8.0 References

AFFA, 2004, Education and compliance - principle 12, Australian Government, Department of Agriculture, Fisheries and Forestry, retrieved 5th July 2004 from *http://www.affa.gov.au/content/output.cfm?ObjectID=D2C48F86-BA1A-11A1-A2200060B0A01326.*

Agardy, T.S. 1995, The science of conservation in the coastal zone: new insights on how to design, implement, and monitor marine protected areas. A Marine Conservation and Development Report, IUCN in collaboration with WWF, Gland, Switzerland. pp.72.

Agardy, T.S. 1997, *Marine Protected Areas and Ocean Conservation*, Academic Press, California.

Analytical Software, 2001, *Statistix for Windows*, Analytical Software, Tallahassee.

Anderson, K.P. and Ursin, E. 1977, 'A multispecies extension to the Beverton and Holt theory of fishing, with accounts of phosphorus circulation and primary production', *Meddelelser Fra Danmarks Fiskeri-og Havundersogelser*, **7**:319-435.

ANZECC (Australian and New Zealand Environment Conservation Council), 1998, Core Environmental Indicators for reporting on the State of the Environment, a discussion paper for public comment, ANZECC State of the Environment Reporting Task Force, Canberra, July 1998.

Apostolaki, P., Milner-Gulland, E.J., McAllister, M.K. and Kirkwood, G.P. 2002, 'Modelling the effects of establishing a marine reserve for mobile fish species', *Canadian Journal of Fisheries and Aquatic Science,* **59**: 405-415.

Arriola, F.J. 1940, 'A preliminary study of the life history of *Scylla serrata* (Forskal)', *Philippine Journal of Science*, **73**: 437-454

Ayling, A.M. and Ayling, A.L. 1997, *Bramble Reef Replenishment Area – Third Post Opening Survey,* Great Barrier Reef Marine Park Authority, Townsville.

Ballantine, W. J. 1995, 'Networks of "no-take" marine reserves are practical and necessary', *in: Marine Protected Areas and Sustainable Fisheries*, (eds) N.L. Shackell and J.H.M. Willison, Science and Management and Protected Areas Association, Centre for Wildlife and Conservation Biology, Acadia University, pp 13-20.

Ballantine, W.J. 1997, 'No-take reserve networks support fisheries', *in: Developing and Sustaining World Fisheries Resources: The State of Science and Management, proceedings 2nd World Fisheries Congress*, CSIRO Publishing, Melbourne.

Bartleet, A., Kennelly, S. and Brayford, H. 1993, *Proceedings of the Mud Crab Workshop, Terrigal, NSW*, NSW Fisheries, Sydney.

Beddington, J.R. and Rettig, R.B. 1984, 'Approaches to the regulation of fishing effort', *FAO Fisheries Technical Paper*, **243**: 39 pp.

Begon, M, 1979, *Investigating Animal Abundance*, Edward Arnold, London, pp. 8-9.

Bell, J.D. and Pollard, D.A. 1989, 'Ecology of fish assemblages and fisheries associated with seagrasses', *in: A Treatise on the Biology of Seagrasses with Special Reference to the Australian Region,* (eds) A.W.D. Larkham, A.J. McComb and S. Shepard, Eldsevier Amsterdam.

Bender, E.A., Case, T.J. and Gilpin, M.E. 1984, 'Perturbation experiments in ecology: theory and practice', *Ecology*, **65**: 1-13.

Beverton, R.J.H., and Holt, S.J. 1957, 'On the fishery dynamics of exploited fish populations', *Fishery Investigations*, London, Series **2:**19.

Bhuiyan, A.L. and Islam, M.J. 1981, 'Tolerance and distribution of *Scylla serrata* in response to salinity of Karnafully Estuary', *Bangladesh Journal of Agriculture*, **6**(1): 7-15.

Blaber, S.J.M., Cyrus, D.P., Albaret, J-J., Chong Ving Ching Day, J.W., Elliot, M., Fonseca, M.S., Hoss, D.E., Orensanz, J., Potter, I.C. and Silvert, W. 2000, 'Effects of fishing on the structure and functioning of estuarine and nearshore ecosystems', *ICES Journal of Marine Science*, **57**:590-602.

Bohnsack, J.A. 1996, 'Maintenance and recovery of reef fishery productivity', *in*: *Reef Fisheries* (eds) N.V.C. Polunin and C.M. Roberts, Chapman and Hall, London, pp. 283-313.

Bohnsack, J.A. 1998, 'Application of marine reserves to reef fisheries management', *Australian Journal of Ecology* **23**: 298-304.

Bohnsack, J.A. 2000, 'A comparison of the short-term impacts of no-take marine reserves and minimum size limits', *Bulletin of Marine Science* **66**: 635-650.

Breen, D.A., Avery, R.P. and Otway, N. 2003, 'Broad-scale biodiversity assessments for marine protected areas in NSW, Australia', *in*: *World Congress on Aquatic Protected Areas Proceedings* (eds) J. Beaumer, A.Grant and D. Smith, Cairns 2002, Queensland University Press, pp. 120-131.

Brick, R.W. 1974, 'Effects of water quality, antibiotics, phytoplankton and food on the survival and development of larvae of *Scylla serrata*', *Aquaculture*, **3**:231-244

Broad, T.L., Townsend, C.R., Closs, G.P. and Jellyman, D.J. 2002, 'Riparian land use and accessibility to fishers influence size class composition and habitat use by longfin eels in a New Zealand river', *Journal of Fish Biology*, **61**:1489-1503.

Broadhurst, M.K. 2004, *The 2004 Botany Bay Research Challenge: Preliminary Results from an Experiment to Assess the Survival of Fish Released by Recreational Anglers*, Report to Saltwater Recreational Fishing Trust, NSW Fisheries Research Institute.

Buechner, M. 1987, 'Conservation in insular parks: simulation models of factors affecting the movement of animals across park boundaries', *Biological Conservation*, **65**:108-111.

Bullimore, B. A., Newman, P. B., Kaiser, M.J., Gilbert, S.E. and Lock, K.M. 2001, 'A study of catches in a fleet of "ghost-fishing" pots', *Fishery Bulletin*, **99**:247-253.

Butcher, P. 1999, The demographics of mud crab (*Scylla serrata*) populations caught in different marine park zones in the Wooli River, NSW, (*honours thesis*), University of New England, Armidale, Australia.

Butcher, P. 2001, 'The benefits of marine park zones to mud crabs in the Wooli River, NSW', *Fisheries New South Wales - The Journal of Sustainable Fishing*, (eds) D. Smith, NSW Fisheries, **4**(1) p.9.

Butcher, P. A., Boulton, A. J. and Smith, D.A. 2003, 'Mud crab (*Scylla serrata:* Portunidae) populations as indicators of the effectiveness of estuarine marine protected area', *in*: *World Congress on Aquatic Protected Areas proceedings,* (eds) J. Beaumer, A. Grant and D. Smith, Cairns 2002, Queensland University Press, pp. 421-427.

Butcher, P. and Malcolm, H. 2003, ICOLL Mud crab monitoring program #1 – Solitary Islands Marine Park, NSW (*progress report*), NSW Marine Parks Authority, Coffs Harbour.

Butcher, P. and Malcolm, H. 2004, ICOLL Mud crab monitoring program #2 – Solitary Islands Marine Park, NSW (*progress report*), NSW Marine Parks Authority, Coffs Harbour.

Byrnes, T. 1997, Environmental status of the Wooli Wooli estuary, Solitary Islands Marine Park, North Coast NSW, *Integrated project*, Southern Cross University, Lismore.

Carpenter, S.R., Kitchell, J.F. and Hodgson, J.R. 1985, 'Cascading trophic interactions and lake productivity', *BioScience*, **35**:634-639.

Caswell, H., Fujiwara, M. and Brault, S. 1999, 'Declining survival probability threatens the North Atlantic right whale', *in: Proceedings of the National Academy of Sciences of the United States of America*, **96**(6): 3308-3313.

Causey, B.D. 2003, 'Success Factors in the implementation and management of aquatic protected areas', *in*: *World Congress on Aquatic Protected Areas proceedings* (eds) J. Beaumer, A. Grant and D. Smith, Cairns 2002, Queensland University Press, pp. 275-284.

Cheewasedtham, C. 1990, Fishery biology of mud crab (*Scylla serrata* Forskal) in Klong Ngao Mangrove Forest, Rauong Province, *M.Sc. Thesis*, Chulalongkorn University, Bangkok, Thailand.

Childress, M.J. 1997, 'Marine reserves and their effects on lobster populations: report from a workshop', *Australian Journal of Marine and Freshwater Research*, **48**: 1111-1114.

Chubb, C.F. 1994, 'Reproductive biology: issues for management', *in*: *Spiny Lobster Management*, (eds) B.F. Phillips, J.S. Cobb and J. Kittaka, Blackwell Scientific, pp. 191-212.

Cole, R.G., Ayling, T.M. and Creese, R.G. 1990, 'Effects of marine reserve protection at Goat Island, northern New Zealand', *New Zealand Journal of Marine and Freshwater Research*, **24**: 197-210.

Committee on Scientific Issues in the Endangered Species Act (CSIESA) 1995, *Science and the Endangered Species Act*, National Academy Press, Washington, D.C.

Conover, D.O., Travis, J. and Coleman, F.C. 2000, 'Essential fish habitat and marine reserves: an introduction to the second mote symposium in fisheries ecology', *Bulletin of Marine Science*, **66**(3):527-534.

Cowan, L. 1984, 'Cultivation of crabs (*Scylla serrata*) to market size in the Philippines', *Crab Farming in Japan, Taiwan and the Philippines*, Brisbane, Queensland Department of Primary Industries, no. Q184009.

Creese, R.G. and Breen D.A. 2003, 'Marine Projected areas in New South Wales, Australia: challenges for research', *in: Conserving Marine Environments: Out of sight out of mind*, (eds) P. Hutchings and D. Lunney, Royal Zoological Society of New South Wales, Mosman, NSW.

Crowder, L.B., Lyman, S.J., Figueira, W.F. and Priddy, J. 2000, 'Source-sink population dynamics and the problem of siting marine reserves', *Bulletin of Marine Science,* **66**: 799-820.

Dahl-Tacconi, N. 2003, 'Information requirements for designing evaluations of management effectiveness for marine protected areas: an Indonesian case study', *in*: *World Congress on Aquatic Protected Areas proceedings,* (eds) J. Beaumer, A.Grant and D. Smith, Cairns 2002, Queensland University Press, pp.477-485.

Davenport, J. & Wong, T.M. 1987, 'Responses of adult mud crabs (*Scylla serrata*) Forskal to salinity and low oxygen tension', *Comparative Biochemistry and Physiology*, **86**(1): 44-47.

Davey, K. 2003, 'Creating a National System of Marine Protected Areas – a conservation perspective', *in*: *World Congress on Aquatic Protected Areas proceedings,* (eds) J. Beaumer, A. Grant and D. Smith, Cairns 2002, Queensland University Press, pp. 103-105.

Davidson, R.J. 2001, 'Changes in population parameters and behaviour of Blue Cod (*Parapercis colias*; Pinguipedidae) in Long Island - Lokomohua Marine Reserve, Marlborough Sounds, New Zealand', *Aquatic Conservation: Marine and Freshwater Ecosystems* **11**, 417-435.

Dayton, P.K. 1998, 'Ecology - reversal of the burden of proof in fisheries management', *Science*, **279**: 821–822.

Dayton, P.K., Thrush, S.F., Agardy, M.T. and Hofman, R.J. 1995, 'Environmental effects of marine fishing', *in: Aquatic Conservation: Marine and Freshwater Ecosystems,* **5**: 205–232.

Dudley, N., Hockings, M. and Stolton, S. 1999, 'Measuring the effectiveness of protected area management', *in*: *Partnerships for Protection: New Strategies for Planning and Management for Protected Areas*, (eds) S. Stolton and N. Dudley, Earthscan, London, pp. 249-261.

EA (Environment Australia) 2002, *Assessment of the Northern Territory Mud Crab Fishery* (September 2002), Environment Australia, Canberra.

Edgar, G. J. and Barrett, N. S. 1999, 'Effects of the declaration of marine reserves on Tasmanian reef fishes, invertebrates and plants', *Journal of Experimental Marine Biology and Ecology,* **242**,107-144.

Fairweather, P. G. 1991, 'Statistical power and design requirements for environmental monitoring', *Australian Journal of Marine and Freshwater Research*, **42**: 555-67.

Fielder, D.F. and Heasman, M.P. 1978, *The mud crab*, Queensland Museum, **11**: pp 15.

Fisher, J., Murphy, P. and Craik, W. 2003, 'Marine protected areas and fishing closures as fisheries maagement tools', *in*: *World Congress on Aquatic Protected Areas proceedings,* (eds) J. Beaumer, A. Grant and D. Smith, Cairns, 2002, Queensland University Press, pp. 14-18.

Forbes, A.T. and Hay, D.G. 1988, 'Effects of a major cyclone on the abundance and larval recruitment of the portunid crab *Scylla serrata* (Forskal) in the St Lucia Estuary, Natal, South Africa', *South African Journal of Marine Science*, **7**:219-225.

Frid, C.L.J., Clark, R.A. and Hall, J.A. 1999, 'Long term changes in the benthos on a heavily fished ground off the NE coast of England', *Marine Ecology Progress Series*, **188**: 13-20.

GBRMPA (Great Barrier Reef Marine Park Authority), 1999, *Great Barrier Reef reference file,* Great Barrier Reef Marine Park Authority, Townsville.

Gell, F.R. and C.M. Roberts, 2002, *The Fishery Effects of Marine Reserves and Fishery Closures*, WWF-US, 1250 24th Street, NW, Washington, DC 20037, USA.

Glasby, T.M. 1997, 'Analysing data from post-impact studies using asymmetrical analysis of variance: a case study of epibiota on marinas', *Australian Journal of Ecology*, **22**:448-459.

Graham, F. 1990, 'Kite vs Stork', *Audubon*, **92**(5): 104-110.

Gribble, N.A. and Robertson, J.W.A. 1998, 'Fishing effort in the far-northern section cross shelf closure area of the Great Barrier Reef Marine Park: the effectiveness of area-closures', *Journal of Environmental Management*, **52**:53-67.

Goñi, R., Reñones, O. and Quetglas, A. 2001, 'Dynamics of a protected Western Mediterranean population of the European spiny lobster *Palinurus elephas* (Fabricius, 1787) assessed by trap surveys', *Marine and Freshwater Research* **52**, 1577-1587.

Gopurenko, D. and Hughes, J.M. 2002, 'Regional patterns of genetic structure among Australian populations of the mud crab, *Scylla serrata* (Crustacea: Decapoda): evidence from mitochondrial DNA', *Marine and Freshwater Research*, **53**:849-857.

Guénette, S., Lauck, T. and Clark, C. 1998, 'Marine reserves: from Beverton and Holt to the present', *Reviews in Fish Biology and Fisheries,* **8**, 251-272.

Gunderson, D.R. 1993, *Surveys of Fisheries Resources*, John Wiley and Sons. Inc., New York.

Haddon, M. and Wear, R.G. 1987, 'Biology of feeding in the New Zealand paddle crab *Ovalipes catharus* (Crustacea, Portunidae)', *New Zealand Journal of Marine and Freshwater Research*, **21**: 55-64.

