Research, part of a Special Feature on Applying Landscape Science to Natural Resource Management

A Methodology to Map Ecosystem Functions to Support Ecosystem Services Assessments

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ABSTRACT. The project developed and trialed a method of mapping ecosystem functions in South East Queensland using biophysical data layers in preference to land use surrogates. Biophysical data and surrogates were identified for 19 ecosystem functions and maps were produced for each. Data layers for each ecosystem function were standardized for mapping purposes using existing expert advice or data quantiling. Two versions of the total ecosystem function overlap maps were also produced, showing areas of high ecosystem function that have the potential to contribute to high ecosystem service provision. This method was successfully used to replace land use surrogates in most cases, and produced maps that planners and decision makers considered credible. The mapping exercise allowed an ecosystem services framework (the SEQ Ecosystem Services Framework) to be embedded in a statutory planning document, used in a State of the Region Report and to influence planning decisions at a local government level.

Key Words: *ecosystem functions; ecosystem services; GIS mapping; land use planning; South East Queensland*

INTRODUCTION

Ecosystem services (ES) are the benefits people receive from ecosystems (Millennium Ecosystem Assessment 2005). According to Maynard et al. (2010:5), quantification and mapping of ecosystem services provides key information identifying: "(a) areas that provide a high level of service requiring protection or management to maintain service provision (b) areas that provide specific ecosystem functions or services and (c) changes in ecosystem service provision over time".

Spatial representation of the relative provision of ecosystem services across a landscape is critical for incorporating ecosystem services into processes for integrated urban and regional planning. However, mapping the location of ecosystem service derivation and provision can be constrained by the lack of data that describe landscapes in terms of services. ES are not commonly considered in land use planning because the tools and information for decision makers have not yet been available. This includes information on who the beneficiaries of ecosystem services are, along with their perceptions of the value of ecosystem services.

Ecosystem function maps were produced to provide spatial support for the SEQ Ecosystem Services Framework (henceforth, the Framework), an agreed framework developed by SEQ stakeholders to identify, measure, and value ecosystem services specifically for land use and natural resource management policy and planning (Maynard et al. 2010). Although a brief overview of the Framework are provided, the focus in this article is only on the production of the ecosystem function maps.

According to the Framework, those areas in SEQ showing a high amount of ecosystem function also have the potential to

provide a high amount of ecosystem service(s). The key distinction between ecosystem functions and services is that functions are regarded as having both intrinsic and potential anthropocentric values, while services are defined only in terms of their benefits to people. For example, the ecosystem function of pollination is important for sustaining ecosystems and biodiversity for its own sake, while the service of pollination refers more specifically to the pollination of food or fuel crops of use to humans, or even indirectly for maintaining ecosystems and biodiversity to continue the supply of ecosystem services. The approach of mapping the ecosystem functions that underlie ecosystem services as a way forward to the eventual mapping of ecosystem services and their beneficiaries was adopted. Other researchers (Kremen and Ostfield 2005, Sanchirico and Mumby 2009) have highlighted the importance of understanding functional linkages between species and specific ecosystems and functional relationships between species for understanding ecosystem services.

Previous ecosystem service mapping approaches have used land use and land use zones as surrogates (Costanza et al. 1997, Costanza et al. 2006, Liu et al. 2010). This approach provides a rapid path to ecosystems service mapping but may not be sufficient in itself for detailed planning purposes. Land use describes what humans perceive as the land's utility whereas land cover describes the actual measured properties of the land surface (Witte et al. 2006, Carlson and Arthur 2000). Land use mapping is often done on a cadastral basis and can lack the sub-cadastral resolution of land cover. Land use mapping can also miss the topographic context of land use, which can impact on the provisioning of ecosystem function and services (Carlson and Arthur 2000). The SEQ Ecosystem Services Framework (Maynard et al. 2010) requires that the mapping

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be tied to enough specific information so that it could be used in both strategic and individual planning decisions. To try and address the issues by just using pure land use information, the ecosystem functions were mapped using a combination of land cover, lithographic attributes, topographic context, and in some instances, land use. This approach also allows for the exploration of different levels of functionality both between and within land uses.

This article reports on the identification and mapping of nineteen (19) ecosystem functions, which were recognized as underpinning the provision of ecosystem services in the South East Queensland (SEQ) region of Australia. It describes the method used in mapping individual functions and how these maps were overlaid to produce "Total Ecosystem Function" maps.

