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The definitive version is available at

<http://dx.doi.org/10.1016/j.envsci.2016.07.013>

Hallett, C.S., Valesini, F., Scanes, P., Crawford, C., Gillanders, B.M., Pope, A., Udy, J., Fortune, J., Townsend, S., Barton, J., Ye, Q., Ross, D.J., Martin, K., Glasby, T. and Maxwell, P. (2016) A review of Australian approaches for monitoring, assessing and reporting estuarine condition: II. State and Territory programs. Environmental Science & Policy, 66 . pp. 270-281.

<http://researchrepository.murdoch.edu.au/32476/>



1 **A review of Australian approaches for monitoring, assessing and reporting estuarine**
2 **condition: II. State and Territory programs**

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5 4 C.S. Hallett ^{a, *}, F.J. Valesini ^a, P. Scanes ^b, C. Crawford ^c, B.M. Gillanders ^d, A. Pope ^e, J.
6 5 Udy ^f, J. Fortune ^g, S. Townsend ^g, J. Barton ^e, Q. Ye ^h, J. Ross ^c, K. Martin ⁱ, T. Glasby ^j, P.
7 6 Maxwell ^f

8 ^a Centre for Fish and Fisheries Research, School of Veterinary and Life Sciences, Murdoch
9 University, South Street, Murdoch, Western Australia, Australia

10 ^b Estuaries and Catchments Science Unit, Office of Environment and Heritage, Sydney, New
11 South Wales, Australia

12 ^c IMAS Fisheries and Aquaculture Centre, University of Tasmania, Hobart, Tasmania,
13 Australia

14 ^d Southern Seas Ecology Laboratories, School of Biological Sciences & Environment
15 Institute, University of Adelaide, South Australia, Australia

16 ^e School of Life and Environmental Sciences, Deakin University, Warrnambool, Victoria,
17 Australia

18 ^f Healthy Waterways, Brisbane, Queensland, Australia

19 ^g Aquatic Health Unit, Department of Land Resource Management, Palmerston, Northern
20 Territory, Australia

21 ^h Inland Waters and Catchment Ecology, South Australian Research and Development
22 Institute, South Australia, Australia

23 ⁱ Great Barrier Reef Marine Park Authority, Townsville, Queensland, Australia

24 ^j Port Stephens Fisheries Institute, Department of Primary Industries, Port Stephens, New
25 South Wales, Australia

26
27 * Corresponding author. Email: c.hallett@murdoch.edu.au Telephone: +61 8 9239 8808
28

29 **Abstract**

30 In contrast to Europe, the USA and South Africa, Australia has no specific, overarching
31 federal legislation to underpin a nationally-coordinated framework for monitoring, assessing
32 and reporting estuarine condition. This has resulted in a complex mosaic of diverse
33 approaches and governance structures, hindering the ability to make inter-State comparisons.
34 In this second part of a comprehensive three-part review, we present a systematic appraisal of
35 current and impending approaches for measuring and reporting estuarine condition in each of
36 Australia's States and Territories. A concise summary is provided in each case, supported by
37 extensive appendices containing detailed accounts of relevant monitoring and reporting
38 programs. We synthesise and evaluate this output at the State/Territory level, highlighting
39 areas of improvement and major gaps.

40
41 **Keywords** Estuary, ecological status, health, monitoring, management, reporting
42

43 **1. Introduction**

1
2 44 Consideration and management of water resources across the USA and Europe have changed
3
4 45 fundamentally in recent decades following the respective implementation of the Clean Water
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6 46 Act and the Water Framework Directive (WFD). These pieces of legislation have
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8 47 necessitated innovation, refinement and consolidation of the practices and tools that are used
9
10 48 to assess and report the condition of aquatic ecosystems, including estuaries (Gibson et al.,
11
12 49 2000; Hering et al., 2010; Birk et al., 2012). Most importantly, and despite their many
13
14 50 criticisms (Moss, 2008; Hering et al., 2010; Adler, 2013), both the Clean Water Act and the
15
16 51 WFD aim to manage water resources in a more holistic, ecologically relevant and
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18 52 environmentally sustainable manner (Hering et al., 2010; Adler, 2013), requiring greater
19
20 53 coordination of activities and approaches across large spatial scales.

21
22 54 Recently, several initiatives have been proposed to better integrate estuarine
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24 55 monitoring, assessment and reporting programs across Australia under a common and more
25
26 56 holistic framework. These are outlined in Part I of this three-part review (Hallett et al.,
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28 57 submitted I). However, and in contrast to the situation in Europe and the USA, Australia has
29
30 58 no specific federal legislation to mandate and thus underpin such a framework. Responsibility
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32 59 for environmental management in Australia lies primarily with the States, creating disparities
33
34 60 across the nation in the policies, legislation, governance and approaches for monitoring and
35
36 61 reporting the ecosystem health of estuaries (Smith et al., 2001; Borja et al., 2008, 2012;
37
38 62 Hallett et al., submitted I).

39
40 63 Previous reviews of Australian approaches for monitoring, assessing and reporting
41
42 64 estuarine condition have largely been limited to specific ecosystem components, particular
43
44 65 regions or States, or have considered only a small number of high-profile programs (e.g.
45
46 66 Barton, 2003; Hirst, 2008; Borja et al., 2012). We aim to address this gap through a timely
47
48 67 and comprehensive review, focussing in this second part on a systematic description of
49
50 68 current and impending approaches in each of Australia's States and Territories. We then
51
52 69 synthesise and evaluate this output against characteristics of international best practice
53
54 70 (Hallett et al., submitted I), highlighting major strengths and weaknesses within each State.
55
56 71 Appendices A–G (supplementary material) provide detailed descriptions of the elements,
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58 72 procedures, thresholds and reporting employed under each of the programs considered in the
59
60 73 following text, with extensive referencing of source material.
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58 75 **2. Queensland**

76 South-East Queensland (SEQ; Fig. 1), from the NSW border north to Noosa, has the most
77 intensive water quality monitoring program in Queensland. This monitoring has been
78 synthesised and publicly reported through an annual report card, monthly updates, annual
79 technical reports and various web pages for the past 15 years under the Healthy Waterways
80 Partnership (www.healthywaterways.org). Prior to 1999 and the establishment of the Healthy
81 Waterways Ecosystem Health Monitoring Program (EHMP) in SEQ, much of the monitoring
82 and reporting effort in Queensland was local and intermittent, with limited processes for
83 synthesising or disseminating outputs.

84 The first step towards a more comprehensive and cohesive monitoring program began
85 in the State capital, Brisbane, in 1997 with the design and implementation of a baseline
86 monitoring program (Dennison and Task DIBM Team, 1999), which grew over several years
87 from a focus on Moreton Bay and its adjoining estuaries to a regional monitoring program
88 that assessed 'ecosystem health' at ~260 estuarine and marine sites throughout SEQ. The
89 EHMP has released annual report cards since 2000, establishing an expectation among
90 community and political leaders for the annual snapshots of waterway health. The
91 independent status of the Healthy Waterways Partnership has facilitated the continuation of
92 the EHMP and annual production of report cards, despite significant political and institutional
93 changes during this period.