Hall S.J. 1999, *The Effects of Fishing on Marine Ecosystems and Communities*, Blackwell Science, Oxford.

Halpern, B.S. and Warner, R.R. 2002, 'Marine reserves have rapid and lasting effects', *Ecology Letters,* **5**, 361-366.

Hammitt, W. E. and Cole, D. N. 1987, *Wildland Recreation: Ecology and Management*, John Wiley and Sons, Canada.

Hannan, J.C. and Williams, R.J. 1998, 'Recruitment of juvenile marine fishes to seagrass habitat in a temperate Australian estuary', *Estuaries*, **21**: 29-51.

Heasman, M.P. 1980, Aspects of the general biology and fishery of the mud crab (*Scylla serrata*) (Forskal) in Moreton Bay, Queensland, *Ph.D. thesis*, The University of Queensland.

Heasman, M.P., Fielder, D.R. and Shepherd, R.K. 1985, 'Mating and spawning in the mud crab, (*Scylla serrata*) (Forskal) (Decapoda:Portunidae), in Moreton Bay, Queensland, *Australian Journal of Marine and Freshwater Research*, **46**:774-784.

Hill, B.J. 1974, 'Salinity and temperature tolerance of zoeae of the portunid crab *Scylla serrata'*, *Marine Biology*, **25**: 21-24.

Hill, B.J. 1975, 'Abundance, breeding and growth of the crab *Scylla serrata* in two South African estuaries', *Marine Biology*, **42**: 119-126.

Hill, B.J. 1976, 'Natural food, foregut clearance-rate and the activity of the crab *Scylla serrata*', *Marine Biology*, **34**: 109-116.

Hill, B.J. 1978, 'Activity, track and speed of movement of the crab *Scylla serrata* in an estuary', *Marine Biology*, **47**: 135-141.

Hill, B.J. 1979, 'Aspects of the feeding strategy of the predatory crab *Scylla serrata'*, *Marine Biology*, **55**: 209-214.

Hill, B.J. 1980, 'Effects of temperature on feeding and activity in the crab *Scylla serrata'*, *Marine Biology*, **59**: 189-192.

Hill, B.J. 1982, *The Queensland mud crab fishery*, Queensland Fisheries Branch, Queensland Fisheries Information series.

Hill, B.J. 1994, 'Offshore spawning by the portunid crab *Scylla serrata* (Crustacea: Decapoda)', *Marine Biology*, **120**: 479-484.

Hill, B.J., Williams, M.J. and Dutton, P. 1982, 'Distribution of juvenile, subadult and adult *Scylla serrata* (Crustacea: Portunidae) on tidal flats in Australia', *Marine Biology*, **69**: 117-120.

Hockings, M. and Phillips, A. 1999, 'How well are we doing? - Some thoughts on the effectiveness of protected areas', *Parks*, **9**:5-14

Hockings, M., Stolton, S. and Dudley, N. 2000, Evaluating effectiveness: a framework for assessing the management of protected areas, IUCN World Commission on Protected Areas Best Practice Protected Area Guidelines (**6**), IUCN Gland.

Hockey P.A.R. and Branch, G.M. **1984**. 'Oystercatchers and limpets: impacts and implications', *Ardea,* **72**: 199–200.

Hutchings, P.A. and Recher, H.F. 1982, The fauna of Australian Mangroves. *Proc. Linn. Soc. NSW*, **106**:83-121.

Hyland, S.J., Hill, B.J. and Lee, C.P. 1984, 'Movement within and between different habitats by the portunid crab *Scylla serrata'*, *Marine Biology*, **80**: 57-61.

Jennings, S. and Polunin, N.V.C. 1996, 'Effects of fishing effort and catch rate upon the structure and biomass of Fijian reef fish communities', *Journal of Applied Ecology*, **33**:400-412

Jennings, S. 2000, 'Patterns and predictions of population recovery in marine reserves', *Reviews in Fish Biology and Fisheries* **10**: 209-231.

Johnson, D.R., Funicelli, N.A. and Bohnsack, J.A. 1999, 'Effectiveness of an existing estuarine no-take fish sanctuary within the Kennedy Space Centre, Florida', *North American Journal of Fisheries Management,* **19**:436-435.

Jones, J. B. 1992, 'Environmental impact of trawling on the seabed: a review'. *New Zealand Journal of Marine and Freshwater Research*. **26**:59-67.

Kaiser, M.J. and de Groot, S.J. 2000, *Effects of fishing on non-target species and habitats*, Blackwell Scientific, Oxford.

Kailoa, P.J., Williams, M., Stewart, P.C., Reichelt, R., McNee, A. and Grieve, C. 1993, *Australian Fisheries Resources*, Bureau of Resource Sciences and the Fisheries Research and Development Corporation Canberra.

Keenan, C.P., Davie, P.J.F. and Mann, D. 1998, 'A revision of the Genus *Scylla* de Haan 1833 (Crustacea: Decapoda: Brachyura: Portunidae)'. The Raffles Bulletin of Zoology. **46**:217-245.

Kelleher, G. and Kenchington, R. 1992, *Guidelines for Establishing Marine Protected Areas,* A Marine Conservation and Development Report, IUCN, Gland, Switzerland.

Kelleher, G. 1999, *Guidelines for Marine Protected Areas,* IUCN, Gland, Switzerland and Cambridge, NY.

Kelly, S., Scott, D., MacDiarmid, A.B. and Babcock, R.C. 2000, 'Spiny lobster, *Jasus edwardsii* recovery in New Zealand marine reserves', *Biological Conservation,* **92**: 359-369.

Kelly, S., Scott, D. and MacDiarmid, A.B. 2002, 'The value of a spillover fishery for spiny lobsters around a marine reserve in northern New Zealand', *Coastal Management,* **30**:153-166.

Kenchington, R.A. 1990, *Managing Marine Environments*, Taylor and Francis New York Inc., New York.

Kennelly, S.J. 1995, 'The issue of catch in Australia's demersal trawl fisheries', *Reviews in Fish Biology and Fisheries*, **5**:213-234.

King, M. 1995, *Fisheries Biology, Assessment and Management*, Fishing News Books, Blackwell Science Ltd, Oxford.

Knuckey, I.A. 1999, Mud crab, *Scylla serrata*, population dynamics in the Northern Territory, Australia and their relationship to the commercial fishery, *Ph.D. thesis*, Northern Territory University, Northern Territory, Australia.

Kramer, D.L. and Chapman, M. 1999, 'Implications of fish home range size and relocation for marine reserve function', *Environmental Biology of Fishes*, **55**:65-79.

Kuster, C. 1997, Environmental status of the Sandon River estuary, Solitary Islands Marine Park, *Integrated project*, Southern Cross University, Lismore.

Lauck, T., Clark, C., Mangel, M. and Munro, G.R. 1998, 'Implementing the precautionary principle in fisheries management through marine reserves', *Ecological Applications* **8**(1): 572-578.

Launer, A.E. and Murphy, D.D. 1994, 'Umbrella species and the conservation of habitat fragments: a case of a threatened butterfly and a vanishing grassland ecosystem', *Biological Conservation*, **69**: 145-153.

Laurneson, L.J.B., Potter, I. C., Lenanton, R. and Hall, H. 1993, 'The significance of length at sexual maturity, mesh size and closed fishing waters to the commercial fishery for the catfish *Cnidoglanis macrocephalus* in Australian estuaries', *Journal of Applied Ichthyology*, **9**:210-221

Leffler, C.W. 1972, 'Some effects of temperature on the growth and metabolic growth of juvenile blue crabs *Callinectes sapidus* in the laboratory', *Marine Biology*, **14**:104-110.

Macbeth, W.G., Pollard, D.A., Steffe, A.S., Morris, S. and Miller, M. 2002a, 'Relative abundances of fish and crustaceans and water quality following the fish kill of early February 2001 in the Richmond River, northern New South Wales', *in*: *Scientific Reports on the Recovery of the Richmond and Macleay Rivers following Fish Kills in February and March 2001*, (eds) S. Kennell and T. McVea, NSW Fisheries Final Report Series (39).

Macbeth, W.G., Pollard, D.A., Steffe, A.S., Morris, S. and Miller, M. 2002b, 'Relative abundances of fish and crustaceans and water quality following the fish kill of early March 2001 in the Macleay River, northern New South Wales', *in*: *Scientific Reports on the Recovery of the Richmond and Macleay Rivers following Fish Kills in February and March 2001*, (eds) S. Kennelly and T. McVea, NSW Fisheries Final Report Series (39).

Mcdonald, S. 1997, Status report for the Corindi river/estuary at Red Rock, Northern NSW, *Integrated Project*, Southern Cross University, Lismore.

McLusky, D.S. 1981, *The Estuarine Ecosystem*, Blackie and Son, Glasgow.

McPherson, R. 2002, 'Assessment of T bar anchor tags for marking the Blue Swimmer Crab *Portunis pelagicus* (L.)', *Fisheries Research*, **54**: 209 – 206.

Meanwell, S. 1996, Status of recreational fisheries in the Solitary Islands Marine Reserve, *Integrated Project*, Southern Cross University, Lismore.

Meffe G.K. and Carroll, C.R. 1997, *Principles of Conservation Biology*. Sinauer Associates, Sunderland, MA.

Menge, B.A., Berlow, E.L., Blanchette, C.A., Navarette, S.A. and Yamada, S.B. 1994, 'The keystone species concept: variation in interaction strength in a rocky intertidal habitat', *Ecological Monographs*, **64**: 249-286.

Miller, R.J. 1979, 'Entry of *Cancer productus* to baited traps', *J. Cons. Int. Expor. Mer*, **39**: 220- 225.

Miller, R.J. 1980, 'Design criteria for crab traps', *J. Cons. Int. Expor. Mer*, **39**: 140-147.

Moore, P.G. 1999, 'Fisheries exploitation and marine habitat conservation: a strategy for rational coexistence'. *Aquatic Conservation: Marine and Freshwater Ecosystems*, **9**: 585-591.

MPA, 2000, *Solitary Islands Marine Park (NSW), Solitary Islands Marine Reserve (Commonwealth) – planning issues and options paper (March 2000),* NSW Marine Parks Authority, Coffs Harbour.

MPA, 2001, *Background Resource document for the Solitary Islands Marine Park*, NSW Marine Parks Authority, Coffs Harbour.

MPA, 2002, *Overview of the Zoning Plan, Solitary Islands Marine Park, April 2002,* NSW Marine Parks Authority, Coffs Harbour.

MPA, 2003, *Strategic Framework for the Evaluation and Monitoring of Marine Parks in NSW (July 2003*), NSW Marine Parks Research Committee, NSW Marine Parks Authority, Sydney.

MPA, 2004, *Marine Parks Authority: New South Wales*. 'NSW Marine Parks Authority website', retrieved 17th march 2004 from *http://www.mpa.nsw.gov.au/index.html*

Murawski, S.A., Brown, R., Lai, H.L., Rago, P.J. and Hendrickson, L. 2000, 'Large-scale close areas as a fisheries management tool in temperate marine systems: the Georges Bank experience', *Bulletin of Marine Science,* **66**:775-798.

Murray, S.N., Ambrose, R.F., Bohnsack, J.A., Botsford, L.W., Carr, M.H., Davis, G.E., Dayton, P.K., Gotshall, D., Gunderson, D.R., Hixon, M.A., Lubchenco, J., Mangel, M., MacCall, A., McArdle, D.A., Ogden, J.C., Roughgarden, J., Starr, R.M., Tegner, M.J. and Yoklavich, M.M. 1999, 'No-take reserve networks: sustaining fishery populations and marine ecosystems', *Fisheries,* **24**:11-25.

Navarette, S.A. and Menge, B.A. 1996, 'Keystone predation and interaction strength: interactive effects of predators on their main prey', *Ecological Monographs*, **66**: 409-429.

NSW Fisheries, 2003, *Discussion paper for Grey Nurse Shark Protection*, NSW Fisheries, Sydney

NSW Fisheries, 2004, 'Crab nets – Hoop or lift net', NSW Fisheries, retrieved 14th May 2004 from http://www.fisheries.nsw.gov.au/rec/sw/crab_nets.htm

O'Dor, R.K., Forsythe, J., Webber, D.M., Wells, J. and Wells, M.J. 1993, 'Activity levels of nautilus in the wild', *Nature*. **362**:626-628.

Onyango, S.G. 2002, 'The breeding cycle of *Scylla serrata* (Forskal, 1755) at Ramisi River estuary, Kenya', *Wetlands Ecology and Management*, **10**:257-263.

Otway, N., M. and Macbeth, W.G. 1999, *Physical effects of hauling on seagrass beds*, NSW Fisheries Office of Conservation, Cronulla, NSW.

OzEstuaries, 2004, 'OzEstuaries', Australian Government Geoscience Australia, retrieved 5th July 2004 from http://www.ozestuaries.org/.

Paddack, M.J. and Estes, J.A. 2000, 'Kelp forest fish populations in marine reserves and adjacent exploited areas of central California', *Ecological Applications,* **10**: 855-870.

Parado-Estapa, Fe D. and Quinito, E.T. (undated), 'Larval survival and megalopa production of *Scylla sp.* at different salinities', *Proceedings of an international scientific forum on mud crab aquaculture and biology*, April 1997, Darwin.

Parrish, R. 1999, 'Marine reserves for fishery management: why not?', *California Cooperative and Fisheries Investigations*, **40**:77-86.

Pease, B.C. and Grinberg, A. 1995, *New South Wales Commercial Fisheries Statistics 1940 to 1992*, Fisheries Research Institute, Cronulla, NSW.

Perrine, D. 1978, *The Mangrove Crab (Scylla serrata) on Ponape, East Caroline Islands*, Marine Resources Division, Trust Territory of the Pacific Islands.

Phelan, M and Hay, T. 2002, 'Mud Crabs - $13 million' *in*: *Northern Territory Fish News*, issue 1. 4pp.

Pillai, K.K. and Nair, N.B. 1968, 'Observations of the breeding biology of some crabs from the southwest coast of India', *Journal of Marine Biology Assessment India*, **15**:754-770.

Planning NSW, 2003, *Guidelines for the Environmental Impact Assessment of Draft Fishery Management Strategies for Commercial Ocean Prawn Trawl, Fish Trawl and Ocean Trap and Line Fisheries*, NSW Department of Planning.

Polhemus, D.A., 1993, 'Conservation of aquatic insects, Worldwide crisis of localised threats', *American Zoologist*, **33**: 588-598

Power, M.E., Tilman, D., Estes, J.A., Menge, B.A., Bond, W.J., Scott Mills, L., Daily, G., Castilla, J.C., Lubchenko, J. and Paine, R.T. 1996, 'Challenges in the quest for keystones', *BioScience,* **46**: 609–621.

Prince, J. and Diver, G. 2001, 'Industry survey of the Orange Roughy Stocks on the South Tasman Rise Fishery 2000', *Australian Fisheries Management Authority*, Biospherics Pty Ltd., retrieved 12th March 2004 from *http://www.marine.csiro.au/orag/publications/Year2001/STRMonitoringFinalRpt2000.PDF*

QLD DPIF, 2004, 'Recreational fishing rules in Queensland – tidal waters', *Queensland Department of Primary Industries and Fisheries*, retrieved 12th May 2004 from *http://www.dpi.qld.gov.au/fishweb/11416.html#gear*

Rainer, S.F. 1984, 'Temporal changes in a demersal fish and cephalopod community of an unexploited coastal area in northern Australia', *Australian Journal of Marine and Freshwater Research*, **35**:747-768

Rainer, S.F. and Munro, I.S.R. 1982, 'Demersal fish and cephalopod communities of an unexploited coastal environment in northern Australia', *Australian Journal of Marine and Freshwater research*, **33**:1039-55

Ray G.C. 1996, 'Coastal-marine discontinuities and synergisms: implications for biodiversity conservation', *Biodiversity and Conservation,* **5**: 1095–1108.

