

- Pollock, B.R. (1985) The reproductive cycle of yellowfin bream, *Acanthopagrus australis* (Günther), with particular reference to protandrous sex inversion. *J. Fish Biol.* **26**: 301-311.
- Robinson, K.I.M., Gibbs, P.J., Barclay, J.B. and May, J.L. (1983) Estuarine flora and fauna of Smith's Lake, New South Wales. *Proc. Linn. Soc. N.S.W.* **107**: 19-34.
- State Pollution Control Commission (SPCC) (1981) *The ecology of fish in Botany Bay. Report BBS 23B. Environmental control study of Botany Bay.* Sydney, Australia. 78 pp.
- Warburton, K. and Blaber S.J.M. (1992) Patterns of recruitment and resource use in a shallow-water fish assemblage in Moreton Bay, Queensland. *Mar. Ecol. Prog. Ser.* **90**: 113-1276.
- West, R.J. (1993) *Northern Rivers Report. Part A: Estuarine Fisheries Resources.* NSW Fisheries Research Institute Internal Report. Fisheries Research Institute: Cronulla.

NEW SOUTH WALES COASTAL AQUATIC ESTATE

R. J. WILLIAMS, F. A. WATFORD, M. A. TAYLOR & M. L. BUTTON
 Fisheries Research Institute
 Cronulla, NSW 2230, Australia

ABSTRACT

There is a need to recognise and understand better the habitat and wildlife values of the waterbodies within the coastal zone of New South Wales. To assist in achieving this objective, 1: 25 000 topographic maps were used to find and count all bodies of water, irrespective of size, discharging to that part of the Tasman sea offshore of NSW. Over 950 waterbodies were found, with most being small, ephemeral streams. We collectively denote these waterbodies as the NSW "Coastal Aquatic Estate".

Key words: *Coastal Aquatic Estate, coastal waterbasins, coastal waterbodies, Great Dividing Range, Tasman Sea*

INTRODUCTION

There have been occasional attempts to describe facets of the whole of the New South Wales coastal zone. Goodrick (1970) was probably the first with his analysis of changes in the area of different types of wetland present at the time of colonial settlement and 1969. Descriptions of the major coastal drainages were provided within 28 volumes published by the then Water Conservation and Irrigation Commission (1966-1974). Other broad overviews include Quint and Edward's (1983) survey of coastal headlands, Roy's (1984) classification/evolutionary scheme for the three principal types of estuaries, the Coastal Council's (1985) identification of individual wetlands within State Environmental Planning Policy 14, Adam *et al.*'s (1988) summary of the phytosociology of saltmarsh and Short's (1993) description of beaches. The Estuary Management Manual (Anon. 1992) set out a structure within which data needs could be identified; the State Rivers and Estuaries Policy (Anon. 1993) sought to provide a coherent legislative and policy framework for management and reporting on the condition of the coastal (and fresh) waters of NSW. More recently, the likely extent

of acid sulfate soils has been mapped (Atkinson *et al.* 1996).

Other works dealing with the whole of the coast include Bell and Edwards' (1980) list and description of the condition of 137 waterbodies, and West *et al.*'s (1985) inventory showing the distribution of saltmarsh, mangrove and seagrass in 132 estuaries. Many of the estuaries identified in these two studies are well known because of their size, presence of urban centres or tourist facilities. However, many smaller waterbodies are known only at the regional level, e.g., to landowners, council officers, commercial and recreational fishers and 4WD enthusiasts. Unfortunately, the ecological functions of these small waterbodies are little understood. For example, it is well known that the waters of the NSW coast are nutrient poor (Rochford 1984), but during wet weather the discharge of nitrogen and phosphorus from the small waterbodies must augment the nutrient pool, particularly adjacent to urban areas. Likewise, their role in maintaining biodiversity for plant, fish, amphibian and other biotic communities is little understood.

In light of increasing population pressure, the optimal management of the coastal zone requires decision makers and the general public be aware of the whole of the coastal aquatic estate. To our knowledge no comprehensive list of the coastal waterbodies of NSW has ever been published.