94 The release of the first SEQ Ecosystem Health Report Card in 2000, aligned with
95 growing pressure from communities, politicians and managers, stimulated changes in the
96 monitoring and reporting of water quality across Queensland (Appendix A). Communities
97 and governments were increasingly aware of the negative anthropogenic impacts on
98 waterways and regulators were seeking to reduce environmental pollution, concerned
99 primarily with nutrients, sediment and pesticides. This led to new monitoring programs
100 focused on water quality attributes as management objectives, although regional differences
101 in data collection and reporting approaches remained problematic (Appendix A).

102 A subsequent major community and political driver of improvements to estuarine
103 water quality focussed on the Great Barrier Reef (GBR), with the release of a Scientific
104 Consensus Statement emphasising the importance and urgency of declining water quality and
105 the connections between land management practices and reef health. This was followed in
106 2003 by the release of the Reef Water Quality Protection Plan (Reef Plan), which aimed to
107 reverse the decline in the quality of water flowing into the GBR by improving land
108 management practices, and in 2009 by the establishment of the Paddock to Reef Integrated
109 Monitoring, Modelling and Reporting Program (Paddock to Reef Program), which uses

110 catchment monitoring and modelling of water quality and pollutants, including pesticides, to
111 provide an integrated assessment of the likely pollution load into estuaries, and thereby into
112 the nearshore GBR Lagoon (Appendix A). Catchment monitoring is complimented by
113 monthly water quality monitoring in estuaries that contribute pollutants to the GBR Lagoon,
114 and by a Marine Monitoring Program (MMP) that assesses both water quality and the health
115 of critical habitats, such as seagrass and coral, within the Lagoon (Appendix A; noting that
116 the GBR Lagoon is not considered an estuary for the purposes of this review).

117 The above developments have helped to stimulate interest, especially from catchment
118 organisations, in the collection and reporting of information on the condition of other
119 estuaries and waterways across Queensland. Most recently, the Fitzroy River Partnership has
120 developed a report card approach for reporting on the condition of both fresh and estuarine
121 waters (Fitzroy Partnership for River Health, 2014), following a similar model to the Healthy
122 Waterways report card (Appendix A). The State Government is also working with local
123 government, industry and community groups in Gladstone Harbour (GHHP, 2014) and the
124 Mackay-Whitsunday region (MWHRRP, 2015) to develop regionally-specific reporting
125 methods that will assess the water quality and environmental condition of estuarine and
126 coastal waterways (Appendix A).

127 Many of the current regional programs in Queensland are focussing on developing an
128 integrated ‘triple bottom line’ approach to data collection and reporting that will continue to
129 assess ecosystem health, but will also report on the social benefits and economic aspects of
130 estuaries/waterways (e.g. Healthy Waterways, Gladstone Harbour; Appendix A), to better
131 inform the sustainable development and utilisation of estuarine and nearshore coastal
132 environments.

133 **3. New South Wales (NSW)**

134 Estuary monitoring in NSW is specifically focussed on long term trends in estuary health. It
135 aims to collect a focussed set of data from as many systems as possible, allowing tracking of
136 trends through time and in response to management (NSW DECCW, 2010). Estuary
137 management in NSW is primarily the responsibility of local government, with technical and
138 policy support from State government. Until recently, management has focussed on estuary
139 foreshores and entrances, but in the last decade that has shifted to catchments, reflecting a
140 recognition that they are often the primary source of pressure on estuaries. This represents a
141 problem for local government as managers, since they may not have jurisdiction in the
142 catchments.
143

144 Estuary monitoring previously operated under two largely separate programs. From
145 the 1970s to 1990s, Public Works departments collected physical data (e.g. water height,
146 salinity, temperature, bed depth) and environment and fisheries agencies collected biological
147 and water condition data, including fish biodiversity and habitat use and State-wide
148 macrophyte mapping (West et al., 1985; Creese et al., 2009; Appendix B). Environment
149 agencies initially focussed on the impacts of point source pollution on estuarine water quality,
150 which led to an almost complete removal of industrial sources. Since the late 1990s, much
151 government research has focused on the effects of diffuse catchment-based pollution on
152 estuarine ecology.

153 High-level recognition of the need to better manage threats to NSW estuaries was
154 demonstrated by the Healthy Rivers Commission and particularly its Coastal Lakes Enquiry
155 in the early 2000s (HRC, 2002). In 2006, the NSW ‘Monitoring, Evaluation & Reporting’
156 (MER) Strategy was initiated by the State Government to measure progress towards State-
157 wide condition targets (NSW DECCW, 2010). This Strategy implemented a co-ordinated
158 approach to future monitoring and, in 2010, commanded State of the Catchment (SoC)
159 reports from each of the 13 Catchment Management Authorities (CMAs) (Creese et al., 2011;
160 Roper et al., 2011).

161 The current estuary monitoring design under the NSW MER Strategy is based on a
162 ‘pressure-stressor-outcome’ model, supported by a range of conceptual models that depict
163 qualitative links between these components. The primary focus of recent and current
164 monitoring and research is on land-derived nutrients and sediments, although localized
165 threats or impact sources (e.g. acid sulfate soils) exist in some areas and require local
166 monitoring and management. Estimates of annual average total nitrogen, total phosphorus,
167 total suspended solid loads and freshwater flows are modelled for each subcatchment of
168 every estuary in NSW, with further data on entrance modification, human population density,
169 shoreline modification, fishing pressure and climate change (Roper et al., 2011; Appendix B).

170 Estuarine health indicators used in the MER program represent elements of system
171 structure, function and composition and were designed to be cost effective and practicable at
172 a State scale. They include the following.

- 173 • eutrophication: microalgal abundance (measured as phytoplankton chlorophyll *a*),
174 macroalgal abundance, water clarity (measured as turbidity)
- 175 • habitat availability: extent of seagrasses, mangroves and saltmarshes
- 176 • fish assemblages: species diversity, composition, abundance.

177 State government currently measures a primary indicator suite comprising chlorophyll
178 *a*, turbidity and macrophytes in over 30 different estuaries (plus 10 fixed estuaries) per year,
179 focussing on the north, central and south regions of NSW on a three year rolling cycle (Roper
180 et al., 2011). Monitoring has typically been designed to enable comparisons between
181 locations subjected to different levels of anthropogenic pressures, with data tested against
182 reference systems with little disturbance in their catchments (ANZECC and ARMCANZ,
183 2000; Scanes et al., 2007). Local government also carries out additional monitoring using
184 standard protocols. Results are presented in report cards using standardised methods of data
185 analysis (OEH, 2013; Appendix B; Fig. 2).