Recher, H.F. 2003, 'Where land and water meet' (foreword) *in*: *Conserving Marine Environments Out of Sight, out of Mind,* (eds) P. Hutchings and D. Lunney, Royal Zoological Society of New South Wales, Mosman, NSW, pp iii-vi.

Roberts, C.M. 1994, 'Rapid build-up of fish biomass in a Caribbean Marine Reserve', *Conservation Biology*, **9** (4):815-826.

Roberts, C.M. and Polunin, N.V.C. 1991, 'Are marine reserves effective in management of reef fisheries?', *Reviews in Fish Biology and Fisheries* **1:**65-91.

Roberts, C.M., Bohnsack, J.A., Gell, F.R., Hawkins, J.P. and Goodridge, R. 2001, 'Effects of marine reserves on adjacent fisheries', *Science* **294**: 1920-1923.

Robertson, W.D. 1989, 'Factors affecting catches of the crab *Scylla serrata* (Forskal) (Decapoda): Portunidae) in baited traps: Soak time, time of day and accessibility of the bait', *Estuarine Coastal and Shelf Science*, **29**(2):161-170.

Robertson, W.D. and Kruger, A. 1994, 'Size at maturity, mating and spawning in the portunid crab (*Scylla serrata*) (Forskal) in Natal, South Africa', *Estuarine and Coastal Shelf Science*, **39**:185-200.

Robinson, L.A. and Frid, C.L.J. 2003, 'Dynamic ecosystem models and the evaluation of ecosystem effects of fishing: can we make meaningful predictions?', *Aquatic Conservation: Marine and Freshwater Ecosystems,* **13**: 5-20.

Rowe, S. 2000, 'Movement and harvesting mortality of American lobsters (*Homarus americanus*) tagged inside and outside no-take reserves in Bonavista Bay, Newfoundland', *Canadian Journal of Fisheries and Aquatic Science,* **58**: 1336-1346.

Rowley, R.J. 1992, *Impacts of marine reserves on fisheries - a report and review of the literature, science and research, series no 51.* Department of Conservation, Wellington, New Zealand.

Roy, P. S., Williams, R. J., Jones, A. R., Yassini, I., Gibbs, P. J., Coates, B., West, R. J., Scanes, P. R., Hudson, J. P. and Nichol, S. 2001, 'Structure and function of south-east Australian estuaries', *Estuarine, Coastal and Shelf Science,* **53**: 351–384.

Rudkin, K.C., Kirkwood, J.M., Hero, J. and Arthur, M.J. 2003, Do estuarine no-take reserves affect the abundance and length frequencies of fishery targeted species? – an assessment of two North Queensland Estuarine 'no-take' Marine Park Zones, *in*: *World Congress on Aquatic Protected Areas Proceedings,* (eds) J. Beaumer, A. Grant and D. Smith, Cairns 2002, Queensland University Press, pp. 500-510.

Ruello, N.V. 1973, 'The influence of rainfall on the distribution and abundance of the school prawn *Metapenaeus macleayi* in the Hunter River region (Australia)', *Marine Biology*. **23**: 221-228

Russ, G.R., 2002, 'Yet another review of marine reserves as reef fishery management tools', pp. 421-443, *in*: *Coral Reef Fishes: Dynamics and Diversity in a Complex Ecosystem,* (ed) P.F. Sale, Academic Press, San Diego, California, USA

Russ, G.R. and Alcala, A.C. 1996, 'Do marine reserves export adult fish biomass? Evidence from Apo Island, Central Philippines', *Marine Ecology Progress Series,* **132**:1-9.

Russ, G.R. and Alcala, A.C. 1998, 'Natural fishing experiments in marine reserves 1983-1993: roles of life history and fishing intensity in family responses', *Coral Reefs,* **17**: 399-416.

Russell, M. 1998, 'Strategies for reopening a coral reef to fishing after commercial fish stocks have been replenished (using Bramble reef replenishment area as an example)', *in: Proceedings of the Australian Coral Reef Society 75th Anniversary Conference, Heron Island, The University of Queensland, Brisb*ane, (eds) J.G. Greenwood and N.J. Hall, pp.193-198.

Saenger, P. 1995, 'The status of Australian estuaries and enclosed marine waters', *in: Status of the Marine Environment Report for Australia, Technical Annex 1,* (eds) Zann, L.P. and Kailola, P., Department of the Environment, Sport and Territories, Canberra, pp. 53-59.

Sainsbury, K.J. 1987, 'Assessment and management of the demersal fishery on the continental shelf of northwestern Australia', *in: Tropical Snappers and Groupers – Biology and Fishery Management,* (eds) J.J. Polovina and S. Ralston, Boulder, COL: Westview Press, pp. 465-503.

Sainsbury, K.J. 1988, 'The ecological basis of multispecies fisheries and management of a demersal fishery in tropical Australia', *in: Fish Population Dynamics*, 2nd ed. (ed) J.A. Gulland, London: John Wiley, pp. 349-82.

Sainsbury, K.J. 1991, 'Application of an experimental approach to management of a tropical multispecies fishery with highly uncertain dynamics', *ICES Marine Science Symposium,* **193:** 301-20.

Sale, P.F., Doherty, P.J., Eckert, G.l., Douglas, W.A. and Ferrell, D.J. 1984, 'Large-scale spatial and temporal variation in recruitment to fish poplations on coral reefs', *Oecologia*, **65**:191-198.

Shanmugam, S. and Bensam, P. 1980, 'On the fishery for the crab *Scylla serrata* (Forskal) at Tutocorin during 1974-75', *Indian Journal of Fish*, **27**:102-111.

Sheaves, M.J. 1992, 'Patterns of distribution and abundance of fishes in different habitats of a mangrove-lined tropical estuary, as determined by fish trapping', *Australian Journal of Marine and Freshwater Research*, **43**:1461-79.

Shipp, R.L. 2002, '*No take marine protected areas (nMPAs) as a fisheries management tool, a pragmatic perspective',* Report to the Fish America Foundation.

Shirley, M.A. and Wolcott, T.G. 1991, 'A telemetric study of microhabitat selection by premoult and moulting blue crabs, Callinectes sapidus (Rathbun), within a sub-estuary of the Pamlico River, North Carolina', *Marine Behaviour and Physiology*, **19**:133-148.

Simberloff, D. 1998, 'Flagships, umbrellas and keystones: is single species management passé in the landscape era?', *Biological Conservation*, **83**:247 – 257.

Sladek-Nowlis, J. and Roberts, C.M. 1999, 'Fisheries benefits and optimal design of marine reserves', *Fishery Bulletin*, **97**:604-616.

Smith, G. and Sumpton, W. 1989, 'Behaviour of the commercial sand crab Portunis pelagicus (L.) at trap entrances, *Asian Fisheries Science*, **3**: 101-113.

Stevens, P.W. and Sulak, K.J. 2001, 'Egress of adult sport fish from an estuarine reserve within Merritt Island National Wildlife Refuge, Florida', *Gulf of Mexico Science,* **2**: 77-89.

Stone, A. 1999, '*Wooli Estuary floodplain management plan'*, Patterson Britton & Partners, Sydney.

Smyth, P.O. 1980, 'Callinectes (Decapoda: Portunidae) larvae in the middle Atlantic Bight, 1975-1977', *Fishery Bulletin US*, **78**:251-265.

Tanner, M. and. Liggins, G, W. 2001, *New South Wales Commercial Fisheries Statistics*, NSW Fisheries Centre, Cronulla, NSW.

Tewifik, A. and Bene, C. 2003, 'Effects of Natural Barriers on the spill-over of a marine mollusc: implications for fisheries reserves', *Aquatic Conservation: Marine and Freshwater Ecosystems*, **13**: 473-488.

Toole, C.L. 1980, 'Intertidal recruitment and feeding in relation to optimal utilisation of nursery areas by juvenile English sole (*Parophrys vetulus*: Pleuronectidae)', *Environmental Biology and Fisheries*, **5**:484-490.

Underwood, A.J. 1991, 'Beyond BACI: Experimental designs for detecting human environmental impacts on temporal variations in natural populations', *Australian Journal of Marine and Freshwater Research*, **42**: 569-587.

Veerannan, K.M. 1972, 'Respiratory metabolism of crabs from marine and estuarine habitats' (*Scylla serrata*)', *Marine Biology*, **17**:284-290.

Wahle, R.A. 1997, 'Consequences of fishing, with regard to lobster fisheries: report from a workshop', *Australian Journal of Marine and Freshwater Research*, **48**: 1115-1119.

Wallace, S.S. 1999, 'Evaluating the effects of three forms of marine reserve on northern abalone populations in British Columbia, Canada', *Conservation Biology* **13**, 882-887.

Ward, T., Heinemann, D. and Evans, N. 2001, *The Role of Marine Reserves as Fisheries Management Tools: A Review of Concepts*, Bureau of Rural Sciences, Canberra, Australia.

Wassenberg, T.J. and Hill, B, J. 1987, 'Feeding by the sand crab *Portunus pelagicus* on material discarded from prawn trawlers in Moreton Bay, Australia', *Marine Biology,* **95**: 387-393.

Weaver, O.R. and England, R.H. 1986, 'Return of tags with different rewards in Lake Lanier, Georgia', *North American Journal of Fisheries Management,* **6**:132-133.

West, R.J., Thorogood, C.A., Walford, T.R. and Williams, R.J. 1985, *An Estuarine Inventory for New South Wales*, Department of Agriculture, New South Wales, Sydney.

Williams, M.J. 1986, 'Evaluation of Anchor tags for marking the commercial sand crab, *Portunis pelagicus* (L.),(Portunidae: Decapoda)', *Australian Journal of Marine and Freshwater Research*, **37**: 707-712.

Williams, M.J. and Hill, B.J. 1982, 'Factors influencing pot catches and population estimates of the portunid crab *Scylla serrata', Marine Biology*, **71**: 187-192.

Wilson, J. and P. Harrison, 1995, '*Reproduction in sub-tropical corals at the Solitary Islands Marine Reserve and the potential transport of coral larvae'*, Australian Coral Reef Society National Conference, Lismore.

Winer, B.J. 1971, *Statsitical Principles in Experimental Design*, McGraw-Hill: Kogakusha, Tokyo.

Wolcott, T.G. and Hines, A. H. 1989, 'Ultrasonic biotelemetry of muscle activity from free-ranging marine animals: a new method for studying foraging by blue crabs (*Callinectes sapidus*)', *Biological Bulletin,* **176**: 50-56.

Wolcott, T.G. and Hines, A. H. 1990, 'Ultrasonic telemetry of small-scale movements and microhabitat selection by moulting blue crabs (*Callinectes sapidus*)', *Bulletin of Marine Science,* **46**(1): 83-94.

Wolcott, T.G. and Hines, A.H. 1996, 'Advances in ultrasonic biotelemetry for animal movement and behaviour: the blue crab case study. Methods and techniques of underwater research, Smithsonian Institution, Washington D.C., USA', *Proceedings of the American academy of underwater sciences scientific diving symposium.*

Yamasaki, A. and Kuwahara, A. 1990, Preserved area to effect recovery of over-fished Zuwai crab stocks off Kyoto Prefecture, *in*: *Proceedings of the International Symposium on*

King and Tanner Crabs, November 1989, Anchorage, Alaska, Alaska Sea Grant College Program, University of Alaska, Fairbanks, Alaska, pp. 575-585.

Zacharias, M. A. and Roff, J. C. 2001, 'Use of focal species in marine conservation and management: a review and critique', *Aquatic Conservation: Marine and Freshwater Ecosystems,* **11**: 59-76.

Zann, L. 2001, *State of the Environment of the Solitary Islands Marine Park*, Environment Australia.

Zar, J. H. 1999, *Biostatistical Analysis* (4^{th} edition), Prentice-Hall Inc. New Jersey, USA.

9.0 Appendices

Appendix 1 - Sampling dates

Table A1. Sampling dates with tide and moon phase during each trip.