A list and the descriptions of ecosystem functions incorporated in the Framework is provided in Appendix 1. The Method section contains a description of the mapping process. The rationale for each of the data layers and the transformations required to develop the maps is provided in Appendix 2. The Results include a description of the individual function maps and the Total Ecosystem Function map, along with an example of Ecosystem Function 3: Disturbance Regulation. The Discussion section interprets the results and discusses data limitations. Applications of the mapping products and the implications of the methods used are described in the Conclusion.

BACKGROUND

The SEQ region

SEQ holds approximately 70% of the State of Queensland's population and is the fastest growing metropolitan area in Australia (Hinchcliffe 2009). The subtropical climate attracts on average 1057 new residents per week (Australian Bureau of Statistics 2010). The SEQ region is approximately 22,000km^2 of mountain ranges, hills, valleys, rivers, lakes, floodplains, coastal bays, and islands. SEQ is one of the most species-rich regions in Australia; nearly 5,000 native plant species and 900 species of native vertebrate have been recorded (Queensland Government 2003). Figure 1 shows the location of SEQ within Australia.

The SEQ coastal plain is relatively broad and flat, with undulating hills rising to mountains in the north (Glass House Mountains and Blackall Range), south (McPherson Ranges) and west (Great Dividing Range) of Brisbane. Eleven (11) major river systems and their tributaries traverse the coastal plain and form estuaries to Moreton Bay and the open coast. Moreton Bay is a mosaic of over 300 islands including three major sand islands and significant areas of coastal swamps, heathlands, mangroves, and sand dunes.

Fig. 1. The SEQ region and its location in Australia.
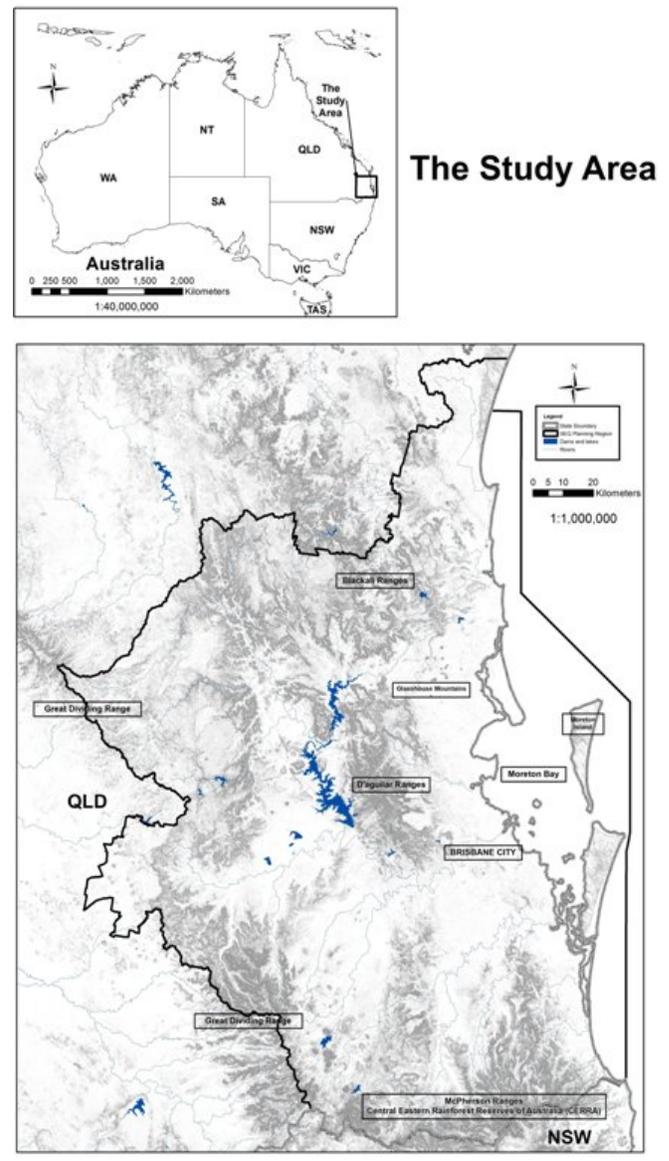
The southern portion of SEQ is dominated by volcanic highlands and includes parts of the Central Eastern Australia World Heritage area. The western area contains rich agricultural soils among the mountain ranges. These upland areas contain a diversity of plant and animal life that is often shared with grazing enterprises and rural residential land uses. The western catchments harvest water for the growing urban population settled mostly along the coast.