186 Some of the above indicators (e.g. macroalgal abundance) are still under
187 development, while others such as fish assemblage composition were assessed for the 2010
188 report cards in a subset of estuaries and are unlikely to be repeated. Interpretation of these
189 indicators and identification of appropriate management directions is facilitated by the
190 contextual data (water heights, salinity, nutrient concentrations, coloured dissolved organic
191 matter, etc.) that are collected concurrently.

192 Several recent developments have sought to extend the monitoring and reporting of
193 estuarine condition in NSW. The Office of Environment and Heritage are developing
194 indicators of estuary ecological function (Scanes et al., 2010) and modelling the effects of
195 stressors on seagrass. There have also been some new developments in the monitoring of
196 micro-organisms to provide an early warning of ecological impacts (Sun et al., 2012) or help
197 explain patterns in processes such as nitrogen cycling. Finally, NSW has increasingly focused
198 on tools to provide local CMAs and government with an ability to assess the relative risk that
199 land-based activities pose to each estuary, and an ability to test future scenarios of risks posed
200 by development plans, e.g. a Coastal Eutrophication Risk Assessment Tool (CERAT;
201 http://www.ozcoasts.gov.au/nrm_rpt/cerat/index.jsp; Littleboy et al., 2009; Sanderson and
202 Coade, 2010).

4. Victoria

205 Much of Victoria's past estuarine monitoring effort has focused on four large systems, three
206 of which are essentially marine embayments (Port Phillip Bay, Western Port Bay and Corner
207 Inlet/Nooramunga) and the other of which is one of Australia's largest estuaries (Gippsland
208 Lakes) (Fig. 1). Routine monitoring of Victoria's other estuaries has, however, increased over
209 the last decade, in addition to some regional and system-specific programs addressing select
210 aspects of estuary health. While there have also been some key advances in this area (see

211 below), a consistent broad-scale monitoring program is yet to be implemented across the
212 State (Appendix C).

213 Several authors have reviewed the available data, research and/or monitoring
214 programs concerning the health of Victoria's estuaries (Barton, 2003; Mondon et al., 2003;
215 Arundel and Barton, 2007; Arundel et al., 2009; Barton et al., 2008; Hirst, 2008). Various
216 data gaps were identified, and the Victorian Government responded by instigating a major
217 program to compile information on the number, type, physical size, threats and assets of the
218 State's estuaries, including data on the physical and population attributes of their catchments
219 (Barton et al., 2008; Pope et al., 2015). Other data gaps included estuarine water quality and
220 biotic data at appropriate spatio-temporal resolutions, which have precluded testing of causal
221 links between specific threats and condition indicators (Barton et al., 2008; Arundel et al.,
222 2009).

223 A major step towards standardised monitoring, evaluation and reporting of the
224 condition of Victoria's estuaries occurred in 2009 with the development of the Index of
225 Estuarine Condition (IEC). This composite index integrates indicators from six themes
226 representing different aspects of estuarine condition, i.e. physical form, hydrology, water
227 quality, sediment, flora and fauna (Arundel et al., 2009; Appendix C). It is intended that
228 results from the IEC will support State-wide monitoring of estuarine resource condition,
229 inform management priorities and guide resource allocation for threat mitigation and asset
230 protection. As recommended by Arundel et al. (2009), the measures proposed for the IEC
231 were trialled to ensure they could be sampled adequately across the State, appropriate
232 baseline or reference conditions could be defined and the indicators scored into five condition
233 bands. Individual measures are aggregated at the theme level before the theme scores are
234 aggregated to give an estuary score (Pope et al., 2015). The scale at which the IEC will be
235 applied will be finalised by 2016 and will form part of the Victorian eight-year water strategy
236 cycle, subject to available funding (DEPI, 2013).

237 Recent changes in Victorian Government policy have also led to a major shift in key
238 strategies for managing the State's estuaries. Prior to this, the major legislation relating to
239 estuaries was the Coastal Management Act 1995 (currently under revision), which enabled
240 strategic planning on the coastal region and led to development of management plans for
241 individual estuaries. In 2013, the Victorian Waterway Management Strategy (VWMS; DEPI,
242 2013), which integrates State, national and international policy and legislation, replaced the
243 Victorian Catchment Strategy and associated regional plans under the Catchment and Land
244 Protection Act 1994. Regional Waterway Strategies (RWSs) provide the vehicle by which the

245 VWMS is delivered, and have been developed in five regional areas. They identify
246 appropriate management activities for adapting to sea level rise, mitigating adverse effects
247 associated with coastal land use and development, managing estuary entrances and enhancing
248 connectivity, maintaining and improving environmental condition, setting water quality
249 objectives and determining environmental water requirements, and managing coastal acid
250 sulfate soils (DEPI, 2013).

251 While the changes in governance and recent work towards a more consistent estuarine
252 assessment, monitoring and reporting approach across Victoria are substantial and positive,
253 issues remain in terms of the uncertainty of future resourcing. Further improvements towards
254 coordinating the coastal management framework are thus required, and continued research is
255 needed to strengthen the evidence base for planning and management.

257 **5. Tasmania**

258 Monitoring of the condition of Tasmanian estuaries has been sporadic, except for several
259 larger and seriously degraded systems and those containing aquaculture operations.
260 According to the latest State of the Environment (SoE) report for Tasmania (Tasmanian
261 Planning Commission, 2009), the condition of the State's estuaries is variable, pressures are
262 generally increasing and information and knowledge is poor for most estuaries.

263 The longest continuous monitoring program of estuarine condition in Tasmania has
264 occurred in approximately 20 shellfish growing areas since the mid-1980s (the Tasmanian
265 Shellfish Quality Assurance Program; Appendix D). Similarly, compliance monitoring
266 around oyster and salmon farms to quantify their environmental impacts has also provided
267 information on estuarine health. While such monitoring in the 1990s focused on localised
268 effects under and/or near shellfish intertidal racks, salmon cages and/or longlines, the focus
269 since 2000 has been on broad-scale, estuary-wide effects, and particularly those of increased
270 nutrients from salmon farms. Limits on dissolved nutrient emissions from finfish farms in the
271 D'Entrecasteaux Channel and Huon Estuary were introduced by Government in 2009,
272 together with a regulatory monitoring program to assess water quality and sediment
273 condition.

274 In addition to the above systems, the Derwent and Tamar estuaries have significant,
275 ongoing monitoring programs. The Derwent Estuary (Fig. 1) is one of the most heavy metal-
276 polluted estuaries worldwide, due to past dumping of industrial waste over many decades.
277 The Derwent Estuary Program was established in 1999 to restore the estuary and an ongoing
278 monitoring program has tracked its health, incorporating water quality, ten-yearly sediment

279 surveys and periodic surveys of phytoplankton, habitats and selected fauna. Findings are
280 communicated via annual report cards and a five-yearly State of the Derwent report
281 (Appendix D). The Tamar Estuary and Esk Rivers Program similarly monitors and reports on
282 waterway health (predominantly focused on water quality), as well as coordinating activities
283 to reduce pollutant loadings. A Tamar Estuary Ecosystem Health Assessment Program was
284 established in 2009 to coordinate data collection across the estuary, and report cards are
285 produced annually, with accompanying technical monitoring reports.