STUDY SITE

There are four drainage divisions in NSW (NSW Water Resources, undated); one of these (Drainage Division Number 2) encompasses the area east of the Great Dividing Range. Within this drainage division there are 22 drainage basins (Figure 1). Twenty of the 22 basins drain to the Tasman Sea through NSW while the remaining two (on the far south coast, Nos.

221 and 222) discharge through Victoria. The NSW drainage basins generally focus on one major river (Table 1), but there are exceptions to this rule. Four basins contain two large waterbodies: Waterbasin 205 contains the Bellinger and Nambucca Rivers, Waterbasin 211 has Lake Macquarie and the Tuggerah Lakes, Waterbasin 213 has the Parramatta and Georges Rivers, Waterbasin 216 contains the Clyde River and Jervis Bay. One basin (214) has no major waterbody at all. The basins vary considerably in size, with the three largest being near equivalent in area: Clarence River (22660 km²), Hunter River (22020 km²) and the Hawkesbury River (21730 km²). The smallest basins are the Wollongong Coast (751 km²) and the Brunswick River (492 km²).

Unfortunately, the drainage basins as originally defined do not adequately cater for current management requirements. To deal with this problem, the basin boundaries were refined to create Catchment Management Units (Table 1) (EPA 1996). Some of these management units split basins into catchments, e.g., Waterbasin 205 - Bellinger River, whereas others in the metropolitan region, e.g., Waterbasin 213 - Sydney Coast/Georges River, split basins into subcatchments.

METHODS

In the course of a study (Williams and Watford 1996, Williams and Watford 1997) to examine barriers to tidal flow and identify sites where estuarine rehabilitation projects could be initiated, we previewed three scales of topographic map produced by the Land Information Centre (LIC, previously the Central Mapping Authority): 1: 25 000, 1: 10 000 and 1: 4 000. Maps at the two finer scales have 2m contour intervals that adequately define the coastal floodplains, but are available for relatively small portions of the coast (Land Information Centre 1993). The 1: 25 000 scale maps provide complete coverage of the coast, requiring 148 maps; the most current maps of this scale were obtained. Each waterbody draining to, or in close proximity to, the Tasman Sea, irrespective of size was listed and counted. Even the smallest of creeks, shown by a thin blue line on the maps, and presumed to flow

only during wet weather, were counted. Some of the blue lines occasionally disappeared adjacent to urban centres, implying that parts of the natural channel had been contained within a pipe or culvert. To check on the names and locations of some waterbodies we also used the maps produced by the then Forestry Commission of New South Wales (various dates).

Large and medium size waterbodies were readily assigned to their respective basins (Table 1). It was less easy to assign some of the smaller waterbodies, particularly those near the basin margins. The scale at which the basin boundaries were originally mapped (NSW Water Resources, undated) was so coarse as to require an estimate as to which of the two adjacent basins held the small waterbody. We did not assess drainages on the islands of NSW, e.g., Lord Howe Island or Montague Island. The net result is a first assignment of all waterbodies to the east coast drainage basins of NSW.

RESULTS

Examination of the 1: 25 000 topographic maps showed 952 coastal waterbodies connected to, or in close proximity to, the Tasman Sea. The full list of waterbodies is shown in Appendix 1.

Those waterbodies not directly connected to the sea were four perched, freshwater lakes. Of the remainder, 70 are large enough to appear to be permanently open to the sea. In contrast, 878 are small, intermittent streams, and of these the vast majority (691) are unnamed on the maps. During field inspections to locate the tidal barriers (Williams and Watford 1996, Williams and Watford 1997), many of the waterbodies unnamed on the topographic maps were identified by sign posts with local names.

The distribution of waterbodies within each drainage basin is shown in Table 2. The minimum number of waterbodies per basin was one, that being the Tweed River in Basin 201; whereas the maximum number of waterbodies was 193 in Basin 216. Seven basins have 20 or fewer waterbodies, and two basins have more than 100. There is a tendency for the

