THE EMPIRICAL STUDY OF MARINE BIOLOGICAL RESOURCES

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DESCRIPTION OF THE THEME

Introduction

The papers presented in this thesis represent my contributions to the empirical study of marine biological resources. This research has adopted the same experimental approach to: (i) develop scientifically validated techniques to solve specific problems; (ii) use these techniques to detect patterns and form conceptual models about the processes that may have caused them; (iii) do manipulative field experiments to support or refute hypotheses derived from these models; (iv) use these results to develop new models and hypotheses and to test them in new experiments; and (v) recommend, where appropriate, changes to the management of the resources examined. A rigorous, empirical approach is the common feature throughout my research (in its overall direction and subject-to-subject execution) and represents one of the few attempts to adopt such an approach across the three fields in which I have worked: (1) the ecology of underwater kelp systems; (2) the biology of and fishery for a commercially exploited crab; and (3) solving by-catch problems in commercial trawl fisheries.

The ecology of underwater kelp systems
Principal publications 1 to 8, 12 to 14, 17, 19, 21 and 25.

Studying the ecology of underwater kelp systems provided me with excellent opportunities to develop the empirical framework that underpinned all my subsequent research. First, because kelp systems are relatively accessible (compared to deepwater commercial species - see below), I was able to adopt an experimental approach quite cheaply and independently. Second, the structure and dynamics of kelp systems allowed me to isolate their component parts and processes for experimental manipulation. Third, the ecosystem-wide approach I used taught me the necessary techniques for dealing with whole assemblages of a wide diversity of species.

My research in kelp systems firstly developed new, in situ methods via a series of manipulative field experiments and pilot surveys (using SCUBA) and their analysis using analyses of variance and cost-benefit techniques. This involved testing the accuracy and biases associated with using settlement plates to study algal colonization (Paper 1) which led to the development of the world’s first practical underwater microscope (Paper 3) and an underwater suction sampler for micro-invertebrates (Paper 4).

These methodological studies provided the techniques used in subsequent surveys and experiments that identified patterns in the effects of physical disturbances (Paper 6) and temporal variabilities (Papers 2 and 5) on the structures of kelp systems. Next, I developed hypotheses about the processes which may have caused these patterns which were then tested in several manipulative field experiments. These experiments examined the inhibitory effects of turfing algae on kelp colonization (Paper 7), the roles of shading and scour by kelp canopies (Paper 8)...
and the effects of predation by fish (Paper 14). Finally, large-scale, stratified, randomized surveys were done to examine fluctuations in the structures of kelp systems throughout New South Wales (NSW) (Paper 19), geographical consistencies of the effects of physical disturbances along the coast and implications for the future management of these systems (Paper 21). This work contributed to my review of all research done in subtidal algal communities in Australia (Paper 12).

I also contributed to related, though tangential, research in this field by taking part in a joint study to develop strategies for sampling deepwater communities using remote camera technologies (Paper 25). I also completed pilot studies that determined optimal strategies for sampling the harvesting of intertidal biological resources by human scavengers (Paper 13), which led to a large-scale survey and the quantification of these impacts in NSW (Paper 17).

The biology of, and fishery for, a commercially exploited crab
Principal publications 9 to 11, 16, 18, 23, 30 and 54.

The work described under this heading provided me with an opportunity to enter the field of fisheries science by starting with an unstudied, single-species fishery in decline - the NSW oceanic fishery for spanner crabs (Ranina ranina). The expansion of the empirical approach I adopted in kelp systems into this new field proved to be a logical “stepping stone” towards my third (and largest) contribution to the study of marine biological resources (see below).

When starting my work on spanner crabs, I determined that those unknown aspects of its biology and ecology that were most relevant to its continued exploitation were its distributions, abundances and rates of growth. Adopting the approach I used to study kelp systems (manipulative field experiments, pilot surveys and their analysis using analyses of variance and cost-benefit techniques), I developed methods that optimally sampled populations and size-structures of spanner crabs throughout their fishing grounds. This work examined various designs of traps, bait-types, soak-times, competition between traps, effects of currents and spatial heterogeneity, and led to the development of the most optimal survey design possible (Papers 9, 10 and 16).

The stratified, randomized survey so designed was then (and is still) used to assess the status of exploited populations of spanner crabs off NSW (Paper 18). A tagging study was incorporated to determine growth rates of crabs (Paper 54) and the fecundity of the species was also determined (Paper 23). Results from these various studies identified the spawning period for this species and, eventually, led to the legislation of a fishing closure during this period.

Another pattern to emerge from my survey work on spanner crabs was the significant damage incurred by undersized crabs that were caught during commercial operations and discarded (marking the start of my interest in “by-catch” - see below). This damage was quantified and the resultant mortality determined in manipulative experiments in the laboratory and in the field using SCUBA (Paper 11). This information led to new experiments that developed modified fishing gears to catch
spanner crabs which caused less damage to undersize conspecifics (Paper 30). These modifications have since been adopted as law in NSW and Queensland.

**By-catch problems in commercial trawl fisheries**

Principal publications 15, 20, 22, 24, 26 to 29, 31 to 53.

By combining the assemblage-wide, empirical approach developed while working on kelp systems (and enhanced during my research on spanner crabs), with the experience gained in dealing with deepwater commercial fisheries and fishermen (also developed while working on spanner crabs), I was well-placed to tackle an issue that is recognised as one of the most serious and controversial in the worldís fisheries: the by-catch, discarding and consequent wastage of marine species from commercial trawling for prawns and fish.