286 Some smaller estuaries in Tasmania have been periodically monitored, generally over
287 one to two years, during an assessment of conservation status (Barrett et al., 2000), studies of
288 representative Tasmanian estuaries (Murphy et al., 2003), or baseline monitoring programs
289 (Appendix D). Several of these studies have emphasised the need for both water quality and
290 biological data to better assess estuarine condition.

291 An attempt was made in the mid-2000s to establish estuarine water quality indicators
292 and thresholds specific to Tasmanian conditions by convening a panel of estuarine experts,
293 which led to the development of a Tasmanian Indicator Compendium (Mount et al., 2006).
294 Monitoring and management of Tasmanian estuaries was also investigated as part of the
295 Commonwealth-funded Landscape Logic research hub, which led to the development of an
296 Estuarine Decision Tree for identifying the vulnerability of Tasmanian estuaries to human-
297 induced change and supporting their management by standardizing condition assessments
298 (Crawford et al., 2012). The Tasmanian Environmental Protection Agency is currently
299 preparing interim water quality guidelines for the protection of ‘high ecological value’ and
300 ‘slightly to moderately disturbed’ estuaries based on the estuarine decision tree. The interim
301 guidelines for the latter estuaries may also provide aspirational targets for moderately and
302 highly disturbed estuaries.

303 304 **6. South Australia (SA)**

305 Aside from the iconic estuary at the mouth of the Murray River (see below), much of the
306 current estuarine monitoring in SA occurs in Gulf St Vincent and Spencer Gulf (Fig. 1)
307 which, although actually coastal nearshore areas, are often considered to be inverse estuaries
308 (SA DEH, 2007). Very few of the remaining estuaries in SA currently have monitoring
309 programs in place to detect potential changes. Most water quality monitoring occurs in the
310 freshwater parts of the river systems (e.g. upper and middle catchment), with the majority of
311 monitoring that has been undertaken in estuarine reaches being patchy and/or undertaken by
312 private consultants, community groups, schools and other agencies for specific reasons

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(Appendix E). The Department of Environment, Water and Natural Resources (DEWNR) has produced a report card for assessing the status of estuaries throughout SA, including the two Gulfs noted above, but this largely employed the qualitative measures of estuarine condition from the National Land and Water Resources Assessment of 2002. The 2013 report card indicated that estuarine condition was generally poor, that any trends in condition were unknown, and that ongoing monitoring of estuaries was required (DEWNR, 2013). Future reporting measures are unknown.

The SA Environment Protection Authority (EPA) evaluates the consequences of human activities for the ecological condition of SA waters, including estuaries (Goonan et al., 2012; Appendix E). From 1994–2007, a nearshore water quality monitoring, evaluation and reporting program was carried out that involved monthly or quarterly sampling of surface waters, with results reported as a traffic light summary depending on whether variables were below or within national guidelines (e.g. ANZECC and ARMCANZ, 2000). From 2010, the EPA’s aquatic ecosystem Monitoring, Evaluation and Reporting Program (MERP) has used a three-tiered approach to assess nearshore coastal threats and condition, using the spatial framework (biounits, 10s–100s km, and bioregions, 100s–1000s kms) of the Integrated Marine and Coastal Regionalisation of Australia (IMCRA v4.0) (Edyvane, 1999, Appendix E). The MERP compares observed condition (from a monitoring program) with predicted condition (based on an assessment of threats) to generate an Aquatic Ecosystem Condition Report (AECR) that rates condition on a six-point scale from excellent (effectively unimpacted) to very poor (highly disturbed). Reporting typically occurs at the biounit scale but can be rolled up to the bioregional scale for SoE reporting (Gaylard et al., 2013b).

To date, AECRs are available for two bioregions, i.e. lower Spencer Gulf (Gaylard et al., 2013a) and Gulf St Vincent (Nelson et al., 2013) (Fig. 1). Whilst the focus is on nearshore marine waters, some of the larger estuaries in these bioregions (e.g. Barker Inlet, Franklin Harbour, Smoky Bay, Tourville Bay, Baird Bay, Venus Bay and Coffin Bay) are included. However, given the scale of reporting, no specific condition ratings are given for individual estuaries. Future AECRs for estuaries are dependent on resources.

The Coorong, Lower Lakes and Murray Mouth region, which includes the estuarine lagoon and the largely freshwater wetlands of the Lower Lakes, is often considered separately from other South Australian estuaries given its iconic status (e.g. SA DEH, 2007). Two major, broad-scale monitoring programs operate in this region.

(i) The Murray Futures Coorong, Lower Lakes and Murray Mouth Recovery program, which is overseen by DEWNR and addresses various environmental issues facing the region,

347 such as salinization, acid sulphate soils and loss of habitat. Plants, animals and abiotic
1 348 components of the system have been monitored since 2010 to inform on-going management
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3 349 (Appendix E), though it is unclear if or how this program will continue.
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5 350 (ii) The Murray-Darling Basin Authority's Living Murray program, which
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7 351 commenced in 2002 and focuses on increasing environmental water flows to improve the
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9 352 health of six important 'icon sites', one of which is the Lower Lakes, Coorong and Murray
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11 353 Mouth. This program is being managed by DEWNR and overseen by the above Authority.
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13 354 Various monitoring projects are undertaken in the Lower Lakes, Coorong and Murray Mouth
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15 355 region, including those for birds, fish, invertebrates, vegetation, mudflats and water quality
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17 356 (Appendix E). Again, there are uncertainties regarding the longevity of the Living Murray
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19 357 program due to funding constraints.
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22 359 **7. Western Australia (WA)**

23 360 The past decade has seen periodic changes in the governance frameworks and agencies
24
25 361 responsible for monitoring and reporting on estuarine condition across WA. The Department
26
27 362 of Water (DoW) is now the lead agency for estuary management across WA and coordinates
28
29 363 a State-wide water quality program. An exception is the Swan-Canning Estuary, whose
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31 364 management since 1989 has been overseen by a statutory body, the Swan River Trust. In
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33 365 2013 the Trust was subsumed within newly created Department of Parks and Wildlife and
34
35 366 now exists as an advisory body, without statutory powers, within the Rivers and Estuaries
36
37 367 division of the Department.