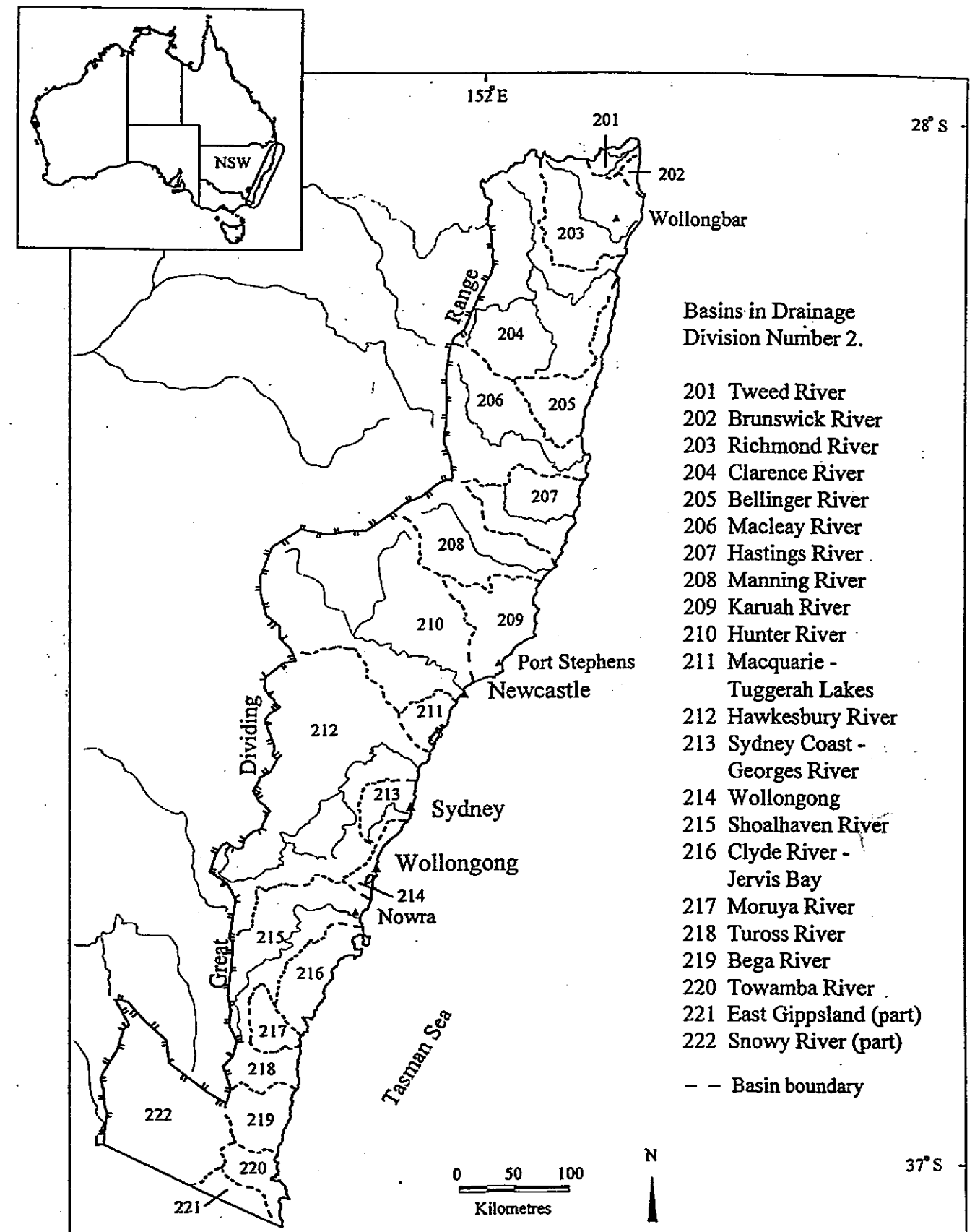


Figure 1. NSW coastal water basins, redrawn from NSW Water Resources (undated)

Table 1. Comparison of NSW Waterbasins and Catchment Management Units draining to the Tasman Sea. Details on waterbasin size and river length from Hill and Harris (1991). Longest river is identified by its basin name unless indicated by superscript. Catchment Management Units from EPA (1996).