Like my research in other fields, I began work on this problem by first developing methods for the identification and quantification of by-catches throughout NSWís oceanic and estuarine prawn-trawl fisheries (Paper 20). Using these methods, large-scale, stratified, randomized surveys of by-catches were done to identify species- and size-specific patterns in by-catches (Papers 36, 37, and 48). At this time I also wrote a comprehensive review of Australian by-catch research (Paper 26).

The survey work led me to develop various hypotheses about modifications to trawl gears that may reduce such discarding, including the places, times and species to be examined. These hypotheses were tested in a large number of field experiments examining various modifications to fishing gears and practices that decreased discards whilst maintaining catches of the targeted prawns and other desired species (Papers 15, 22, 24, 28, 32 to 35, 40, 42 and 43). Following this work, several fishery-specific gear modifications were recommended to managers that reduced problematic by-catches by 40 to 90% with no reduction of targeted species. Additional experiments were done in a flume tank to test hypotheses about how the new modifications altered water flow and influenced the behaviour of fish so that they could escape (Paper 52). Aquarium-based experiments were also done to assess the damage and mortality incurred by fish during their escape from the new devices (Papers 41 and 49).

The involvement of the fishing industry during all stages of this research has meant that the new devices were incorporated into the majority of prawn trawlers in NSW on a voluntary basis (an almost unique situation throughout the world). It is anticipated that these devices will become mandatory in 1999.

The success of this work led me to develop a generalized, empirical protocol to address by-catch problems (Papers 31, 38 and 47). Additional examples of my involvement in the Australian adoption of this protocol are seen in: a stratified, randomized survey of discards from fish trawling in NSW (Paper 44); the testing of a gear-based solution to such discarding (Paper 27); and the resolution of discard problems in a South Australian prawn-trawl fishery (Paper 53). I also led the adoption of this protocol in the large fish-trawl fisheries off the northeastern United States. In this work I analysed data from observer-based surveys to identify and quantify problematic discards in these fisheries and then recommended future
directions for research into solutions (Papers 31, 38 and 39). A more recent study examined the utility of spatial and temporal closures as means for reducing the discard of a particular species in this region (Paper 51).

One area of research that arose from my work on prawn-trawl by-catch in NSW (and related to my earlier work on spanner crabs) was a study of the biology of the scyllarid lobsters, balmain bugs (*Ibacus* spp.), which are commercially exploited species of by-catch (termed “by-product”). After identifying the quantities of balmain bugs discarded by oceanic prawn trawling (Paper 48), I determined that these species should have a legal minimum size limit so that smaller animals (which survived discarding) would have an opportunity to reach sexual maturity before exploitation. Adopting the same approach used in all my previous research, pilot experiments were firstly done to determine appropriate methods for estimating sexual maturity in these species (Paper 29), followed by detailed studies that determined their sizes at sexual maturity, fecundities and migratory habits (Papers 45, 46 and 50). This work led to a recommended minimum legal size limit for this species which should be legislated in late 1998.

**Conclusions**

The quantitative and experimental approach to the study of ecology that I developed during my research in underwater kelp systems was maintained and enhanced throughout my career’s other major fields of investigation (spanner crab research and trawl by-catch). In addition to my various contributions to the study of these marine biological resources, three main attributes have consistently characterized my career.

First, applying an empirical approach at all stages of investigation is a relatively rare situation in the fields of underwater ecology and fisheries science. In the latter field especially, it is more common to adopt parametric procedures to model and/or simulate exploited populations, incorporating many assumptions to account for a lack of empirical data. I avoided the temptations of these “short-cuts” to solve fisheries problems by adhering to a strict philosophy of observation, hypothesis-formulation and experiment.

The second main feature of my work concerns its regular publication in international scientific journals. This is also rare in fisheries science where workers usually opt for rapid publication of unrefereed reports or other forms of “grey” literature. By adhering to a policy of timely publication in anonymously peer-reviewed journals, I believe that I have been able to maintain the quality and credibility of my science.

The final main attribute of my work concerns the future legacy that I believe I have engendered by training new scientists to follow my philosophy of strict empiricism. The large number of co-authored articles that I have published in recent years with my staff and students shows my attempt to develop a group of young people who are well-versed in the procedures, analyses and publication of science that solve fisheries issues in an empirical fashion.
**PRINCIPAL PUBLICATIONS:**

For Papers 1 to 11, 14, 18 to 21, 23, 26, 31, 38, 39, 47, 48 and 51, I was the principal investigator in charge of the research and designed, executed the field and/or laboratory work, analysed and interpreted the results and wrote the paper.

Papers 15, 16, 22, 24, 27 to 29, 32 to 37, 40 to 46, 49, 50, 52 and 54 are those done with my staff and/or students where I encouraged the staff/student to take senior authorship as part of their training in preparing papers, dealing with editors, referees, journals, etc. In all cases, I was the principal investigator in charge of the research and designed the work. I also assisted in the execution of the field and/or laboratory work, did or assisted in the analyses and interpretation of results, and either completely wrote the paper or assisted the staff/student in writing it.

Papers 12, 13, 17, 25, 30 and 53 are those where I was a collaborating scientist in the research, assisting in the design, analysis, interpretation and writing. In all these cases, there were approximately equal contributions by each author.


42. Broadhurst, M.K., S.J. Kennelly and G. O'Doherty, 1997. Specifications for the construction and installation of two by-catch reducing devices (BRDs) used in New


and rapid industry adoption in Gulf St Vincent, South Australia. Fisheries Bulletin, in press.


Ancillary publications, reports and conference papers (not submitted as part of this thesis):