38 368 Approaches to estuarine monitoring and reporting in WA have progressed in recent
39
40 369 years. Standardised monitoring of various water quality variables has been undertaken at
41
42 370 weekly to quarterly intervals across many estuaries in south-western WA since the mid-
43
44 371 1990s, and the resulting data have recently been synthesised as estuary condition statements
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46 372 and reports for several key systems (Appendix F). Additionally, new tools are being
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48 373 developed to better assess estuary condition. For example, the DoW is developing estuarine
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50 374 condition assessments based on a Water Quality Index that combines measurements of
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52 375 chlorophyll *a*, DO, Secchi depth, TN and TP as indicators, and is also undertaking applied
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54 376 research to develop indicators of ecological condition based on seagrass (Kilminster et al.,
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56 377 2014) and sediment biogeochemistry (WA DoW, 2013), for possible inclusion in future
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58 378 monitoring programs (Appendix F).

59 379 The Swan-Canning Estuary, encompassed by the State capital, Perth (Fig. 1), best
60 380 illustrates advances for assessing the condition of WA estuaries. Water quality (physico-

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381 chemistry, nutrients and phytoplankton) has been monitored weekly since the mid-1990s
382 throughout the system and at gauging stations in each subcatchment. Extensive assessments
383 of foreshore condition have been undertaken, and several novel approaches for measuring
384 and reporting estuarine condition have been developed (Appendix F). The latter include an
385 annual monitoring regime to assess and communicate ecological condition using multimetric
386 Fish Community Indices (FCI), implemented since 2012 (Hallett et al., 2012; Hallett and
387 Tweedley, 2014; Fig. 3).

388 There are, however, significant inequalities in the degree of investment, frequency
389 and types of monitoring among WA estuaries. Thus, less urbanised systems to the north of
390 Perth experience little or no monitoring, despite increasing pressures from urbanisation,
391 agriculture and tourism. Moreover, existing monitoring programs remain strongly focused on
392 water quality, restricting most assessments of broader estuarine condition to qualitative
393 statements based on expert opinion (e.g. WA EPA, 2007). These and other basic data gaps
394 have been highlighted frequently (WA DoW, 2007; WA EPA, 2007, 2008; Hugues-dit-Ciles,
395 2012; OAG, 2014) and have led to growing calls for more holistic and ecologically-relevant
396 approaches for monitoring and reporting estuarine condition (e.g. Government of Western
397 Australia, 2004). Additionally, quantitative monitoring and timely reporting of the human
398 pressures and stressors affecting WA estuaries is minimal (Appendix F), which has hampered
399 efforts to discern the causal mechanisms driving trends in condition. This could be addressed
400 by better translating the data from existing monitoring programs into accessible and user-
401 friendly indicators, such as the Index of Sustainable Functionality that was recently applied to
402 the Swan-Canning Estuary (Kristiana et al., 2012) and the DoW's Water Quality Index,
403 although the latter tool has not yet been publicised or reported (OAG, 2014). There is also
404 considerable scope for improving the communication of monitoring outputs, ensuring they
405 are publicised in a comprehensible and timely manner and more clearly aligned with
406 management actions (Appendix F). This might help to overcome a perceived lack of
407 management actions to address declining water quality in WA's estuaries (Metcalf et al.,
408 2014).

409 Lastly, while there has been some recent progress led by the Western Australian
410 Marine Science Institution, there is currently no formal mechanism to coordinate estuarine
411 science and monitoring activities across WA, nor the leadership to ensure that strategic long
412 term plans are executed (WA EPA, 2007; Beazley, 2010). These issues have been
413 exacerbated by uncertainty in funding for even core water quality monitoring in several

414 estuaries across the south-west, emphasising the critical need to ‘future-proof’ estuarine
415 monitoring and reporting.

416

417 **8. Northern Territory (NT)**

418 The majority of NT estuaries are in near-pristine condition (NLWRA, 2002), due largely to
419 their distance from major population centres. Management of these estuaries typically focuses
420 on maintaining and protecting their existing condition, but as monitoring is often limited and
421 benchmarks are not well established (Appendix G), there is little quantitative basis for
422 detecting change. Recent years have, however, seen limited investment in baseline condition
423 assessments, monitoring and reporting for a handful of systems in the ‘Top End’ of the NT,
424 including the Katherine and Darwin regions. For example, the Top End Waterways Project,
425 which commenced in 1995, assesses and reports on the major waterway resources in the
426 Katherine Region, including their estuarine reaches, adapting the river condition and stability
427 approach used in the Queensland ‘State of the Rivers’ assessment (Faulks, 1998).

428 The vast majority of monitoring in the NT is centred on Darwin Harbour (Fig. 1) and
429 its numerous sub-estuaries, whose surrounding catchments support a growing population of
430 >130,000 and the largest concentrations of urban, agricultural and industrial activity in the
431 NT. Water quality monitoring has been undertaken by the Department of Land Resource
432 Management (DLRM) and its predecessors since 1987 (Maraud, 2013), whilst regular and
433 more extensive monitoring and reporting commenced in 2008 and 2009, respectively
434 (DLRM, 2013). The DLRM now annually collates results from its own monitoring programs
435 and some of those undertaken by other government agencies and the private sector, to report
436 on the health of Darwin Harbour. Various water quality variables are now measured at >100
437 sites and compared to objectives set by the Darwin Harbour Water Quality Protection Plan
438 (Fortune and Maly, 2009), to assign water quality grades (A–E) for each region of the
439 harbour (Appendix G), which are published annually via report cards (DLRM, 2013; Maraud,
440 2013).

441 Other monitoring initiatives are also currently active or being established in and
442 around Darwin Harbour (DLRM, 2012), addressing several of the data gaps identified in a
443 previous review of environmental monitoring in the region (DHAC, 2005). These include
444 monitoring of sediment quality, mangroves, aquatic pests, phytoplankton, fish, seagrass and
445 dolphins (Fortune and Drewry, 2011; DLRM, 2012; Appendix G).

446 To date, however, there has been no integration of the outputs from the above
447 biophysical and ecological monitoring programs with the report cards for Darwin Harbour,

1 448 which remain strongly focused on water quality. Moreover, many of the logistical and
2 449 administrative barriers identified by DHAC (2005) are still relevant today, including the
3 450 inaccessibility of monitoring data, fragmented and overly-technical reporting of outputs, and
4 451 the lack of accountability of monitoring agencies to the community. There also remains little
5 452 coordination of monitoring activities among the government departments, industry groups
6 453 and other relevant agencies (DHAC, 2005; Fox, 2011). An Integrated Monitoring and
7 454 Research Program (IMRP) has thus been proposed for the Darwin region to help address
8 455 many of these issues and to develop and integrate more ecologically relevant measures of
9 456 ecosystem condition across marine, estuarine and freshwater habitats (DHAC, 2005; Fox,
10 457 2011). As with all such endeavours, the success of the IMRP will depend on its ability to
11 458 overcome the challenges of coordinating numerous stakeholders with divergent interests and
12 459 ensure funding streams and continuity of management. To this end, the recent securing of \$20
13 460 million of funding for the IMRP over 40 years, as part of an offset agreement between
14 461 INPEX Corporation and the NT Government, represents a significant step forward.