Drainage Basin Number	NSW Water Basin Name	Catchment Area (km ²)	Length of Longest River (km)	Catchment Management Unit
201	Tweed River	1110	80	Tweed
202	Brunswick River	492	23	Brunswick
203	Richmond River	6940	80	Richmond
204	Clarence River	22660	394	Clarence
205	Bellinger River	3440	115	Bellinger
			-	Part of Clarence
			-	Nambucca
206	Macleay River	11450	400	Macleay
207	Hastings River	4530	100	Hastings/Camden Haven
208	Manning River	8420	250	Manning
209	Karuah River	4480	90	Karuah/Great Lakes
210	Hunter River	22020	467	Hunter
211	Macquarie-Tuggerah Lakes	1630	45 ¹	Lake Macquarie
			-	Tuggerah Lakes
212	Hawkesbury River	21730	472	Hawkesbury-Neapean
			-	Brisbane Water
			-	Blue Mountains
			-	Coxs River
			-	Wollondilly
213	Sydney Coast-Georges River	1890	75 ²	Sydney Northern Beaches
			-	Middle Harbour
			-	Lane Cove River
			-	Upper Parramatta
			-	Strathfield
			-	Cooks River
			-	Georges River
214	Wollongong Coast	751	18 ³	Hacking
			-	Illawarra
215	Shoalhaven River	7300	332	Upper Shoalhaven
			-	Part of Lower Shoalhaven
216	Clyde River-Jervis Bay	3260	12 ⁴	Part of Lower Shoalhaven
			-	Part of Lower South Coast
217	Moruya River	1550	95	Part of Lower South Coast
218	Tuross River	2180	100	Part of Lower South Coast
219	Bega River	2850	70	Part of Far South Coast
220	Towamba River	2200	90	Part of Far South Coast
Total		130883		

Longest rivers: ¹ Wyong River, ² Georges River, ³ Hacking River, ⁴ Clyde River

highest number of waterbodies per basin to occur on the south coast: 90 in Basin 214, 193 in Basin 216, 92 in Basin 219, 141 in Basin 220. One hundred and forty five of the waterbodies in Basin 216 and 120 of the waterbodies in Basin 220 were unnamed.

DISCUSSION

For comparative purposes, the 130 or so waterbodies identified by Bell and Edwards (1980) and West *et al.* (1985) have been assigned to their respective basins (Table 3). Due to time and other resource constraints, these studies focused on the large, well recognised waterways. Unfortunately, some users might assume that there are no other waterbodies of significance. It is premature and inappropriate to draw this conclusion, and even if it were to be sustained for any one waterbody over any defined interval of time, the long term function, particularly in terms of nutrient contribution to offshore waters, cannot be discounted.

Boundaries for the major waterbasins of NSW were defined over 30 years ago in a series of volumes published by the then NSW Water Conservation and Irrigation Commission (1966-1974). Subsequently, the basin boundaries were mapped for the whole of the state (NSW Water Resources, undated). The method by which the prototype basin boundaries were drawn is not known to us, but we assume they were constructed from contours and other features presented on 1: 100 000 or 1: 25 000 maps, two common scales in use when the volumes about individual water basins were produced. Both of these scales are adequate to locate large and medium size waterbodies, but present difficulties in assigning the ephemeral streams at the edges of the basins. This in turn implies that catchment managers may be unaware of all waterbodies for which they are responsible, and so concentrate on the larger systems.

While we obtained the most recently available 1: 25 000 topographic maps, some of them were produced at least 25 years ago and are probably in need of updating (Appendix 2). It should be noted that over time a number of small creeks,

particularly in urban areas, have been subsumed within stormwater drains and so are uncountable. The actual number of waterbodies present on the NSW coast may never be known.

A more accurate inventory of coastal waterbodies may require the editing of old maps or the creation of new ones, some of which will be in electronic form (Eamonn Clifford, pers. comm., 1997). Ideally, the next generation of maps should define the sub-basins, at least for the larger tributaries.

The NSW coastal zone is recognised as a dynamic zone, fulfilling many needs and changing quickly in its human demographics and infrastructure. Furthermore, the geomorphology of the zone may be about to change due to global warming and sea level rise. It is also recognised as a fragile, damaged environment and calls have been made for rehabilitation (e.g., Hancock 1993). Some of these calls have been answered (Streever 1997).