Such diverse landscapes attract pressure for multiple land use, which is often at odds with the sustainable management of natural resources in the region. The challenge for regional planning is to spatially describe these landscapes in a manner

that allows planning to protect and enhance ecosystem function and the services they provide to the SEQ and wider community.

The SEQ Ecosystem Services Framework
Of critical importance to the development of the Framework was stakeholder consensus on the structure, terminology, and tools that would support the Framework. Maynard et al. (2012) describe the Framework as consisting of three main elements:

1. Lists and descriptions of four main components for assessment: Ecosystem Reporting Categories (groups of ecosystems), Ecosystem Functions, Ecosystem Services and Human Well-being;

2. A semi-quantitative description of the relationships between these in the form of scores and matrices; and

3. A series of maps identifying spatially where ecosystem services are being derived from in SEQ (i.e., maps of Ecosystem Reporting Categories and Ecosystem Functions).

The project to develop the Framework has relied heavily on a participatory process with inputs from its Steering Group, Working Group, Expert Panels, and Community Workshops. By creating forums for negotiation and information sharing, this approach also increased ownership, empowered stakeholders, and helped bridge different scales of information and forms of knowledge across sectors and disciplines (Millennium Ecosystem Assessment 2005, Cowling et al. 2008, Maynard et al. 2010, Maynard et al. 2012).

MAPPING METHOD
The maps described were prepared using an ESRI ArcGIS platform. The first phase of mapping used the descriptions for each of the ecosystem functions to produce one map for each of the 19 functions incorporated into the Framework. For the purposes of the Framework, ecosystem functions were defined as "the biological, geochemical and physical processes and components that take place or occur within an ecosystem" (Maynard et al. 2010:6).

The second phase of mapping overlaid each of the 19 individual function maps to produce a "Total Ecosystem Function" map. Two Total Ecosystem Function maps have been produced: one based on presence/absence and another on quartile standardization. As the final products (19 individual function and 2 Total Ecosystem Function maps) are a combination of data sources and corresponding map layers, consideration needed to be given to the parent scale, year of creation, accuracy of data, data models, and the minimum mapping unit for each input layer (Millennium Ecosystem Assessment 2005, Troy and Wilson 2006, Maynard et al. 2010).

Mapping was conducted in parallel with the review of definitions of ecosystem functions for the Framework, which necessitated ongoing refinement of appropriate data sets and proposed surrogate layers. Interim map products were subject to review through meetings and Think Tanks by relevant academic and technical experts as well as political and community stakeholders. The results presented are the current version (Version 4) and are subject to ongoing refinement and review as new information and data sets become available.

Lists and descriptions of ecosystem functions
The list of 19 ecosystem functions incorporated into the Framework was adapted from de Groot et al. (2002) during the Expert Panels. The list of ecosystem functions can be considered as broad groupings of ecosystem functions. For example, the function of gas regulation includes the regulation of many gases such as carbon, oxygen or nitrogen regardless of the type of process that transforms this species into its gaseous state. The number of ecosystem functions incorporated in the Framework is a subjective and arbitrary number dependent on the chosen scale or method of delineation. It was considered that the 19 functions defined were comprehensive and most important to the provisioning of ecosystem services in SEQ and a manageable number to assess within the Framework. The list of ecosystem functions and their descriptions is provided in Appendix 1, Table A1.1.

Identification and interpretation of data sets
To map individual ecosystem functions all available geographic information system (GIS) data sets were identified and collected and combined, to represent the 19 different biological, geochemical, and physical processes and components occurring in ecosystems that the Expert Panels had described. A request was made to partners and stakeholders for biophysical data sets of the SEQ landscape, different ecosystem types and land use maps that covered the full extent of the region. Analysis and blending of these multiple data sets was carried out to produce a probable spatial presentation of where in the landscape each particular ecosystem function is occurring.

While most of the data sets used were already developed, a number of ecosystem functions required the development of new data layers; these were developed in-house by the coordinating organization, SEQ Catchments). Seventeen (17) new layers were derived from existing data sets. Appendix 2, Table A2.1 lists the data sets applied to develop the 19 ecosystem function maps, the data source or reference, the rationale for each data set in terms of the function to which it was applied, and comments on the use of the data set or future recommendations for inclusion.