15 462

16 463 **9. Synthesis**

17 464 State and Territory programs were assessed against the criteria of international best practice
18 465 established in part I of this review (Hallett et al., submitted I). Large disparities in the degree
19 466 to which these programs fulfil the evaluation criteria were evident across jurisdictions (Table
20 467 1). Monitoring and reporting programs in NSW and, to a lesser extent, Queensland generally
21 468 met many of the criteria, with the former State, in particular, possessing a well-developed
22 469 legislative and governance framework that links monitoring to management objectives, and a
23 470 rigorous approach to the selection and implementation of appropriate condition indicators. In
24 471 contrast, the other States and the NT rarely met most of the evaluation criteria.

25 472 Some common limitations are apparent across several States, including a continuing
26 473 lack of ecologically-relevant indicators of habitat, floral and faunal condition, and a failure to
27 474 ensure that declining estuarine condition triggers practical management interventions.
28 475 Encouragingly, however, some aspects of Australian monitoring and reporting practices have
29 476 improved across most States in recent years, and most notably the communication of
30 477 monitoring outputs via various media. Several impending or recently implemented State
31 478 initiatives and programs also promise to address many of the identified limitations in the
32 479 coming years. For example, there is considerable potential for the IEC (Pope et al., 2015) to
33 480 dramatically improve monitoring and reporting of estuarine condition across Victoria, and the
34 481 planned expansion of the South Australian MERP to encompass a much greater number of

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1 482 estuaries will help ensure that monitoring and reporting practices finally fulfil the
2 483 requirements of the State's Environment Protection Act 1993 (Goonan et al., 2012) and are
3 484 comparable across the State.
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5 485

7 486 **10. Conclusions**

8
9 487 Part two of this review has highlighted the enormous diversity of policies and approaches for
10 488 monitoring, assessing and reporting estuarine condition across the States and Northern
11 489 Territory of Australia. Common limitations include (i) over-reliance on physico-chemical
12 490 elements of estuarine condition, and primarily water quality, (ii) failure to quantify pressures
13 491 across varied and appropriate spatial scales, and (iii) dramatic inconsistencies in the spatio-
14 492 temporal coverage of monitoring. The latter issue also extends to inter-State comparisons,
15 493 and greatly impacts the ability to compare estuarine condition over broader spatial scales, e.g.
16 494 for national State of the Environment reporting. In the final part of this review (Hallett et al.,
17 495 submitted III) we undertake a broader, national-level synthesis and provide a critical
18 496 appraisal of Australian practices for understanding and reporting estuarine health,
19 497 culminating with some specific recommendations to improve future approaches across
20 498 Australia and beyond.
21

32 500 **Acknowledgements:**

33 501 We are incredibly grateful to the many estuarine researchers and managers who kindly
34 502 provided information and constructive feedback for this work, and to the anonymous
35 503 reviewer of our manuscript whose efforts helped to improve all three parts of this review. We
36 504 also wish to thank Lynda Radke and the attendees of the 2014 National Estuaries Network
37 505 meeting for providing an opportunity to present and develop our work and for their
38 506 invaluable input to this review.
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3 718

4 719 **Tables** (*separate file, attached*)

5 720

6 721 **Table 1**

7 722 Summary assessment of programs for monitoring, assessing and reporting estuarine condition
8 723 in each Australian State or Territory. Programs are scored on the following basis for each of
9 724 the performance criteria identified by Hallett et al. (submitted, part I); 0 = criterion never met;
10 725 1 = criterion rarely met; 2 = criterion often met; 3 = criterion usually/always met. A summed
11 726 national score is also provided for each criterion.

12 727

13 728 **Figure captions**

14 729 **Fig. 1.** Map of Australia, showing the States and Territories, their capital cities, and the
15 730 locations of key estuaries and regions referred to in the text and supplementary material.

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17 732 **Fig. 2.** Catchment and estuary disturbance index results for the Hawkesbury Shelf Bioregion
18 733 of New South Wales. Disturbance is rated from very high (red) to very low (dark green)
19 734 (Roper et al., 2011).

20 735

21 736 **Fig. 3.** Mean offshore Fish Community Index scores and resulting condition grades (A, very
22 737 good; B, good; C, fair; D, poor; E, very poor) for each zone of the Swan Canning Estuary,
23 738 Western Australia, and for the estuary as a whole, in summer and autumn of 2014. LSCE,
24 739 Lower Swan Canning Estuary; CE, Canning Estuary; MSE, Middle Swan Estuary; USE,
25 740 Upper Swan Estuary.

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27 742 **Supplementary material**

28 743 (*See separate appendices A–G; for publication as online appendices*)

