nitrogen isotope signatures are altered by fractionation between trophic levels. This fractionation means that nitrogen is useful for indicating the trophic level of consumers, but not for tracing sources. Sulphur isotope signatures are particularly conservative, faithfully tracing trophic pathways even over many trophic interactions. Sulphur is therefore the most useful element to employ in conjunction with carbon (Connolly *et al.* 2004). Analysis of lipids can also be useful where isotopes are unable to resolve food webs.

Overall, stable isotope analysis is a useful and efficient tool for detecting trophic shifts resulting from harvesting of aquatic animals. It can be used both *in situ* on reefs and *ex situ* in adjacent soft-sediment habitats, and can be used to analyse shifts in trophic pathways for individual species or suites of species at any level from herbivores to higher carnivores.

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