Standardization of data sets
To develop the individual function maps, each of the data sets was standardized to produce a common currency to facilitate the overlaying process within the GIS environment. The aim

of this standardization process was to reduce each data set to a "presence" or "absence" (0 or 1) and to ensure all data sets were at a consistent scale (25m x 25m grid). Two methods of standardization were applied:

- Method A: For some data sets expert advice was provided with the Metadata and supporting documents. Using this advice, each data set was reduced to a presence or absence (0 or 1). For example, the Core Habitat data set from the Biodiversity Planning Assessment provided data as low, medium, high, and very high, which was reclassified as 1, 2, 3, and 4 respectively. These were further reclassified to a standardized score of 0 (absent) for scores 1 and 2 and a standardized score of 1 (present) for scores 3 and 4 (i.e., only the 2 highest scores were retained).

- Method B: Where there was no inherent expert advice with the original data set for a presence or absence, quartile splits were used for numerical data. After arranging the data in ascending order a quartile split distributes the data into 4 equal parts (Serfling 1980). This would produce a range of scores from 1 through to 4. Scores of 1 and 2 were reclassified as absent and 3 and 4 as present, the same as in Method A.

Map production
The 19 ecosystem function maps were produced by overlaying the selected suite of standardized data sets to produce extent maps for each ecosystem function. While each data layer was not weighted in the individual ecosystem function overlay process, it was subjected to a prioritization process during standardization. Appendix 2, Table A2.1 is the resultant master list including a description of the contribution of each data set to a component of ecosystem function with relevant references.

While experts or resource managers may find utility in the individual ecosystem function maps, decisions makers at the regional level were looking for a product that summarized the level of ecosystem function provided. Those of the planning profession took the view that while we as yet could not map specific ecosystem services, we could protect those services in a planning sense by protecting areas that supplied a range of the necessary ecosystem function(s). This point of view led to the trialing of two styles of ecosystem function overlay maps (Total Ecosystem Function maps).

The first Total Ecosystem Function map (titled: Presence/Absence) was developed by further reducing the information in each individual function map (e.g., Ecosystem Function 3: Disturbance Regulation) to a presence or absence and then overlaying all 19 function maps. For example, in the Disturbance Regulation map, if a cell was highlighted as performing that function it became present (values = 1). If no data were identified to support that the function was performing in that area (cell) it became absent (0). Individual

ecosystem function maps were then overlaid. The resulting Total Ecosystem Function map had a data range of 0 - 19.

The second Total Ecosystem Function map (titled: Quartile) was produced by quartiling each of the 19 individual function maps as described in the Total Ecosystem Function Maps section, Method B; maintaining all values 1 - 4 and then overlaying them. For example, each function map had a highest score of 4 and when combined (overlaid), cells in the resulting Total Ecosystem Function map had a potential data range of 0 – 76.

Peer review and version analysis
Each stage in the development of the Framework is an iterative process of data collection, analysis, and review (Maynard et al. 2010). The first stage of peer review, including the mapping products, involved the presentation of the maps and underpinning data sets to the Steering Group containing representatives from State and Local Governments, nongovernment organizations, and leading academics. Once suggestions were accounted for through any required modifications, the maps and underpinning data sets were presented to an open forum of interested persons and organizations (the Working Group). Forums have seen representation from federal, state and local governments, agricultural organizations, business, industry, and nongovernment organizations.

RESULTS

Individual ecosystem function maps
In all, 19 ecosystem function maps were produced as well as two versions of Total Ecosystem Function maps. All 19 ecosystem function maps are contained in Appendix 3 presented as Figure A3.1 to A3.19. A brief interpretation of one of the 19 individual ecosystem function maps, namely, Function 3 (Disturbance Regulation) will now be presented. The map itself is presented as Figure A3.3 in Appendix 3.

Disturbance Regulation
The description of this function as developed through the Expert Panels includes: the capacity of the soil, regolith, and vegetation to buffer the effects of wind, water, and waves through water and energy storage capacity and surface resistance. The soil profile stores water and reduces runoff. Vegetation enhances infiltration and provides surface resistance. Degraded soils and landscapes have a reduced capacity. Soil properties (e.g., depth, surface texture) and vegetation structure are important.