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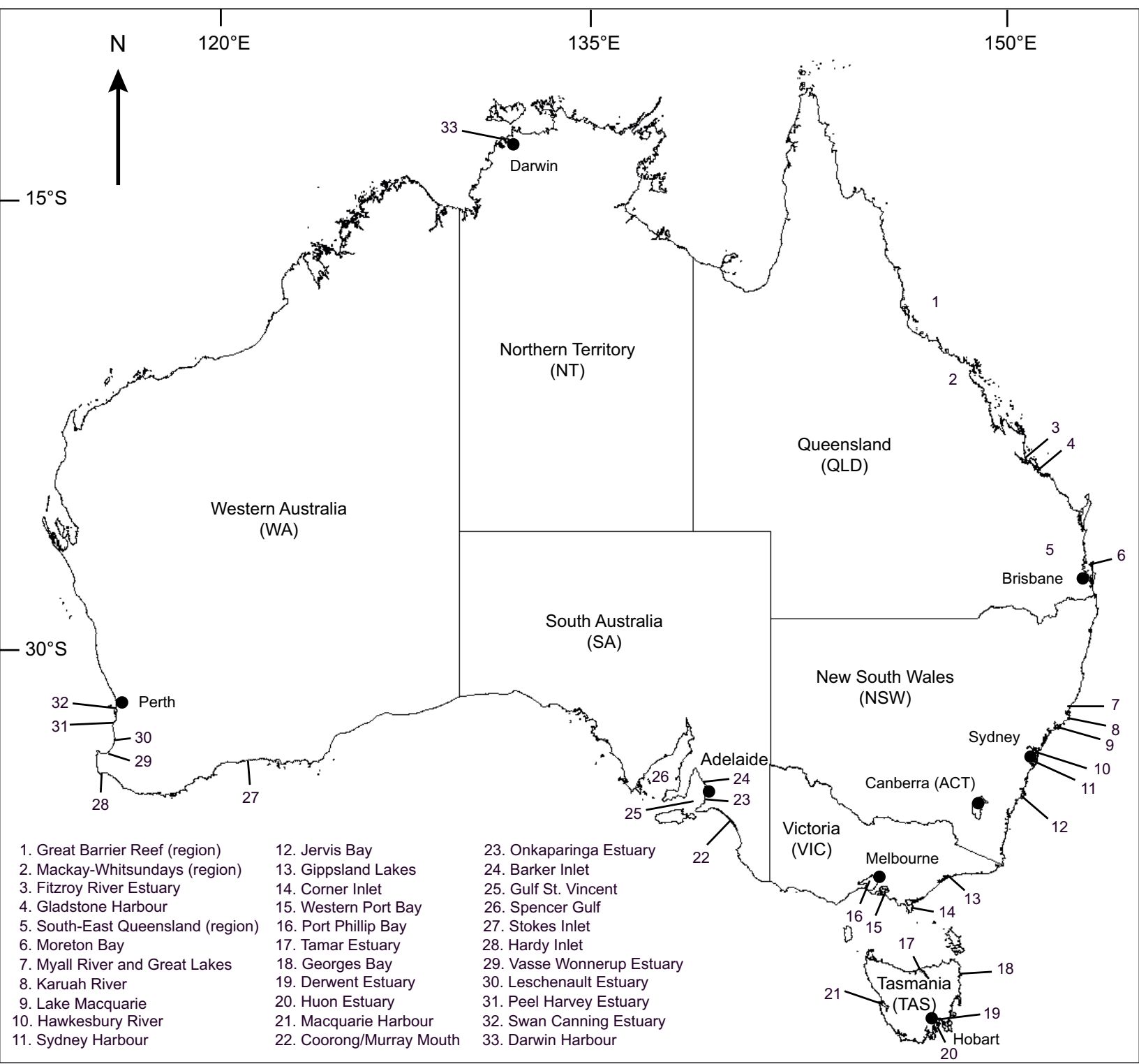
Table 1. Summary assessment of programs for monitoring, assessing and reporting estuarine condition in each Australian State or Territory. Programs are scored on the following basis for each of the performance criteria identified by Hallett et al. (submitted, I); 0 = criterion never met; 1 = criterion rarely met; 2 = criterion often met; 3 = criterion usually/always met. A summed national score is also provided for each criterion.

Performance criterion ^a	Queensland	New South Wales	Victoria	Tasmania	South Australia	Western Australia	Northern Territory	Total (/21)
1 Monitoring and assessment is underpinned by the DAPSI(W)R(M) (i.e. Driver-Activity-Pressure-State Change-Impact (on Welfare)-Response (Measures) framework, or similar.	2	3	2	1	1	1	0	10
2 Monitoring and assessment addresses specific management objectives and forms an integral part of an adaptive management cycle.	2	3	2	1	2	1	1	12
3 Monitoring addresses a legislated requirement for assessing and reporting estuarine condition and trends.	2	3	3	1	0	1	2	12
4 Monitoring and assessment programs adopt an holistic view of ecological condition and employ relevant, cost-effective indicators of State Change, including physical and chemical water quality; sediment quality; habitats; key flora and fauna; and ecosystem processes/functions.	2	2	1	1	1	1	1	9
5 Monitoring and assessment programs employ indicators that are sensitive to changes in estuarine condition, i.e. they can detect 'signals' of anthropogenic pressure against the 'noise' of natural variability.	2	3	1	1	1	1	2	11
6 Appropriate reference conditions, and scoring thresholds that distinguish condition classes and/or limits of acceptable change, are established for each indicator using objective, independent data on estuarine condition or anthropogenic pressure.	2	3	2	1	1	1	2	12
7 Monitoring and assessment programs employ indicators that enable condition to be reliably compared among estuaries and allow for monitoring outputs to be 'scaled up' for reporting across multiple spatial scales, as required.	2	3	2	0	1	1	1	10

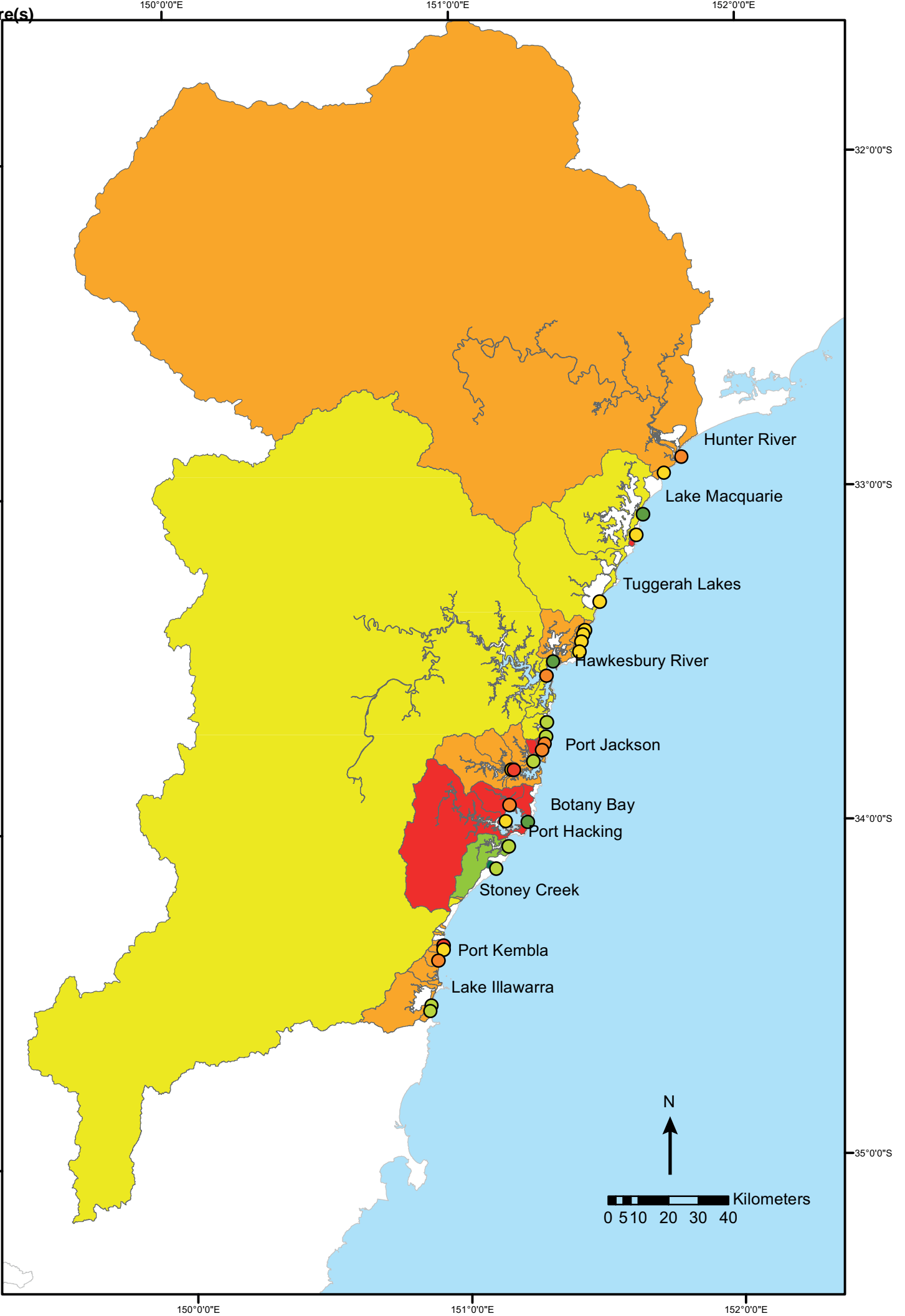
Performance criterion ^a	Queensland	New South Wales	Victoria	Tasmania	South Australia	Western Australia	Northern Territory	Total (/21)
8 Monitoring and assessment outputs are integrated for reporting and decision-making purposes.	3	3	1	1	1	1	1	11
9 Reporting of monitoring and assessment outputs is conducted at relevant time scales, utilises formats suitable for the lay person/politician, and is widely accessible and publicised.	3	2	2	1	1	1	2	12
10 Monitoring and assessment outputs elicit a management response when limits of acceptable change (based on a target or thresholds) are exceeded.	1	2	1	0	1	1	1	7
Summary totals (/30)	21	27	17	8	10	10	13	
	Marked regional variation in the spatial scale and intensity of monitoring programs prevents State-wide comparisons of estuarine condition. Increasing adoption of biotic and social indicators. Reporting of monitoring outputs is typically performed annually and is widely accessible.	An exemplary State-wide monitoring and reporting program, stratified by estuary type and catchment disturbance, assesses the condition of all estuaries against common benchmarks. Monitoring outputs are reported as integrated pressure and condition indices.	Recent policy changes enhanced coordination of monitoring programs across the State. However, most programs are currently focused on water quality, and monitoring outputs are rarely integrated for reporting purposes.	Monitoring programs are strongly regionalised, with different objectives, methods, indicators and reporting. In many cases, monitoring has been short term, ad-hoc and not effectively tied to specific management objectives. There is little capacity to compare condition among systems.	Many estuaries are yet to be monitored under a recently implemented State-wide Monitoring, Evaluation and Reporting Program. In many cases, reporting of condition currently relies on qualitative information or outdated monitoring data, with limited capacity to inform management.	Marked regional variation in the spatial scale and intensity of monitoring programs. Most are strongly focused on water quality. There is currently little integration of monitoring outputs for reporting purposes, and reporting for many systems is not timely or widely accessible.	Monitoring and reporting is almost wholly focused on the Darwin Harbour region. Although not well-aligned with Drivers, Pressures and Impacts on Human welfare, recent programs are moving towards more holistic and integrated approaches to monitoring and reporting condition.	