In spite of this preliminary list, there remains a need to identify *all* of the waterbodies within the NSW coastal zone, to have an understanding of their general functions, and to provide for regular updates on the status of each. In this way the smaller waterbodies will become better known by the general public. Collectively, the sum of the small and the large waterbodies could be considered the NSW "Coastal Aquatic Estate". In conjunction with previous efforts which have documented coastal headlands (Quint and Edwards 1982) and beaches (Short 1993), this inventory of waterbodies will assist in the better management of the coastal zone of NSW.

ACKNOWLEDGEMENTS

Eamonn Clifford of the Land Information Centre is thanked for advice on the status and future of mapping in NSW; Paul Adam, Philip Gibbs and Bill Streever are thanked for their comments, as are the two anonymous reviewers.

Table 2. Summary of named and unnamed waterbodies by drainage basin.

Drainage Basin Number	NSW Water Basin Name	Number of Waterways					
		Freshwater (Perched)	Estuarine				Total
			Open	Intermittently Open			
				Named	Unnamed	Subtotal	
201	Tweed River	0	1	0	0	0	1
202	Brunswick River	0	4	2	6	8	12
203	Richmond River	0	2	4	35	39	41
204	Clarence River	0	2	0	4	4	6
205	Bellinger River	2	9	16	37	53	64
206	Macleay River	0	3	3	29	32	35
207	Hastings River	0	2	8	19	27	29
208	Manning River	0	1	3	0	3	4
209	Karuah River	0	2	2	42	44	46
210	Hunter River	0	1	2	4	6	7
211	Macquarie-Tuggerah Lakes	0	1	6	48	54	55
212	Hawkesbury River	0	3	9	22	31	34
213	Sydney Coast- Georges River	0	10	6	18	24	34
214	Wollongong Coast	1	3	45	41	86	90
215	Shoalhaven River	0	2	3	9	12	14
216	Clyde River-Jervis Bay	0	11	37	145	182	193
217	Moruya River	0	1	2	3	5	6
218	Tuross River	0	2	14	32	46	48
219	Bega River	1	4	10	77	87	92
220	Towamba River	0	6	15	120	135	141
Total		4	70	187	691	878	952

Table 3. Distribution of waterbodies in the waterbasins of Drainage Division No. 2 (NSW Water Resources, undated). Number of waterbodies named on 1: 25 000 topographic maps shown and compared with two previous studies.

Number	Water Basin Name	This study			Bell & Edwards (1980)	West <i>et al.</i> (1985)
		Named	Unnamed	Total		
201	Tweed River	1	0	1	2 (1)	1
202	Brunswick River	6	6	12	6 (2)	6
203	Richmond River	6	35	41	7 (3)	3
204	Clarence River	2	4	6	4 (4)	2
205	Bellinger River	27	37	64	20 (5)	17
206	Macleay River	6	29	35	2 (6)	4
207	Hastings River	10	19	29	7 (7)	4
208	Manning River	4	0	4	1	1
209	Karuah River	4	42	46	6 (8)	7 (12)
210	Hunter River	3	4	7	1 (9)	1
211	Macquarie-Tuggerah Lakes	7	48	55	3 (10)	2
212	Hawkesbury River	12	22	34	7	7
213	Sydney Coast-Georges River	16	18	34	8 (11)	7 (13)
214	Wollongong	49	41	90	6	7
215	Shoalhaven River	5	9	14	2	3
216	Clyde River-Jervis Bay	48	145	193	17	22 (14)
217	Moruya River	3	3	6	2	3
218	Tuross River	16	32	48	11	10
219	Bega River	15	77	92	13	13
220	Towamba River	21	120	141	12	12 (15)
Total		261	691	952	137	132

N.B. We defined waterbodies as having a single connection to the Tasman Sea. In some cases the counts of Bell and Edwards (1980) and West *et al.* (1985) include tributaries to the main arm of the river, or the bay into which the river empties; the presence of these branches is noted in the brackets above and listed below.