	Sample date	High tide			Low tide			Maximum tide	Moon phase
		Time	(m)	(m)	Time	(m)	(m)	movement (m)	(coming up to)
Dec-98	28th - 30th	4-39am	1.46	1.41	10-45am	0.53	0.29	1.17	First quarter
Jan-99	25th - 27th	3-00am	1.44	1.40	9-00am	0.54	0.37	1.07	First quarter
Feb-99	26th - 28th	5-00am	1.57	1.18	11-46am	0.47	0.43	1.14	Full moon
Mar-99	28th - 30th	5-44am	1.64	1.33	12-23am	0.48	0.34	1.30	Full moon
Apr-99	14th - 16th	6-29am	1.75	1.67	12-52am	0.27	0.41	1.48	New Moon
May-99	29th - 31st	7-19am	1.37	1.77	1-37am	0.46	0.35	1.42	Full moon
Jun-99	12th - 14th	6-31am	1.50	1.93	12-39am	0.32	0.22	1.71	New Moon
Jul-99	14th - 16th	9-00am	1.35	1.96	2-44am	0.13	0.22	1.83	First quarter
Aug-99	16th - 18th	11-37am	1.34	1.40	5-24am	0.29	0.49	1.11	First quarter
Nov-99	20th - 22nd	6-30am	1.50	1.52	12-09am	0.44	0.29	1.23	Full moon
Dec-99	27th - 29th	12-24am	1.29	1.77	6-58am	0.50	0.34	1.43	Last quarter
Jan-00	28th - 30th	2-42am	1.29	1.28	8-31am	0.67	0.48	0.81	Last quarter
Feb-00	23rd - 25th	11-43am	1.67		5-28am	0.34	0.30	1.37	Full moon
Mar-00	18th - 20th	7-52am	1.82	1.47	2-24pm	0.20	0.30	1.62	Full moon
Apr-00	28th - 30th	3-10am	1.46	1.21	10-06am	0.56	0.75	0.90	Full moon
May-00	20th - 22nd	9-18am	1.33	1.81	3-35am	0.40	0.41	1.41	Last quarter
Jun-00	26th - 28th	2-28am	1.43	1.41	9-04am	0.42	0.66	1.01	New Moon
Jul-00	18th - 20th	9-17am	1.27	1.82	3-30am	0.29	0.39	1.53	Last quarter
Aug-00	19th - 21st	10-44am	1.42	1.61	4-39am	0.26	0.44	1.35	Last quarter
Sep-00	14th - 16th	9-19am	1.47	1.73	3-18am	0.18	0.28	1.55	Full moon
Oct-00	20th - 22nd	2-10am	1.12	1.59	7-47am	0.49	0.38	1.21	Last quarter
Nov-00	23rd - 25th	7-15am	1.55	1.43	2-08am	0.20	0.28	1.35	New Moon
Dec-00	19th - 21st	4-07am	1.29	1.43	9-52am	0.58	0.33	1.10	Full moon
Jan-01	18th - 20th	4-33am	1.37	1.20	10-46am	0.63	0.44	0.93	Full moon
Feb-01	22nd - 24th	8-39am	1.76	1.34	2-10am	0.39	0.32	1.44	New Moon
Mar-01	17th - 19th	2-59am	1.41	1.03	9-49am	0.68	0.65	0.76	Last quarter
Apr-01	23rd - 25th	7-43am	1.65	1.77	1-44am	0.42	0.33	1.44	New Moon
May-01	28th - 30th	12-31pm	1.26		6-31am	0.35	0.55	0.91	First quarter
Jun-01	25th - 27th	11-14am	1.33	1.90	5-18am	0.22	0.41	1.68	First quarter
Jul-01	29th - 31st	3-02am	1.21	1.45	9-14am	0.39	0.54	1.06	Full moon
Aug-01	19th - 21st	8-06am	1.40	1.97	2-14am	0.09	0.14	1.88	New Moon
Sep-01	17th - 19th	7-49am	1.51	1.87	1-50am	0.05	0.09	1.82	New Moon
Oct-01	27th - 29th	5-08am	1.13	1.40	10-40am	0.62	0.36	1.04	Full moon
Nov-01	28th - 30th	7-17am	1.54	1.39	12-49am	0.31	0.49	1.23	Full moon
Dec-01	26th - 28th	6-03am	1.43	1.26	12-14pm	0.65	0.65	0.78	Full moon
Jan-02	22nd - 24th	3-25am	1.28	1.24	9-10am	0.77	0.50	0.78	First quarter
Feb-02	26th - 28th	8-15am	1.94	1.45	1-43am	0.30	0.20	1.74	Full moon
Mar-02	29th - 31st	9-28am	1.90	1.78	3-13am	0.16	0.15	1.75	Full moon
Apr-02	25th - 27th	6-31am	1.78	1.73	12-52am	0.33	0.21	1.57	Full moon
May-02	28th - 30th	9-25am	1.33	1.91	3-38am	0.27	0.36	1.64	Last quarter
Jun-02	27th - 29th	9-57am	1.19	1.83	4-13am	0.29	0.41	1.54	Last quarter
Jul-02	29th - 31st	11-37am	1.26	1.62	5-31am	0.33	0.56	1.29	Last quarter
Aug-02	27th - 29th	10-52am	1.38	1.45	4-41am	0.29	0.48	1.16	Last quarter
Sep-02	25th - 27th	10-12am	1.53	1.38	3-54am	0.27	0.43	1.26	Last quarter
Oct-02	16th - 18th	5-11am	1.06	1.44	10-37am	0.56	0.33	1.11	Full moon
Nov-02	28th - 30th	3-35am	1.17	1.56	8-59am	0.61	0.34	1.22	Last quarter
Dec-02	21st - 23rd	9-56am	1.90	1.20	3-17am	0.33	0.31	1.59	Last quarter
Jan-03	24th - 26th	1-17am	1.42	1.63	7-08am	0.45	0.33	1.30	Last quarter
Feb-03	26th - 28th	5-28am	1.58	1.07	12-29pm	0.47	0.49	1.11	New Moon
Mar-03	24th - 26th	1-22am	1.66	1.22	7-59am	0.48	0.52	1.18	Last quarter
Apr-03	25th - 27th	3-35am	1.53	1.17	10.39am	0.47	0.68	1.06	New moon
May-03	29th - 31st	6-39am	1.35	1.72	1.01am	0.53	0.37	1.35	New moon
Jun-03	28th - 30th	6-53am	1.19	1.78	1-26am	0.50	0.39	1.39	First quarter
Jul-03	31st - 2nd	9-31am	1.33	1.90	3-41am	0.21	0.33	1.69	First quarter
Aug-03	29th - 31st	9-03am	1.48	1.86	3-06am	0.13	0.21	1.73	First quarter
	Mean (m)			1.49			0.39	1.32	
	Maximum (m)			1.97			0.75	1.88	
	Minimum (m)			1.03			0.05	0.76	

Appendix 2 - Trap locations
(GIS/GPS locations of all traps used during the study)

Plate A1. Location of individual traps and sites in the Sandon Estuary.

Table A2. Latitude and Longitude coordinates of each trap in the Sandon Estuary.

Trap	Latitude	Longitude	Trap	Latitude	Longitude	Trap	Latitude	Longitude
1a	29° 40.153	153° 18.278	**4a**	29° 41.039	153° 18.213	**7a**	29° 40.679	153° 19.431
1b	29° 40.154	153° 18.355	**4b**	29° 41.021	153° 18.271	**7c**	29° 40.704	153° 19.484
1c	29° 40.137	153° 18.416	**4c**	29° 41.040	153° 18.335	**7c**	29° 40.708	153° 19.548
2a	29° 40.225	153° 18.615	**5a**	29° 41.184	153° 18.604	**8a**	29° 40.499	153° 19.261
2b	29° 40.222	153° 18.683	**5b**	29° 41.156	153° 18.660	**8b**	29° 40.551	153° 19.270
2c	29° 40.202	153° 18.740	**5c**	29° 41.112	153° 18.702	**8c**	29° 40.603	153° 19.312
3a	29° 40.012	153° 18.735	**6a**	29° 40.823	153° 18.721	**9a**	29° 40.239	153° 19.002
3b	29° 39.991	153° 18.796	**6b**	29° 40.776	153° 18.750	**9b**	29° 40.208	153° 19.052
3c	29° 40.010	153° 18.862	**6c**	29° 40.729	153° 18.782	**9c**	29° 40.199	153° 19.119

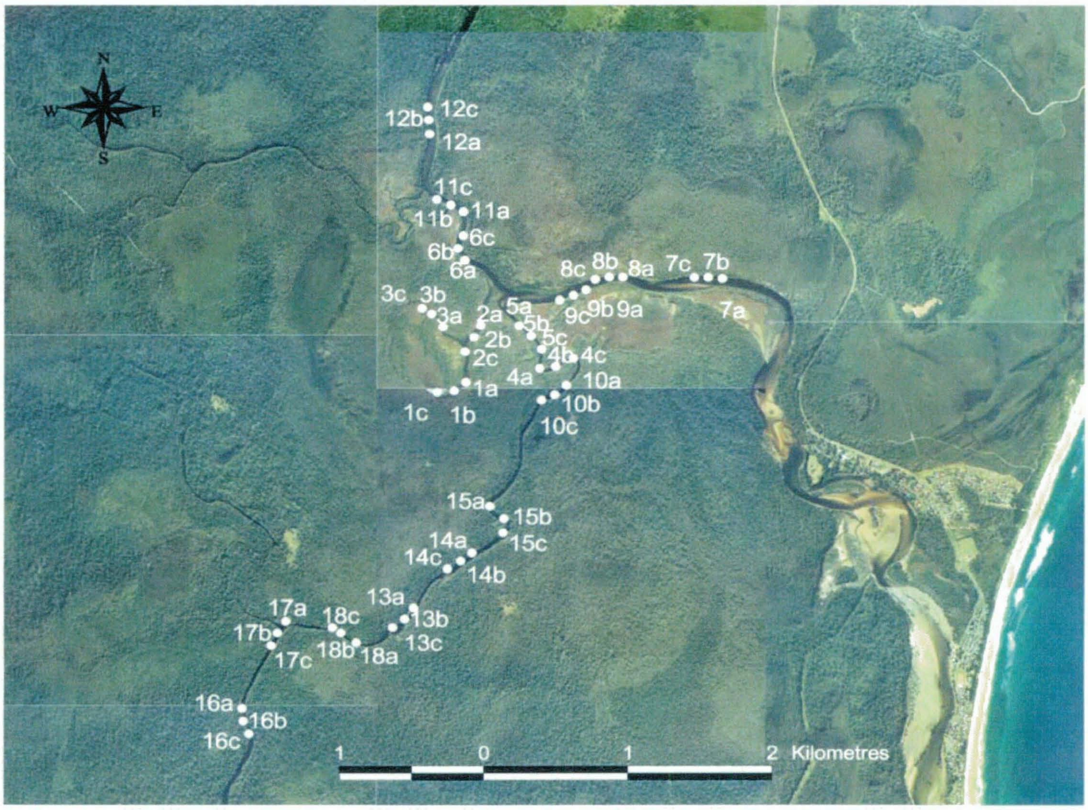


Plate A2.Location of individual traps and sites in the Wooli Estuary.

Table A3. Latitude and longitude coordinates of each trap in the Wooli Estuary.

Trap	Latitude	Longitude	Trap	Latitude	Longitude	Trap	Latitude	Longitude
1a	29°50.772	153°13.800	**7a**	29°50.343	153°14.905	**13a**	29° 51.695	153°13.578
1b	29°50.806	153°13.750	**7c**	29°50.340	153°14.844	**13b**	29° 51.738	153°13.541
1c	29°50.812	153°13.678	**7c**	29°50.340	153°14.783	**13c**	29° 51.773	153°13.490
2a	29°50.539	153°13.863	**8a**	29°50.339	153°14.475	**14a**	29° 51.469	153°13.830
2b	29°50.589	153°13.834	**8b**	29°50.339	153°14.416	**14b**	29° 51.502	153°13.782
2c	29°50.648	153°13.796	**8c**	29°50.348	153°14.355	**14c**	29° 51.534	153°13.724
3a	29°50.545	153°13.701	**9a**	29°50.391	153°14.316	**15a**	29° 51.327	153°13.966
3b	29°50.490	153°13.652	**9b**	29°50.414	153°14.261	**15b**	29° 51.386	153°13.962
3c	29°50.469	153°13.610	**9c**	29°50.433	153°14.204	**15c**	29° 51.277	153°13.905
4a	29°50.715	153°14.117	**10a**	29°50.783	153°14.232	**16a**	29° 52.109	153°12.839
4b	29°50.708	153°14.186	**10b**	29°50.822	153°14.183	**16b**	29° 52.162	153°12.846
4c	29°50.674	153°14.263	**10c**	29°50.843	153°14.126	**16c**	29° 52.215	153°12.869
5a	29°50.541	153°14.028	**11a**	29°50.071	153°13.787	**17a**	29° 51.750	153°13.028
5b	29°50.581	153°14.081	**11b**	29°50.044	153°13.732	**17b**	29° 51.796	153°12.993
5c	29°50.636	153°14.126	**11c**	29°50.021	153°13.673	**17c**	29° 51.849	153°12.965
6a	29°50.270	153°13.794	**12a**	29°49.753	153°13.641	**18a**	29° 51.837	153°13.332
6b	29°50.222	153°13.765	**12b**	29°49.696	153°13.636	**18b**	29° 51.796	153°13.266
6c	29°50.169	153°13.788	**12c**	29°49.642	153°13.632	**18c**	29° 51.773	153°13.229

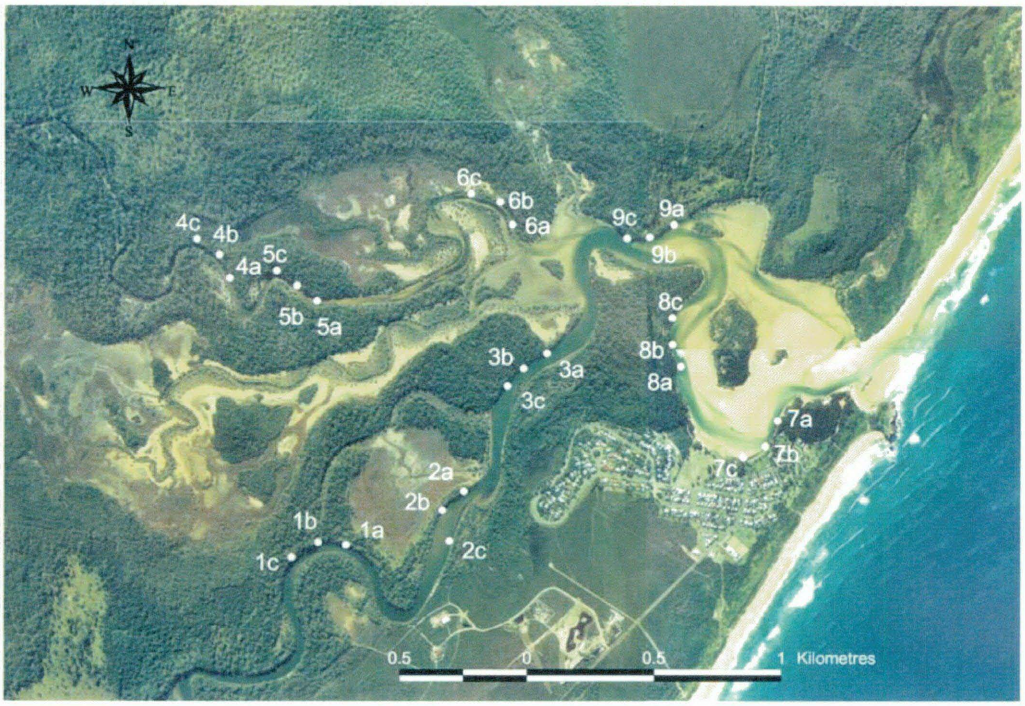


Plate A3.The location of individual traps and sites in Corindi Estuary

Table A4. Latitude and Longitude coordinates of each trap in the Corindi Estuary.

Trap	Latitude	Longitude	Trap	Latitude	Longitude	Trap	Latitude	Longitude
1a	29° 59.177	153° 12.704	**4a**	29° 58.525	153° 12.336	**7a**	29° 58.910	153° 13.757
1b	29° 59.171	153° 12.635	**4b**	29° 58.558	153° 12.391	**7c**	29° 58.965	153° 13.727
1c	29° 59.204	153° 12.570	**4c**	29° 58.607	153° 12.417	**7c**	29° 58.988	153° 13.674
2a	29° 59.061	153° 12.991	**5a**	29° 58.655	153° 12.630	**8a**	29° 58.794	153° 13.521
2b	29° 59.102	153° 12.939	**5b**	29° 58.622	153° 12.580	**8b**	29° 58.747	153° 13.500
2c	29° 59.168	153° 12.956	**5c**	29° 58.591	153° 12.531	**8c**	29° 58.690	153° 13.499
3a	29° 58.767	153° 13.193	**6a**	29° 58.492	153° 13.107	**9a**	29° 58.492	153° 13.501
3b	29° 58.799	153° 13.136	**6b**	29° 58.443	153° 13.077	**9b**	29° 58.518	153° 13.442
3c	29° 58.836	153° 13.096	**6c**	29° 58.425	153° 13.006	**9c**	29° 58.522	153° 13.387

(Aerial photographs used in Arcview for Appendix 2 supplied by Orthophotos, Roger Dwyer & Associates, Coffs Harbour through the NSW Marine Parks Authority – Solitary Islands Marine Park - 2004)

Appendix 3 - Zone sizes in each estuary

Zone sizes in each estuary before (a) and after (b) the August 2002 NSW Marine Park Authority zone change.