These are the areas of landscape that minimize flash floods, storm surges, landslips, excessive runoff, and a whole range of other processes that regulate the peaks and troughs in Australia's highly variable weather and rainfall (White and Karssies 1999). Fifteen (15) data sets or pathways to performing this function were applied to develop this map.

Table 1. The data sets and frequency of use in the 19 individual ecosystem function maps (references to data custodians can be found in Table 2, Appendix 2).

Data Sets Applied	# of EFs applied to
Good Grass Cover[†]	11
Woody Vegetation	10
Wetlands	9
Mangroves, Samphire and Salt Marsh; Floodplains and Coastal Deposits[†]; Woody Vegetation on Streams[†]; Sea Surface[†]; Tidal Zone[†]	7
SEQ Biodiversity Planning Assessment V3.4; Good Agricultural Land (Classes A and B); SEQ Water Bodies; SEQ Streams; Vegetation Corridors	6
Seagrass; Euphotic Zone[†]; Sand and Mudbanks[†]; Vegetation Tracts[†]	5
Fish Habitat Areas; Reefs; Rocky Reefs; Special Biodiversity Values; Woody Vegetation on Slopes[†]; Good Streams[†]	4
Low Total Nitrogen; Low Total Phosphorus; Low Total Suspended Solids; Priority Taxa Nonremnant[†]; High Rainfall[†]; Reservoirs; Threatened Species Habitat; Islands; Island Streams; Wet Forests; Regional Ecosystem Variety[†]	3
High Ecosystem Values Aquatic; Core Habitat; FLAG Lowup; Managed Forests; Marine Park Conservation Zone; Marine Park Habitat Zone; Sand and Gravel above 5m[†]; Deeps and Drops[†]; Heathlands; Midlands[†]; Mountains[†]	2
Broad Agriculture; Grey Nurse Habitat; Grazing; Density of Headwater Streams[†]; Intensive Agriculture; Land less than 5m[†]; Coastal Dunes[†]; Plantations; High Total Nitrogen; High Total Phosphorus; High Total Suspended Solids; Woody Vegetation less than 5m[†]; Wader Habitat and Roosts; Geo Diversity[†]; Scenic Preference; Shelter[†]	1

[†] These data sets were identified data gaps at the time of developing these maps. They were derived for the purposes of this methodology from other data sets listed in this table.

Seven (7) were directly related to vegetation, for example: vegetation on slopes, vegetation on streams, and areas with good groundcover. Other layers included water bodies for the capacity to hold and store water in times of high rainfall, coastal and dune systems for providing protection from coastal erosion during increased wind, waves, and storm surges.

Areas in dark blue on the Disturbance Regulation map show areas of highest data overlap with the coastal areas including the islands highlighted the most. Other areas also with high overlap include the higher elevated and high rainfall areas in the south and the north that still retain larger amounts of remnant vegetation, also, riparian areas and the floodplains at the bottom of these elevated areas. Areas with the least amount of data overlay were those containing agriculture, built infrastructure/settled areas, and some grasslands in the west of the region. Through the Expert Panel process, areas performing the function Disturbance Regulation are most important for providing the ecosystem services of: maintaining water quality, the area and extent of arable land, and buffering against extreme events.

Data sets
To develop the 19 ecosystem function maps, 59 unique data sets were identified that together and in different combinations would provide a representation of where individual ecosystem functions (important for maintaining ecosystems, biodiversity, and provision of ecosystem services) were taking place in the landscape. Some data sets were used to map more than one ecosystem function, but each data set was only applied once within each function even if it was considered that the data set was an appropriate surrogate for more than one pathway. The data sets applied, and the number of ecosystem function maps they were applied to, are presented in Table 1.

From inspection of Table 1 the data sets Good Grass cover, detected Woody Vegetation cover, and Wetlands were applied most in the development of the ecosystem function maps, and they were applied to 11, 10 and 9 ecosystem functions respectively. There were 17 data sets used in five or more ecosystem functions. There were a further 26 data sets used for between two and four ecosystem functions. There were 16 data layers that were used for only one ecosystem function. Data sets developed specifically for the purposes of mapping ecosystem functions, i.e., the 23 derived layers as described in Appendix 2, Table A2.1, were applied in up to 11 functions and five derived layers were in seven or more functions. Six (6) of the derived layers were only used for one function.