^a See Hallett et al. (submitted, I) for explanation and exemplification of these attributes of international best practice.

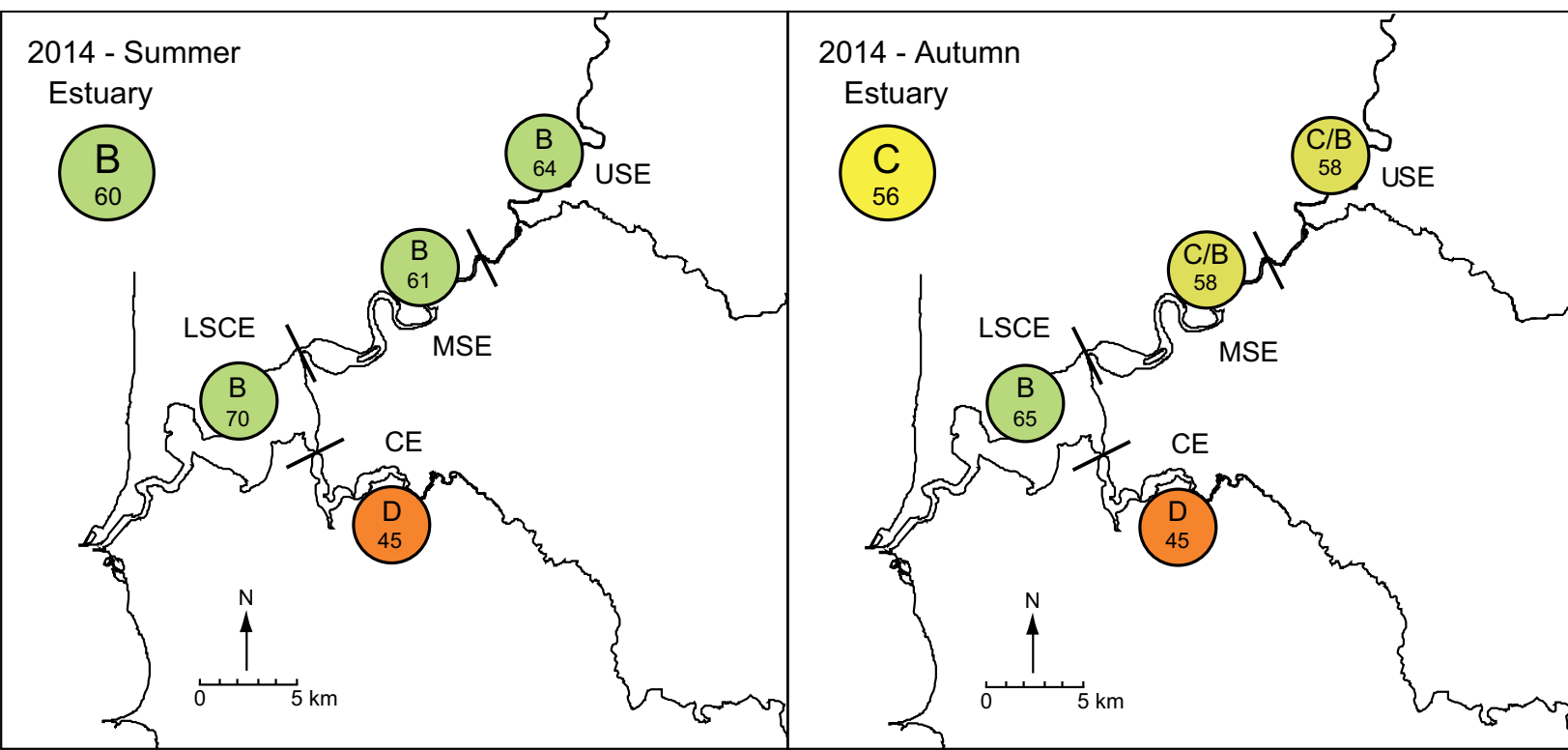
Figure(s)



Figure(s)



Figure(s)



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