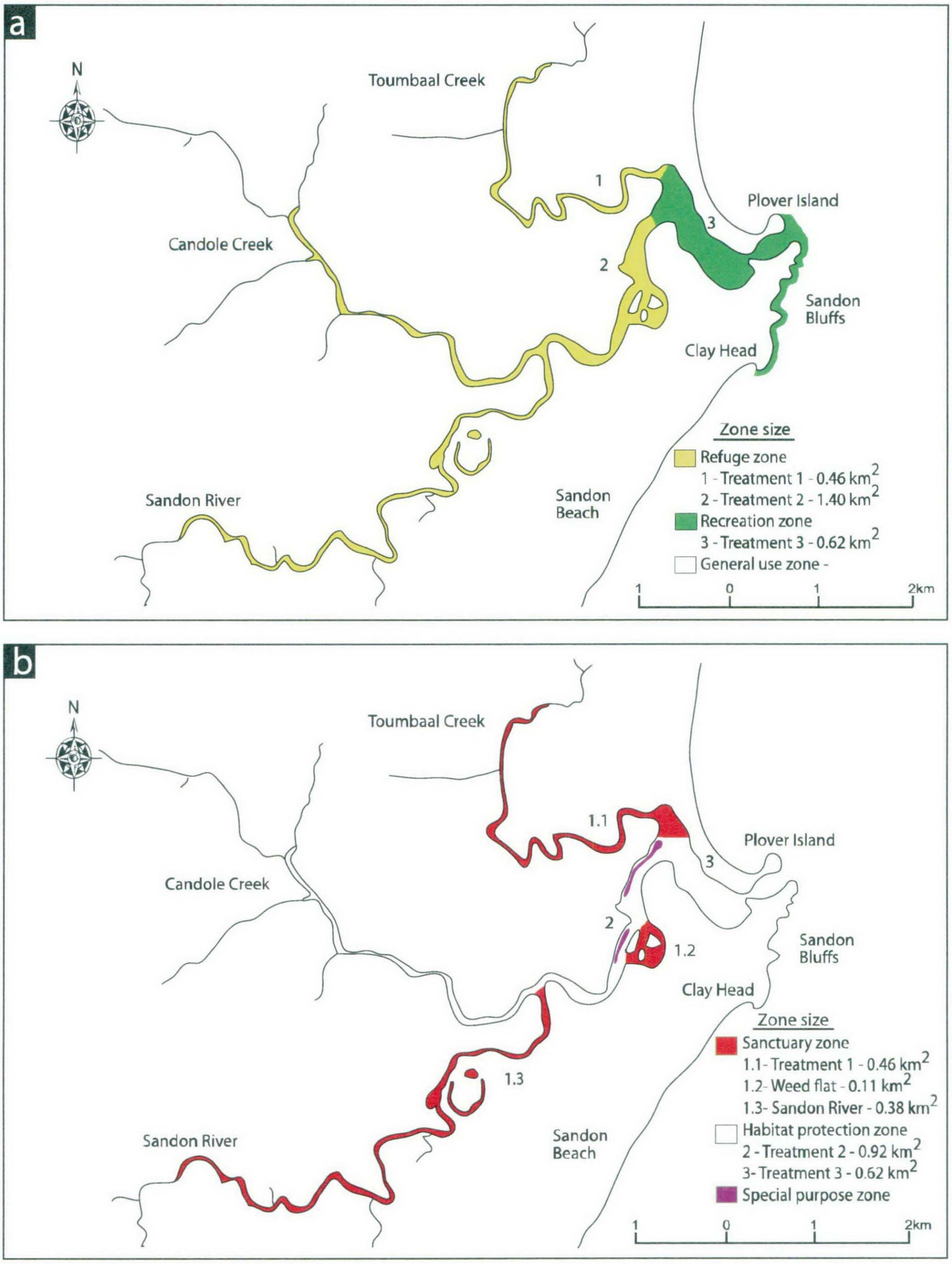


Figure A1. Changes in area of different zoning types before (a) and after (b) the August 2002 zoning change in the Sandon Estuary.

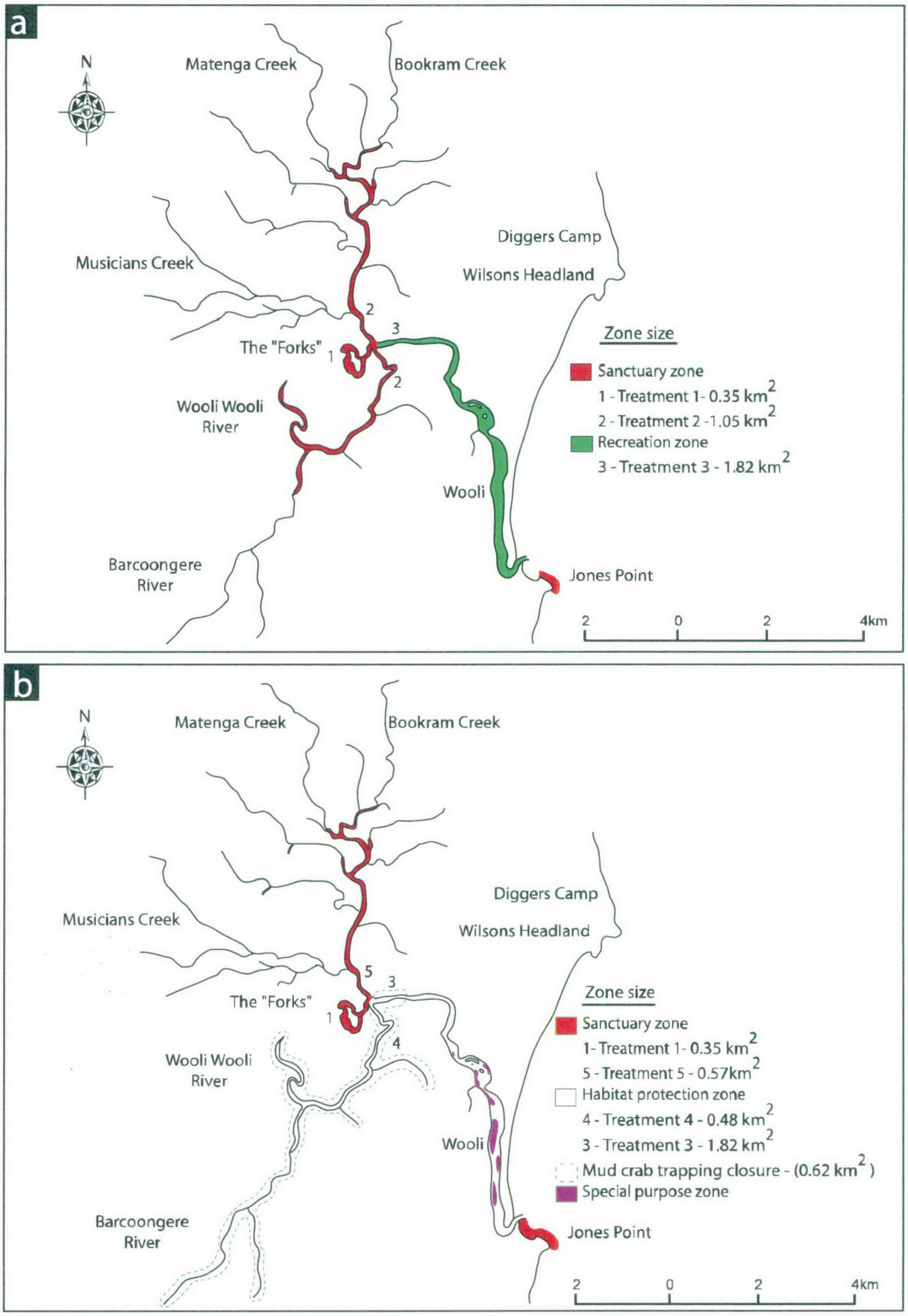


Figure A2. Changes in area of different zoning types before (a) and after (b) the August 2002 zoning change in the Wooli Estuary.

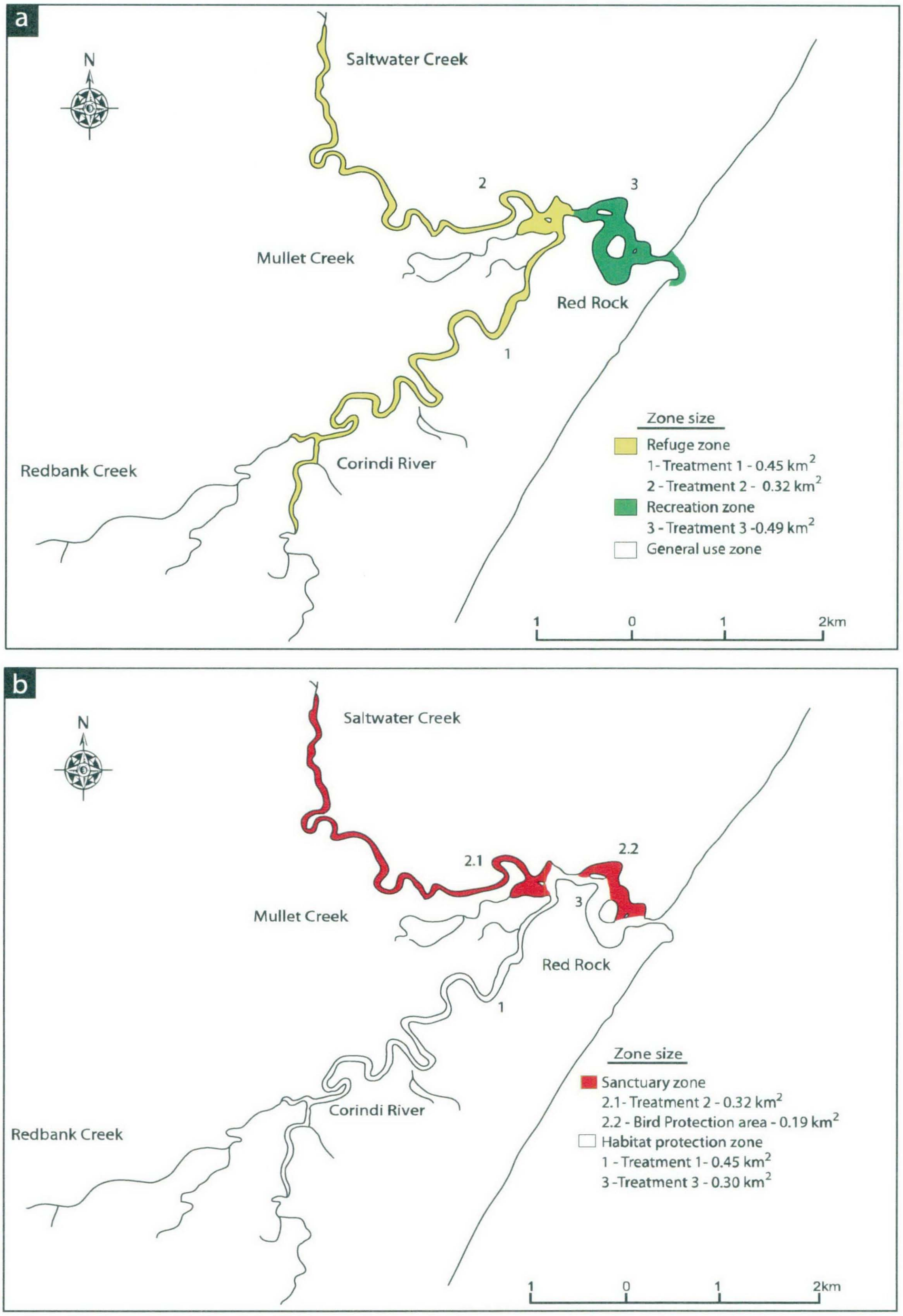


Figure A3. Changes in area of different zoning types before (a) and after (b) the August 2002 zoning change in the Corindi Estuary.

Appendix 4 - Project advertising

Mud crab monitoring program poster used throughout the park at estuary access points

RESEARCH

MUD CRAB

Permit - F98/469

The University of New England with support from the NSW Marine Parks Authority and NSW Fisheries are conducting research on mud crabs from December 1998 till December 2003.

The study is designed to provide information about abundance, size class, gender and recruitment of mud crab populations within and between fished and un-fished areas.

HOW CAN YOU HELP

If you catch a tagged mud crab with a:

- **WHITE TAG (attached to the top of the crab)**, could you please note the information listed below and then return the crab to the water as it is tagged with an expensive telemetry radio tracking tag
- **YELLOW TAG (attached at the base of the abdomen),** could you please note the following information and either keep or release the crab

1 - The date of capture
2 - The length and width of the carapace (if possible)
3 - The capture location
4- TAG Number

send the information to;

Mud Crab Research, Ecosystem Management, UNE, Armidale, 2351 or phone 0438950838 or e-mail pbutcher@metz.une.edu.au

Natural Resources established 1971

UNE The University of NEW ENGLAND

National Marine Science Centre

Mud crab lotto poster

National Marine Science Centre

UNE

MUD CRAB LOTTO

Win $300

Mud crabs have been tagged in estuaries of the Solitary Islands Marine Park since 1998. The National Marine Science Centre is giving you the chance to win cash for returning tags from crabs that you have caught. Just send the tag along with information about where the crab was caught and we will enter you into the competition to win $300. We will also send you back information on the history of the crab since we first tagged it. All tags returned since 1998 will be entered into the draw.

HOW TO ENTER

1. One entry for every tag received. The entry must contain:
- **Your contact details,**
- **The tag from the crab,**
- **The date of capture,**
- **The approximate location caught,**
- **The approximate size** (if measured).

2. Entry by post or personal delivery only addressed to:

Mud Crab Lotto,
National Marine Science Centre,
PO Box J321, Bay Drive,
Coffs Harbour Jetty, NSW 2450

Authorised under NSW Permit No. TPL03/07787

Rules and regulations

1. The competition starts at 5pm Friday 29th August 2003 and closes at 5pm Friday 31st October, 2003. Entries received outside these dates will not be submitted.
2. Employees of the National Marine Science Centre and their direct family are not eligible to submit an entry.
3. Only tags which have been used by staff and students of the NMSC on the mud crab (*Scylla serrata*) are eligible. An example of the tag is located on all advertising material.
4. Only people 18 years or older may submit an entry.
5. The draw will take place at the NMSC on Monday 3rd November at 1pm. The winner will be the first correct entry drawn from the barrel. The winner will be notified by phone and mail within 1 week of the draw and contact details exchanged for the collection of the prize.
6. Results will be published in the Daily Examiner (Grafton) and The Advocate (Coffs Harbour) on Saturday 15th November 2003.

Appendix 5 - Pilot study results (November 1998)

In each estuary, commercial crab traps (section 3.2) were used to sample areas to determine appropriate sites for the estuary manipulation in (Chapter 4), the telemetry sites (Chapter 5) and the natural barrier experiment (Chapter 6). A total of 80 (Wooli) and 60 (Sandon and Corindi) crab traps were set at random sites in each estuary. Each estuary is divided by separate arms and these were consistent where zoning borders occurred. Each estuary was divided into areas depending on whether they were "fished' or 'unfished' and the location of the arm. The Sandon and Corindi estuaries were divided into three arms and Wooli 4 based on these criteria (Figure A1a (sites 1 - 3) Sandon, A2b (sites 1,3 - 5) Wooli, A3a (sites 1 - 3) Corindi). Within each arm, 20 traps were placed at intervals atleast 100 m from each other at random sites to minimise traps competing with each other. Traps were left for 24 h from 8 am and retrieved the following day. Catch per trap provided an estimate of spatial variation within and among areas in each estuary. Even though there was no significant difference between unfished sites in each estuary, it was decided to keep these areas as separate areas for the main study. This gave two 'unfished' sites at Wooli and Corindi and two 'commercial only' sites at Sandon plus one 'fished' site in each estuary. However, some of these sites changed (Chapter 4) as one of the sites at Wooli was divided in two at the 2002 zoning change while other sites consisted of the same design but were exposed to different fishing pressures.