- 1 includes Terranora Broadwater
- 2 includes Cudgen Lake
- 3 includes North Creek, Wilsons River and Bungawalbin Creek
- 4 includes Esk River
- 5 includes Warrell Creek
- 6 includes Macleay Arm
- 7 includes Limeburners Creek and Maria River
- 8 includes Queens Lake
- 9 includes Myall Lakes, lower Myall River
- 10 includes Lake Munmorah
- 11 includes Middle Harbour
- 12 includes Myall Lakes, Myall River and Port Stephens
- 13 includes Botany Bay
- 14 includes Batemans Bay
- 15 includes Twofold Bay

REFERENCES

- Adam, P., N.C. Wilson and B. Huntley. 1988. The phytosociology of coastal saltmarsh vegetation in New South Wales. *Wetlands (Australia)* 7: 35-85.
- Anon. 1992. *Estuary Management Manual*. New South Wales Government report. 198 pp.
- Anon. 1993. *The NSW State Rivers and Estuaries Policy*. New South Wales Government report. 40 pp.
- Atkinson, G., S.D. Naylor, T.C. Flewin, G.A. Chapman, C.L. Murphy, M.J. Tulau, H.B. Milford and D.T. Morand. 1996. DLWC acid sulfate soil risk mapping. In "Proceedings 2nd National Conference of Acid Sulfate Soils" held at Coffs Harbour 5-6 September 1996. Robert J. Smith and Associates and ASSMAC, Australia. pp. 21-26.
- Bell, F. C. and A. R. Edwards. 1980. *An environmental inventory of estuaries and coastal lagoons in New South Wales*. Total Environment Centre, Sydney. 187 pp.
- Coastal Council of New South Wales. 1985. *Coastal Wetlands of New South Wales. A survey and report prepared for the Coastal Council of New South Wales*. NSW Department of Planning and Environment, Sydney. 125 pp.
- Forestry Commission of New South Wales. Various dates between 1983 and 1992. Nine forestry maps of the NSW coast, scale 1: 125 000. Sydney, NSW.
- Goodrick, G. N. 1970. *A Survey Of Wetlands Of Coastal New South Wales*. Technical Memorandum No. 5, September 1970. CSIRO Division of Wildlife Research, Canberra. 36 pp. plus plates and Cartographic Survey.
- Hancock, D.A. (ed.). 1993. Sustainable fisheries through sustaining fish habitat. Australian Society for Fish Biology Workshop, Victor Harbor, SA, 12-13 August 1992. *Bureau of Resource Sciences Proceedings*, AGPS, Canberra. 234 pp.
- Hill, L. and M. Harris. 1991. *Water Facts*. NSW Water Resources Council, Parramatta NSW.
- Land Information Centre. 1993. NSW Catalogue 1993, large scale mapping; 1: 2 000, 1: 4 000, 1: 10 000. Bathurst, NSW.
- Land Information Centre. various dates. 148 topographic maps of NSW, scale 1: 25 000. Bathurst, NSW.
- NSW Water Conservation and Irrigation Commission. 1966-1974. *Survey of Thirty Two N.S.W. River Valleys*. Vols. 1-28.
- NSW Water Resources. undated. *PINNEENA - New South Wales River Basin maps*. 37 pp.
- Quint, G. and O. Edwards. 1982. *Coastal Headlands Survey*, Parts 1-5. Published reports of the National Trust of Australia, Sydney.
- Rochford, D.J. 1984. Nitrates in Eastern Australian coastal waters. *Australian Journal of Marine and Freshwater Research*. 35: 385-397.
- Roy, P. S. 1984. New South Wales estuaries: Their origin and evolution. in Thom, B. G. (ed.) *Coastal Geomorphology in Australia*. Academic Press, Sydney. pp. 99-121.
- Short, A.D. 1993. *Beaches of the New South Wales Coast, A Guide to Their Nature, Characteristics, Surf and Safety*. Australian Beach Safety and Management Program. 358 pp.
- Streever, W. J. 1997. Trends in Australian wetland rehabilitation. *Wetlands Ecology and Management* 5: 5-18.
- West, R. J., C. A. Thorogood, T. R. Walford and R. J. Williams. 1985. *An Estuarine Inventory for New South Wales, Australia*. Fisheries Bulletin 2, Department of Agriculture New South Wales. 140 pp.
- Williams, R. J. and Watford, F.A. 1996. An inventory of impediments to tidal

- flow in NSW estuarine fisheries habitat. *Wetlands (Australia)* 15: 44-54.
- Williams, R. J. and Watford, F.A. 1997. Identification of structures restricting tidal flow in New South Wales, Australia. *Wetlands Ecology and Management* 5: 87-97.