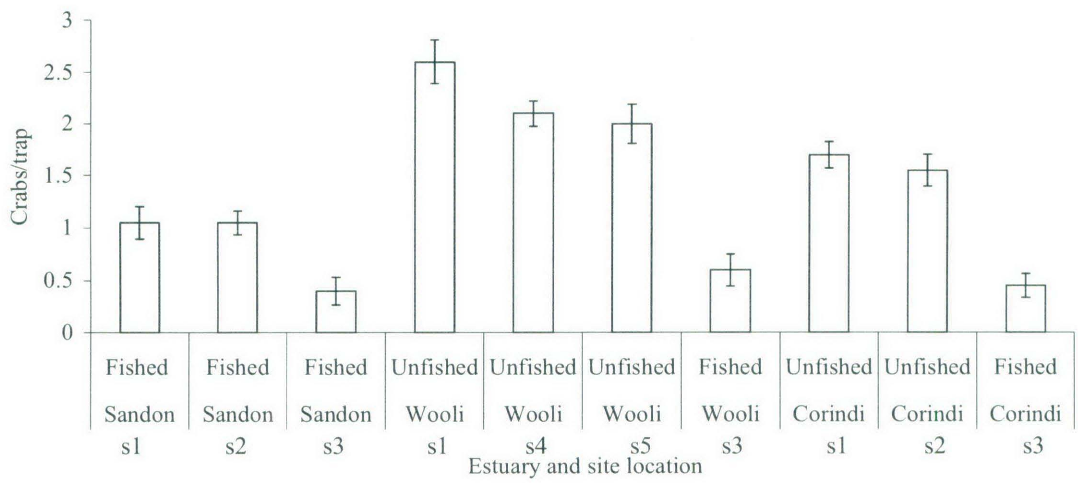


Figure A4. Mean (±SE) number of crabs caught per trap in each site during the pilot study in November 1998. The estuary and site location indicates whether the area was fished/unfished, on maps A1a (Sandon), A2b (Wooli) and A3a (Corindi).

Appendix 6 - Refereed paper

Butcher, P. A., Boulton, A. J. and Smith, D.A. 2003, Mud crab (*Scylla serrata:* Portunidae) populations as indicators of the effectiveness of estuarine marine protected areas *in*: *World Congress on Aquatic Protected Areas proceedings*, (eds) J. Beaumer., A. Grant., and D. Smith, Cairns 2002. Queensland University Press pp 421-427.

MUD CRAB (*SCYLLA SERRATA:* PORTUNIDAE) POPULATIONS AS INDICATORS OF THE EFFECTIVENESS OF ESTUARINE MARINE PROTECTED AREAS

Paul A Butcher[A,B], Andrew J Boulton[A], and Stephen D A Smith[B]

[A]Ecosystem Management, University of New England, Armidale, NSW 2351, Australia.

[B]National Marine Science Centre, University of New England, Coffs Harbour, NSW 2450, Australia.

Abstract

A primary objective of marine parks is to allow controlled access to users while conserving the environment. Zoning is seen as an effective way of managing populations vulnerable to over-fishing but indicator species are needed to show the effectiveness of these zones. As zoning of the Solitary Islands Marine Park (SIMP) on the mid-north coast of New South Wales, Australia, was implemented in the absence of adequate scientific data, we compared abundance, size classes and recruitment of mud crabs in adjacent fished and unfished zones in the SIMP to determine their effectiveness. The study was done in the Wooli Estuary where recreational fishing has been excluded from the Sanctuary Zone since 1991 but has occurred in the adjacent Recreation Zone. Mud crabs were sampled monthly in each zone from December 1998 to June 2002 using commercial wire traps. During the study, 1412 mud crabs were caught, tagged, measured, and sexed. Abundance and mean size of mud crabs was consistently higher in the Sanctuary Zone. Small sub-adult crabs dominated the population in the Recreation Zone. Recruitment of adult crabs to the Recreation Zone from the Sanctuary Zone implied the Sanctuary Zone is an effective source. However, females still need to move through the Recreation Zone to reach the sea to spawn and recreational fishing may be a significant source of mortality. This study shows that targeted recreational species such as mud crabs respond to protection, and zoning in the Wooli Estuary appears to be an effective tool for sustainable fisheries management.

Keywords: mud crab, marine park, estuary, recruitment, fishing

INTRODUCTION

The benefits of marine parks include reported increases in abundance, growth rates, and average size and recruitment of fish, as well as ecosystem benefits through reduced disturbance (Cole *et al.* 1990; Roberts 1994; Childress 1997; Wahl 1997). Special natural features can be protected, providing ecosystem maintenance and ensuring long-term sustainability (Agardy 1997). Tourism, particularly fishing, is a major cause of concern with its impact on certain parts of the marine system (Russell 1996). To minimise this pressure, closed areas, harvest refugia and multi-use marine protected areas are being implemented to protect the marine environment (Agardy 1997). Closed areas or harvest refugia aim to conserve stocks and habitats threatened by over-exploitation and destructive fishing, whereas multi-use marine protected areas safeguard critical habitats while allowing the long-term, sustainable use of marine resources.

Marine park managers need to be able to demonstrate whether the objectives of the different zoning schemes are being met. This can be achieved by demographic studies of differences in abundance, size class, sex ratio and recruitment of indicator species between areas. Ideally, indicator species should be readily caught, taxonomically distinctive, relatively abundant, ecologically significant and, preferably, of direct recreational and commercial importance. For example, in comparing coral trout (*Plectropomus leopardus*) from Bramble Reef in the northern Central Section of the Great Barrier Reef Marine Park, Russell (1996) demonstrated that populations react to opening and closing of marine reserves to fishing. Closure led to an increase in abundance and size class with a rapid depletion of stock when the reef was re-opened to fishing. In a study within a Caribbean marine reserve, Roberts (1994) found that the abundance and mean size of commercial species of fish was greater in protected areas than in adjacent fished areas.

The Solitary Islands Marine Park, mid-north coast, New South Wales (NSW), Australia (29°52'16"S,153°16'06"E), was declared in 1998. It is the first and largest Marine Park in NSW. Its primary aim is to protect representative examples of marine diversity, while catering for a broad range of recreational and commercial activities (MPA 2002). The Wooli Estuary is in the north of the SIMP, with different zones implemented to allow continued commercial and recreational use in some areas while ensuring a sustainable future for fisheries in the SIMP. A Sanctuary Zone was designated in the upper reaches to protect species from fishing and provide a recruitment source to the fished Recreation Zone in the lower estuary (Fig. 1). To determine the effectiveness of these zones in the Wooli Estuary, the mud crab (*Scylla serrata*) was identified as a potential indicator species. Not only is the crab targeted by commercial and recreational fishers, it is large, easily identified, and plays a key role as a predator in the estuarine food web (Hill 1979).

The primary objective of the study was to evaluate the effectiveness of the Sanctuary Zone by comparing the abundance and demographic structure of mud crab populations between the adjacent fished and unfished zones. We hypothesised that if the zoning was currently effective, there should be significantly more crabs in the Sanctuary Zone and the median size class of crabs in the fished Recreation Zone would be smaller owing to the selective harvesting of larger individuals. If the Sanctuary Zone is acting as a 'source' population, there should be a significant number of large crabs recruiting from the Sanctuary Zone to the Recreation Zone.

Study area

The Wooli Estuary is within the SIMP on the NSW mid-north coast (29°52'16"S,153°16'06"E). The Wooli Estuary is a highly infilled barrier estuary with a water area of 1.9 km^2 (Roy *et al.* 2001). The entrance is open and trained by two erected rock walls. Vegetation includes mangroves (0.493 km^2), seagrass (0.028 km^2) and saltmarsh (0.531 km^2) (Roy *et al.* 2001). The substratum throughout the river is sand in the lower reaches and mud in the upper reaches. The water in the upper reaches is tannin-stained most of the time and throughout the estuary during periods of flooding. The estuary is divided into two management zones providing for recreational activities (Recreation Zone) from the mouth to 9 km upstream and full habitat protection (Sanctuary Zone), upstream of this point (Fig. 1).

The Wooli River catchment (190 km^2) includes timbered belts in the upper reaches, and swamps, wetlands, tidal marshes and dune areas in the lower catchment (Stone 1999). The land uses in the Wooli River catchment are Crown land (grazing), National Park and State Forests. The adjacent village of Wooli is a coastal fishing village (pop. 500) with a commercial fishing fleet capturing finfish and crustaceans. Before the SIMP was declared, the river was harvested by commercial fishers for mud crabs, but the decline in mud crabs led to a reduced commercial effort. The Wooli region is increasingly popular as a destination for tourism, of which recreational fishing, particularly for mud crabs, is a major component.

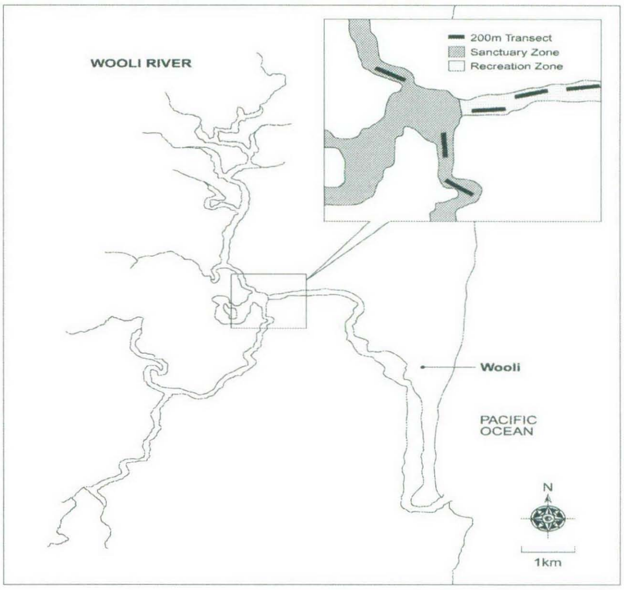


Fig. 1. Location of the study sites at the junction of the Sanctuary and Recreation zones in the Wooli Estuary, Solitary Islands Marine Park.

METHODS

Field

As this aspect of research focused on abundance and recruitment, two study sites were selected either side of the junction of the Sanctuary Zone (Site 1) and the Recreation Zone (Site 2), 9 km upstream from the mouth of the estuary (Fig. 1). Site location was justified from a pilot study conducted in December 1998 which found there to be no difference in crab abundance between the northern and southern arms of the Wooli estuary Sanctuary Zone, while there were significantly more crabs in the Sanctuary Zone than the Recreation Zone. The sites, 300 m apart, were divided into three 200 m transects within 1 km of the junction of the zone border. As the width of the estuary varies from 20 to 30 m within the study site, each transect was randomly placed parallel to the shore with 3 traps per transect to provide nine traps per site. One trap was placed every 100 m in each transect because Williams *et al.* (1982) reported competition between traps at distances <100 m. Each transect was sampled for three consecutive nights, monthly from December 1998 to June 2002.

Mud crabs were captured in commercially designed pots (900 mm x 600 x 300) covered in 20 mm wire mesh because all size classes of crabs were targeted. Each trap had two entrances (250 x 90 mm). Pots were baited with snapper (*Pagrus auratus*), mullet (*Mugil cephalus*) and silver perch (*Bidyanus bidyanus*) and left in the water for 24 h. Captured crabs were sexed, measured for carapace width and length, and tagged with TBA-2 anchor t-tags. Tags were inserted to the right of the abdominal artery where the abdomen and carapace meet, because this junction splits during moulting, reducing the chance of tag loss while preventing harm to the crab. Crabs were released at the capture site. Any crab that was recaptured at the same site within the three-night sampling period was noted but omitted from the results. Captures were compared for overall abundance, size class and recruitment between the Sanctuary Zone and Recreation Zone.

As recreational fishing effort occurred during the study, tags or tag identification numbers from recaptured crabs were collected from recreational fishers to determine whether recruitment was occurring from the adjacent Sanctuary Zone. Recreational fishers returned the tag or recorded the tag number with the approximate location, date, sex and carapace width and length of each crab.

Crabs were allocated to three size classes for comparison. As Heasman (1980) found that the mud crab moulted into adult body form at 140–160 mm carapace width, adult crabs were considered to be those of 150 mm or more, sub-adults had a carapace width of 100–149 mm, and juveniles had carapace widths of 99 mm or less.

Data analysis

The data were initially tested for normality on a Wilk–Shapiro/Rankit Plot to determine whether the variables conformed to a normal distribution (<0.8). Measures of abundance (catch per unit effort) were compared between zones by analysis-of-variance (ANOVA). Normally distributed data were tested by parametric one-way ANOVA, followed by post hoc (Tukey's HSD) pairwise comparison-of-means test with a rejection level of 0.05. This is a useful post hoc test that controls the experimentwise-error-rate while retaining strong power (Analytical Software 1996).

The Kolmogorov–Smirnov test was used to detect any differences in the distributions of crabs caught between the Sanctuary and Recreation zones. This test is sensitive to any differences between the size-class distributions, including differences in means and variances within classes (Analytical Software 1996). All statistical analyses used Statistix (Analytical Software 1996).

RESULTS

Abundance and size

More crabs were caught per unit effort in the Sanctuary Zone than in the Recreation Zone for all months pooled ($F_{5,17}$ = 13.12, *P* = 0.0002) (Fig. 2). There were significantly more adult ($F_{1,5}$ = 43.01, *P* = 0.0028), sub-adult ($F_{1,5}$ = 97.16, *P* = 0.0006), and juvenile ($F_{1,5}$ = 18, *P* = 0.0132) crabs caught per unit effort in the Sanctuary Zone than the Recreation Zone (Fig. 2).

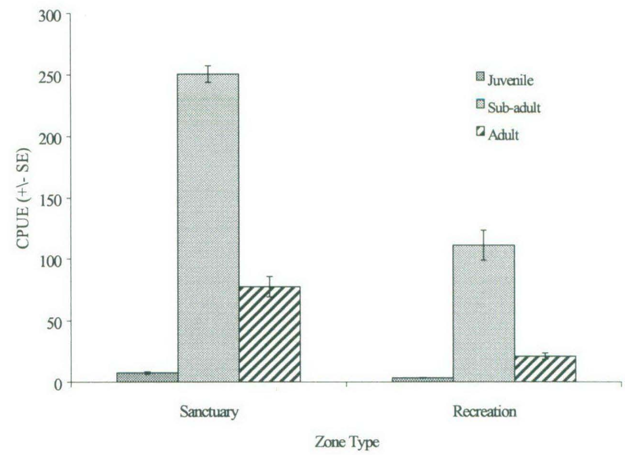


Fig. 2. Mean number of crabs (+/- SE) of different size classes caught per unit effort at each site for all months pooled, Wooli Estuary, NSW. (CPUE = 360 pot nights)

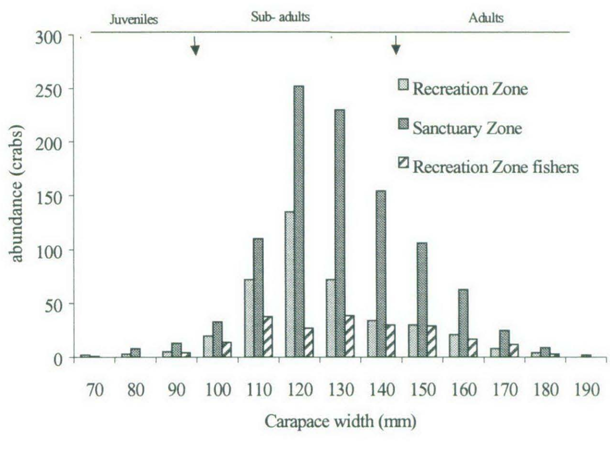


Fig. 3. Abundance by size class for mud crabs tagged in the Sanctuary Zone (*n* = 1006) or Recreation Zone (*n* = 406), and for crabs recaptured by fishers in the Recreation Zone (*n* = 213)

SIZE-CLASS DISTRIBUTION

Actual abundance

The mean carapace width of mud crabs in the Recreation Zone (123.6 mm) was smaller than those in the Sanctuary Zone (136.2 mm). Crabs of 120–170 mm carapace width were more abundant in the Sanctuary Zone than in the Recreation Zone (Fig. 3). Most of the crabs in each zone were in the 120 mm range. The range of actual sizes caught by recreational fishers varied from small sub-adult crabs (100 mm) to large adult crabs (180 mm) suggesting that illegal-size crabs were being caught by some fishers. This was defined from actual tag returns. For crabs to be legally taken by recreational fishers in NSW, they have to have a carapace length of 85 mm (carapace width 128 mm).

Proportion abundance

Overall, the size-class distribution of mud crabs was similar between the Sanctuary Zone and the Recreation Zone (Kolmogorov–Smirnov KS = 0.18, P = 0.1086). However, there were some notable differences in distributions between the size ranges. The Recreation Zone had a larger proportion of crabs between the range of 70–120 mm while the Sanctuary Zone had a greater proportion of crabs in the 130–170 mm size range (Fig. 4). In the Recreation Zone, the distribution was skewed to the left by the larger percentage of smaller sub-adults that were caught and the lack of adult crabs. Equal proportions of larger sub-adult and adult crabs were taken from the Recreation Zone by fishers.

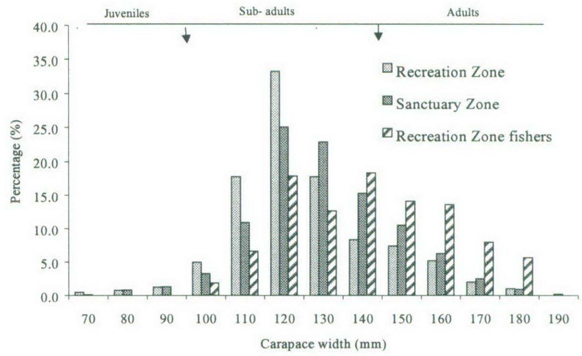


Fig. 4. Size class proportion distribution for mud crabs tagged in the Sanctuary Zone (n = 1006) or Recreation Zone (n = 406), and for Recreation Zone returns from fishers (n = 213).

Movement

In total, 150 (10.6%) of the 1412 tagged crabs were recaptured during the study. A further 213 (15%) crabs were recaptured by recreational fishers in the Recreation Zone (Fig. 5). The Recreation Zone had the higher recapture rate and 11% of the 1006 crabs tagged in the Sanctuary Zone were caught after they had recruited into the Recreation Zone. There was also some recruitment of crabs from the Recreation Zone into the Sanctuary Zone.

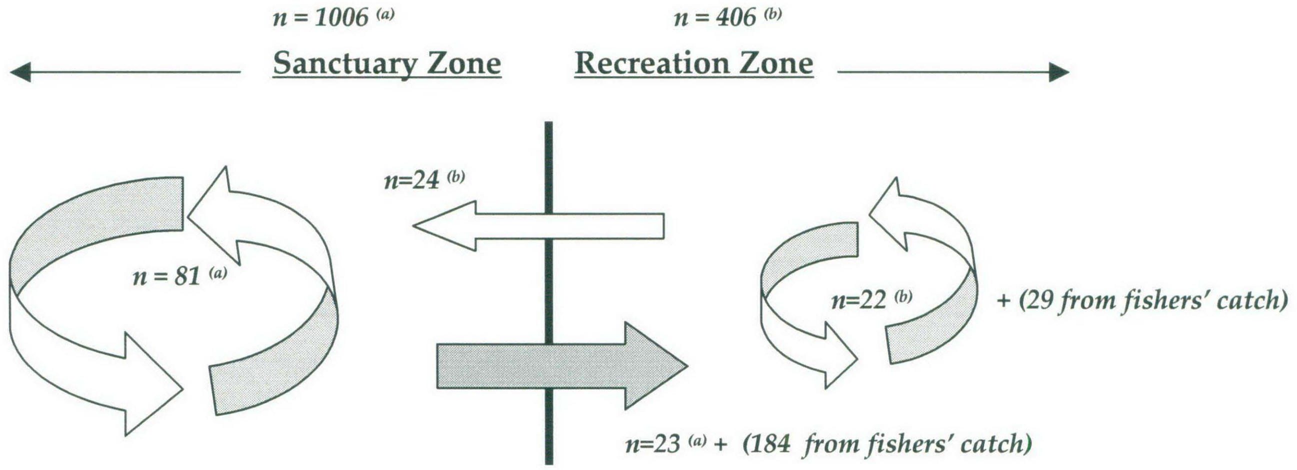


Fig. 5. Movement of crabs; arrows indicate whether they were recaptured in the release zone or in the adjacent zone.

[a] crabs that were originally released in the Sanctuary Zone.

[b] crabs that were originally released in the Recreation Zone.

DISCUSSION

Effectiveness of zoning: abundance of mud crabs

The hypothesis that there would be more crabs in the Sanctuary Zone than in the Recreation Zone in the Wooli Estuary was supported. The catch per unit effort was two-and-a-half times higher in the Sanctuary Zone than in the Recreation Zone. This suggests that the Sanctuary Zone is providing some refuge for mud crabs from exploitation. This finding parallels others where differences have been observed between fished and unfished areas. Roberts (1994) reported that a protected Caribbean Marine Reserve showed an increase in abundance and size class of commercially caught fish species but no difference in population structure of species that were not commercially sought. This suggests that targeted species such as mud crabs will successfully indicate the effectiveness of marine park Sanctuary zones.

Size-class distribution and fishing selectivity

It was predicted that there would be different size-class structures between the two marine park zones, but that, overall, sub-adult and adult crabs would dominate the estuary. If zoning was effective, and extensive illegal fishing was not occurring in the Sanctuary Zone, juvenile and sub-adult crabs would predominate in the Recreation Zone because of selective capture while adults would be relatively more abundant in the Sanctuary Zone. This prediction was also supported by the study. Sub-adults and adults dominated the Sanctuary Zone whereas small sub-adults were common in the Recreation Zone. Recreational fishing effort is likely to be the main reason why the Recreation Zone had low numbers of adults. Adult crabs are the primary targets for recreational fishers while crabs in the Sanctuary Zone are protected from any such removal.

However, the large sub-adult population in the Sanctuary Zone suggests that there may also be substantial natural mortality of adult crabs (although this does not rule out illegal removal of adult crabs). In a study of mud crabs in Deception Bay, Queensland, Hill *et al.* (1982) found that the habitat preferences of crabs of different size-classes varied. Adult crabs were caught mainly in sub-tidal waters while sub-adults moved into the intertidal zone at high tide to feed and retreated to sub-tidal waters at low tide. As the intertidal zone is only small (2–5 m) in this study, the chance of capturing a crab that moved into the intertidal zone was still high because traps were placed directly along the river bank near the small intertidal zone. Juveniles tend to reside in the mangrove zone (Hill *et al.* 1982) so may be unlikely to be found in the main channel. The sampling methods used in this study did not target juveniles, and a better approximation of juvenile abundances could employ the use of artificial substrata such as roofing tiles (Hill *et al.* 1982) that act as a habitat and provide protection for juvenile mud crabs in the intertidal zone.

Size-class distributions illustrate the structure of a population and reveal patterns of selective capture in fisheries. Tracking changes in size-class distribution over time indicates sustainability of the fishery and the effectiveness of control measures such as size limits and zoning restrictions. In this study, the Recreation Zone had a smaller percentage of adult crabs than the Sanctuary Zone. Although this probably reflects differential fishing pressure between the zones (it is likely that the adult crabs have a lower percentage frequency due to exploitation by recreational fishers), natural habitat selection may also be responsible.

In the Wooli Estuary, the Recreation Zone also maintains a small population of juvenile crabs that, if they remain and grow in the same area, will provide a potential fishery for future years. The dominant sub-adult population in the Recreation Zone is at the bottom end of the size class, with carapace widths in the range 110–130 mm. This suggests that approximately 41% of the crabs caught in the Recreation Zone are of legal size (carapace width 128 mm), whereas recruitment from the Sanctuary Zone of large individuals caught by recreational fishers meant that 74% of those crabs are legal size.

Recruitment: "sources" and "sinks"

Although the Sanctuary Zone may contain higher abundances of harvestable crabs, it is important to fishers that these crabs leave the Sanctuary Zone and are available to the recreational fishery downstream. It was predicted that if the zoning system was successful, there would be an 'over-flow' of large crabs into the Recreation Zone and recruitment of small crabs moving into the Sanctuary Zone from the Recreation Zone. Our study showed that a small proportion of crabs moved readily within and between zones, with a steady movement of crabs into the Recreation Zone being evident from the recaptures by recreational fishers. The fact that few crabs were caught in this study (excluding recreational fishers' returns) in the Recreational Zone suggests that crabs entering the Recreation Zone from the Sanctuary Zone are being removed rapidly by the fishery. Therefore, during periods when crabs may not move downstream, the fishery in the

Recreation Zone will be depleted quickly because there is no source of larger legal-sized crabs.

Typically, mud crabs have a limited range of movement in estuaries, yet there is equal chance of recapture at different locations if habitat conditions are appropriate. Hill (1975) reported that 68% of mud crabs recaptured in two South African estuaries had moved less than 1 km from the site of tagging, with the largest movement being 13.5 km. Hyland *et al.* (1984) also suggested that crabs would move on average between 6.6 km for females and 3.7 km for males in Pumicestone Passage in southern Queensland. The greater distance travelled by females may be due to the spawning response of females which move offshore to extrude eggs (Arriola 1940).

Salinity fluctuations during flooding apparently played a major role in the Wooli Estuary where large flushes of fresh water pushed crabs downstream (Butcher unpub. data). Davenport and Wong (1987) found that adult mud crabs could survive in salinities from 2 to 42 ppt and showed no discriminatory behaviour between salinities in this range. This suggests that salinity may not be the major factor pushing crabs downstream and that factors associated with the flooding such as current, increased turbidity, low dissolved oxygen or changes in food resources may be the reason for movement. In the Wooli Estuary, regular floods benefit the mud crab populations in the Recreation Zone by providing an opportunity for crabs to move downstream without fishing pressure, because there is usually a decline in fishing pressure during this period due to unfavourable fishing conditions. Without this sporadic influx of fresh water, it is likely that the Sanctuary Zone would provide little recruitment into the downstream Recreation Zone.

At any time, movement from the Sanctuary Zone could be a result of crabs moving from an area of high population density to one of low population density. Crabs may gain benefits from moving out of the Sanctuary Zone because the greater foraging capacities and lower intra-specific competition outside would potentially increase fitness with little effort needed for foraging and less competition for habitat space.

During the course of this study, it became evident that the behaviour of the recreational fishers changed to reflect the main source of legal-sized crabs. Thus, it was not uncommon to see 10–30 traps immediately downstream of the border between the zones. Crabs moving from the Sanctuary Zone to the Recreation Zone would run the gauntlet of these traps. As the sampling site was downstream of this area of fishing concentration, this would have contributed to the lower catch in the Recreation Zone. It also highlighted the need to consider the specific topography of sites when establishing protective zones. Natural features such as sandbars may provide buffers against such fishing concentration and allow individuals to move out of the zones more freely.

The high percentage frequency of crabs recaptured in the Recreation Zone and little recruitment back into the Sanctuary Zone suggests that if crabs move from the Sanctuary Zone, there is a high chance that they will be caught by fishers before they move back into the Sanctuary Zone. The migration of females to offshore regions during spawning renders them vulnerable to fishing activity when sanctuary zones only protect populations in the upper reaches of estuaries. Females in the Wooli Estuary need to negotiate 9 km of potential fishing pressure before they reach the ocean to spawn. There is a need to develop management plans to meet the needs of this species. Possible changes in management include establishing a mosaic of zones throughout estuaries to protect species that migrate, because the most common and valuable commercial species in NSW are migrants, few are residents and virtually none are transients (Roy *et al.* 2001). Restrictions on the removal of female mud crabs or spawning closures would give females the opportunity to move throughout rivers without being exploited. There is a need to develop legal size limits in line with other Australian States to remove the temptation of illegally taking crabs across the State border to sell.

CONCLUSION

With management plans for the Solitary Islands Marine Park in their early stages of assessment, information from this research is essential for determining the effectiveness of estuarine zones. If the Sanctuary Zone is too small, the fishery may over-exploit the resource. If it is too large, significant revenue is lost to the local community and the fishery is under-exploited. In this study, significant differences in abundance and size class indicate that mud crabs can be used successfully as an indicator species for the effectiveness of estuarine marine protected areas because the crabs are a target species for fishing.

The results of this study provide marine park managers with data to show the community the environmental and fishery benefits of multi-use parks, ensuring the sustainable future of highly valued species. However, zoning schemes will have credibility only if they show sustained success. It is important to continue monitoring marine ecosystems to identify which species react in a measurable way and how each species reacts to different management regimes. According to the results of the present study, mud crabs and their fishery have benefited from Sanctuary Zone protection; however, other species may not react in the same way. Long-term multi-species monitoring systems may resolve this problem in demonstrating the broad-scale effectiveness of marine park zoning.

ACKNOWLEDGMENTS

Paul Butcher's Ph.D. project was supported financially by the University of New England and the NSW Marine Parks Authority. Special thanks to Dr Stuart Rowland (NSW Fisheries) who has supplied large quantities of bait and given guidance. We also thank Libby Sterling, Hamish Malcolm and the staff at the Solitary Islands Marine Park Authority and NSW Fisheries for getting the project off the ground and maintaining compliance at the zones. Thanks also to the many volunteers who provided field support and assistance, and the recreational fishers who returned tags.

REFERENCES

Agardy, T S (1997). *Marine protected areas and ocean conservation.* Academic Press, California.

Analytical Software (1996). *Statistix for windows.* Analytical Software, Tallahassee.

Arriola, F J (1940). A preliminary study of the life history of *Scylla serrata* (Forskal). *Philipp.J.Sci.* **73,** 437-454.

Childress, M J (1997). Marine reserves and their effects on lobster populations: report from a workshop. *Aust.J.Mar.Freshw.Res.* **48,** 1111-1114.

Cole, R G, Ayling, T M, and Creese, R G (1990). Effects of marine reserve protection at Goat Island, northern New Zealand. *N.Z.J.Mar.Freshw.Res.* **24,** 197-210.

Davenport, J, and Wong, T M (1987). Responses of adult mud crabs (*Scylla serrata*) Forskal to salinity and low oxygen tension. *Compar.Biochem.Physiol.* **86**(1), 43-47.

Heasman, M P (1980). Aspects of the general biology and fishery of the mud crab (*Scylla serrata*) (Forskal) in Moreton Bay, Queensland. *Ph.D. thesis, University of Queensland.*

Hill, B J (1975) Abundance, breeding and growth of the crab *Scylla serrata* in two South African estuaries. *Mar.Biol.* **32,** 119-126.

Hill, B J (1979). Aspects of the feeding strategy of the predatory crab *Scylla serrata. Mar.Biol.* **55,** 209-214.

Hill, B J, Williams, M J, and Dutton, P (1982). Distribution of juvenile, subadult and adult *Scylla serrata* (Crustacea: Portunidae) on tidal flats in Australia. *Mar.Biol.* **69,** 117-120.

Hyland, S J, Hill, B J, and Lee, C P (1984). Movement within and between different habitats by the portunid crab *Scylla serrata. Mar.Biol.* **80,** 57-61.

Marine Parks Authority (2002). *Overview of the zoning plan, Solitary Islands Marine Park, April 2002.* Marine Parks Authority, Coffs Harbour.

Roberts, C M (1994). Rapid build-up of fish biomass in a Caribbean Marine Reserve. *Conser.Biol.* **9**(4), 815-826.

Roy, P S, Williams, R J, Jones, A R, Yassini, I, Gibbs, P J, Coates, B, West, R J, Scanes, P R, Hudson, J P, and Nichol, S (2001) Structure and function of south-east Australian estuaries. *Est.Coast. Shelf Sci.* **53**, 351–384.

Russell, M (1996). *Fishing: the effects on the Great Barrier* Reef', Reef Research. http://www.gbrmpa.gov.au/informat/research/issue4_96/4fishing.html.

Stone, A (1999). *Wooli River floodplain management plan.* Patterson Britton & Partners, Sydney.

Wahle, R A (1997). Consequences of fishing, with regard to lobster fisheries: report from a workshop. *Aust.J.Mar.Freshw.Res.* **48,** 1115-1119.

Williams, M J, and Hill, B J (1982). Factors influencing pot catches and population estimates of the portunid crab *Scylla serrata. Mar.Biol.* **71,** 187-192.

Appendix 7 - Journal article

Butcher, P. 2001, 'The benefits of marine park zones to mud crabs in the Wooli River, NSW', *in: Fisheries New South Wales - The Journal of Sustainable Fishing*, (eds) D. Smith, NSW Fisheries, **4**(1) page 9.

Guest

THE BENEFITS OF MARINE PARK ZONES TO MUD CRABS IN THE WOOLI RIVER

Paul Butcher - Natural Resources Ph.D student, University of New England, Armidale.

Marine Parks have been declared to conserve marine biodiversity and marine habitats, while providing for ecologically sutainable use. Marine parks are zoned for multiple use with four zones ranging from the Sanctuary Zone which provides the highest protection (no take) to the General Use Zone, which provides for a range of commercial and recreational activities including fishing.

The Wooli River is situated on the NSW north coast. In 1991 the river became part of the Solitary Islands Marine Reserve which became a Marine Park in 1998. The Wooli River has two types of marine park zones, providing for a variety of uses. The Sanctuary Zone has excluded fishing since 1991 while the Recreation Zone is popular with recreational fishers.

To determine the effectiveness of these zoning schemes within the Solitary Islands Marine Park, mud crab (*Scylla serrata*) populations were assessed in the different zones in the Wooli River.

The principal aim of this study was to determine the effectiveness of the zones over time and on a habitat basis. This was achieved by evaluating variations in abundance, size class, movement and gender ratio both within and between fished and un-fished zones and between shallow mangrove and deep channel habitat types within zones.

Mud crab populations were sampled monthly in each zone from December 1998 to August 2000 using commercial wire traps. Each mud crab captured was tagged with anchor t-tags and released.

The results highlighted the benefits of excluding fishing from areas. The Sanctuary Zone acted as a refuge showing significantly higher abundances of mud crabs than the Recreation Zone. However, population size did not differ between habitats within the Sanctuary Zone.

Sub adults (100-150 mm carapace width) dominated the study sites. The

Mud crab in Wooli River area

average carapace length in the Sanctuary Zone was significantly higher (94 mm) than in the Recreation Zone (87 mm), probably due to selective harvesting of larger crabs by fishers within the Recreation Zone.

There were more males in the river than females, which may be a result of the aggressive feeding behavior of crabs, and the consequent exclusion of females from entering traps.

The highest recruitment into the Recreation Zone occurred during flooding, possibly due to mud crabs moving downstream with the fresh water.

Temperature affected monthly captures and the composition of the catch, with higher abundances and larger crabs occurring during the warmer months.

These results suggest that the Solitary Islands Marine Park zoning structure in the Wooli River has been an effective management tool in protecting mud crab populations and has the potential to do the same in other estuaries. There are benefits to recreational fishers as crabs in the protected zone recruit to the recreational zone.

Further management

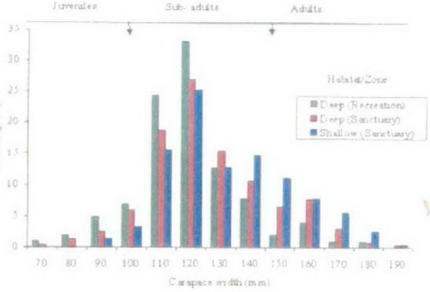
On the basis of research results,there are a number of issues which require further investigation including:

1) a review of the current zone scheme in this area,
2) rehabilitation and protection of mangrove habitats, essential to the growth of juveniles and
3) further research into the protection of female mud crabs.

This study will be continued in the Sandon, Wooli and Red Rock Rivers as part of a Ph.D. over the next three to six years and aims to identify changes in population structure when zones are changed and to identify recruitment into these estuaries.

Paul Butcher,
Ecosystem Management,
University of New England,
Armidale, 2351.
ph -(02) 67731622,
fax -0267732769
e-mail- pbutcher@metz.une.edu.au

Size class distribution



Appendix 8 - Miscellaneous results

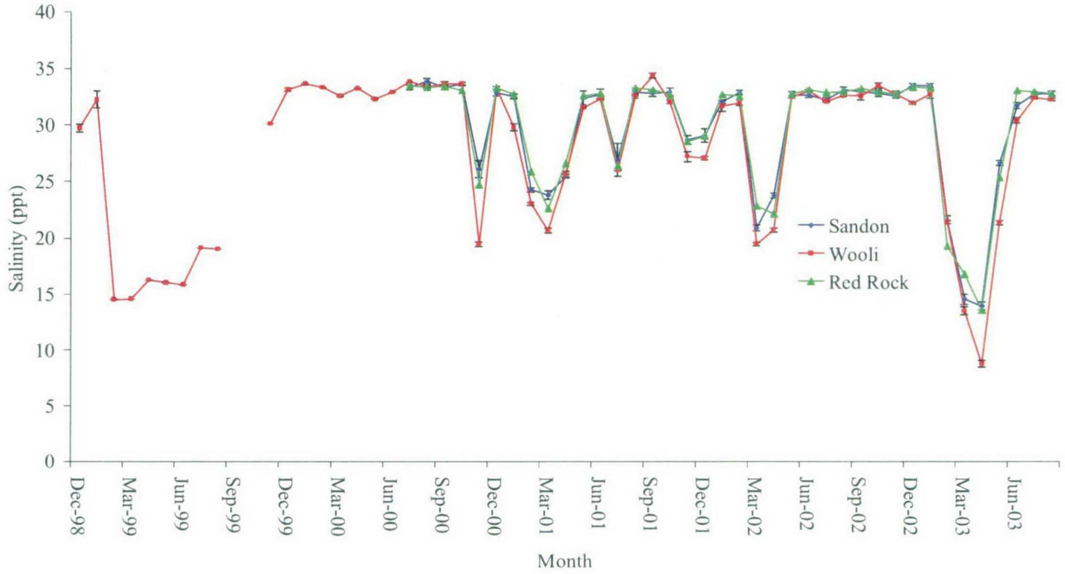


Figure A5. Variation in mean monthly salinity concentrations (± SE) taken at 80% water depth in the Sandon, Wooli and Corindi Estuaries.

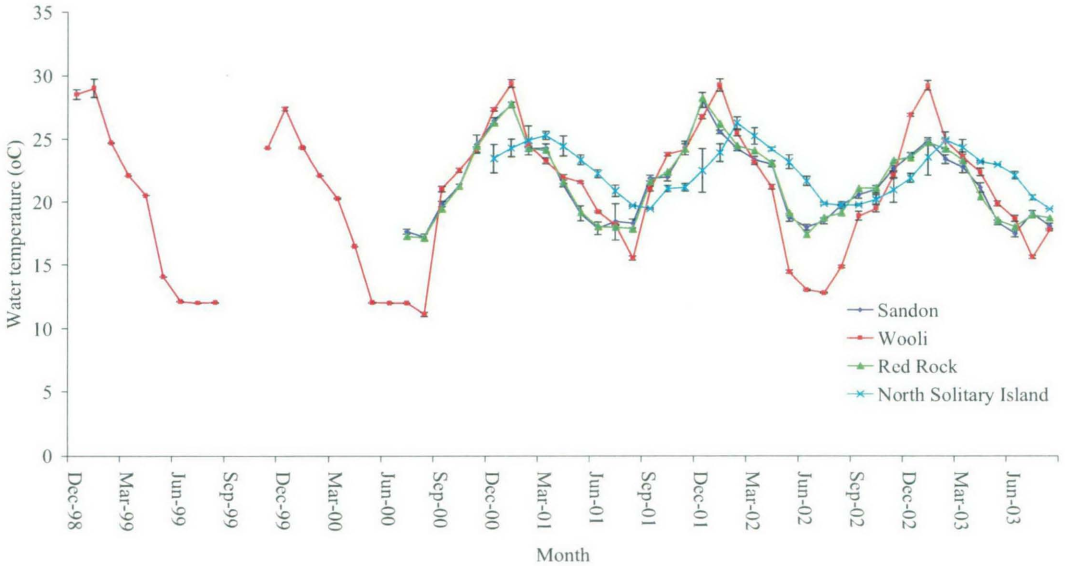


Figure A6. Variation in mean monthly water temperatures (± SE) taken at 80% water depth in the Sandon, Wooli and Corindi estuaries and sea temperature reference site taken from NSW MPA data loggers at North Solitary Island (12 km offshore from the mainland off Wooli).

Bycatch/product

Bycatch/product consisted of Blue Swimmer Crabs (*Portunus pelagicus*) and bottom dwelling fish such as Flathead (*Platycephalus fucus*), Bream (*Acanthopagrus australi*), Estuary Cod (*Epinephelus* species), Luderick (*Girella tricusspidata*), and leatherjacket (*Meuschenia spp.*)

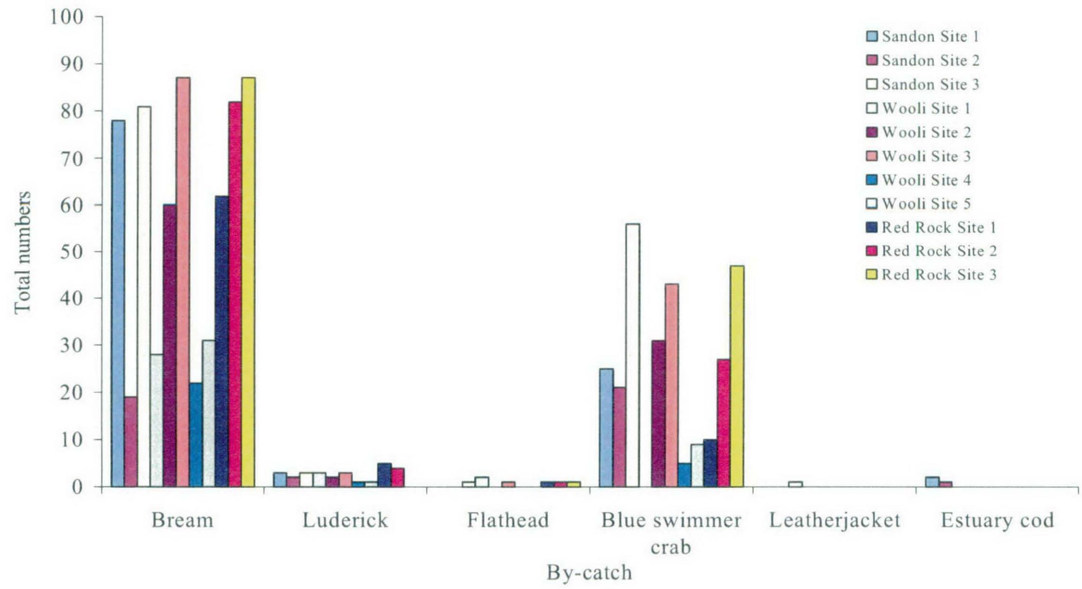


Figure A7. The total number of by-catch/product caught at each site between December 1998 (Wooli) and July 2000 (Sandon and Corindi) to August 2003.

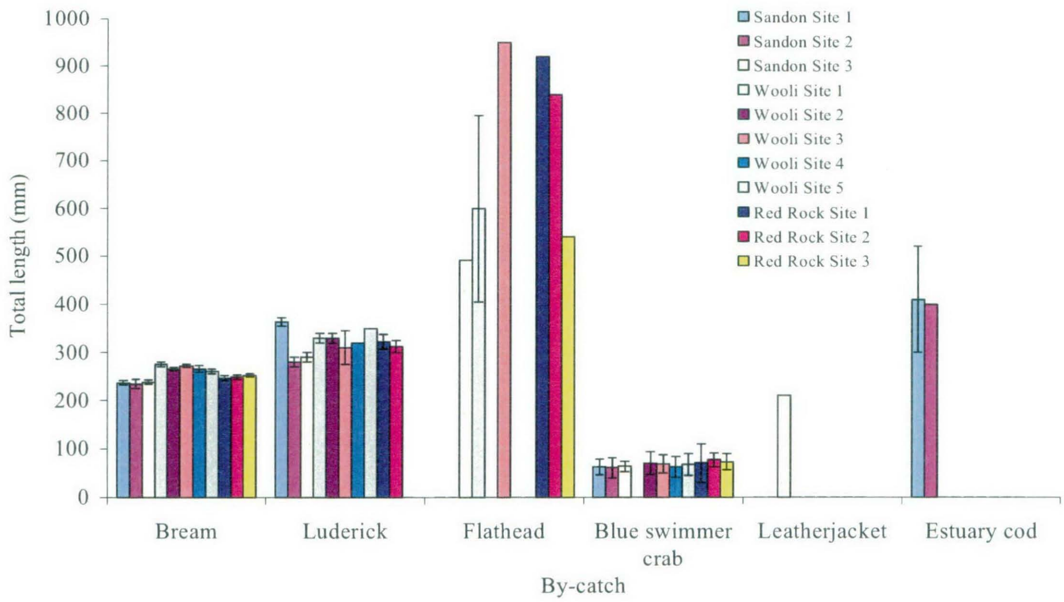


Figure A8. The mean (±SE) length of by-catch/product caught at each site in each estuary between December 1998 (Wooli) and July 2000 (Sandon and Corindi) to August 2003.