Table 2 lists the number of data sets applied to develop each ecosystem function map and the maximum number of data overlays occurring in any given area. It also lists the percentage of area on the map where there were no data to support that the ecosystem function under investigation was being performed here. Percentages are also provided on the amount of area covered by just one data set or multiple data sets. The final column shows the percentage of actual data coverage for each function that contained greater than one data layer.

The highest number of data sets was required to map Supporting Habitats (29) and the lowest number was required to map Barrier Effect of Vegetation (one), Shade and Shelter closely followed with two data sets. On average 10 data sets were required to map each individual function, but overall the number of data sets required to map each function was highly variable. For each ecosystem function, over 50% of the data sets overlap at some place on the resulting map.

Table 2. Summary of extent and data overlap for each ecosystem function map.

Ecosystem Function	# of data sets applied	max # of data set overlap	% of SEQ area no data/ no function	% of SEQ area = 1 data set	% of SEQ area >1 data set	% of data coverage>1 layer
EF 01 Gas Regulation	10	8	13.73	49.12	37.15	43.06
EF 02 Climate Regulation	7	5	3.04	56.63	40.33	41.60
EF 03 Disturbance Regulation	15	9	39.17	24.31	36.52	60.03
EF 04 Water Regulation	8	8	45.50	21.81	32.68	59.97
EF 05 Soil Retention	4	4	51.00	27.29	21.71	44.31
EF 06 Nutrient Regulation	14	11	26.88	26.88	49.02	64.58
EF 07 Waste Treatment	13	10	25.98	34.54	39.48	53.34
EF 08 Pollination	7	6	65.13	16.48	18.39	52.74
EF 09 Biological Control	5	4	65.29	16.49	18.22	52.49
EF 10 Barrier Effect of Vegetation	1	1	68.00	32.00	0.00	0.00
EF 11 Supporting Habitats	29	16	32.28	27.15	40.57	59.91
EF 12 Soil Formation	7	6	61.18	20.15	18.68	48.11
EF 13 Food	16	8	54.83	32.09	13.08	28.95
EF 14 Raw Materials	6	5	63.97	11.65	24.38	67.67
EF 15 Water Supply	11	10	46.87	17.16	35.97	67.69
EF 16 Genetic Resources	15	9	55.82	17.07	27.11	61.36
EF 17 Shade & Shelter	2	2	64.73	33.55	1.72	4.87
EF 18 Pharmacological Resources	9	6	71.97	21.18	6.85	24.43
EF 19 Landscape Opportunity	25	12	2.01	32.97	65.02	66.36

The ecosystem functions Landscape Opportunity, Climate Regulation, Gas Regulation, Nutrient Regulation, Waste Treatment, Supporting Habitats, and Disturbance Regulation occurred over a broad area with 60% coverage of the SEQ region. The ecosystem functions with the narrowest areas were Pharmacological Resources, Barrier Effect of Vegetation, Biological Control, Pollination, Shade and Shelter, Raw Materials, and Soil Formation, which all had less than 40% coverage. If areas of no data/no function are excluded for eleven of the ecosystem functions over 50% of their map area is made up of one or more layers. For two of the ecosystem functions "Shade and Shelter" and "Barrier effect of vegetation" this figure is less than 10%. For the remaining three ecosystem functions it is above 40%. Where there were data, the coincidence of data overlap was strong, revealing the many pathways for those landscapes to provide for ecosystem services.

Total Ecosystem Function Maps
The two Total Ecosystem Function maps are presented as Figures A4.1 and A5.1 in Appendices 4 and 5 respectively, and will now be described in more detail.

Total Ecosystem Function Map: Presence/Absence
The Total Ecosystem Function Map is the composite of all 19 function layers and their interaction within the region. The areas of high function overlap represented by dark blue on the map included largely natural areas, high ecological health streams in headwater areas, elevated landscapes, freshwater wetlands and coastal wetlands, and marine ecosystems, such as seagrass meadows and shallows. It was noted that high ecosystem functions were scattered across the landscape even

within the urban and built environment. Areas of lower ecosystem functions occurred in some cropping areas, urban and rural residential areas, and the marine environment. In some cases such as the marine environment, data gaps were the cause of low scoring.

Table 3 shows across the region peaks in ecosystem function overlap occurred at two, four, seven, 14 and 18 overlying functions with the highest peak at seven function overlaps. Areas that had just one mapped function occupied 17.32 % of the area and only 0.42% had no mapped function. Only 2.92% of the area had the highest possible function overlap (i.e., 19 functions). This method of map development compensated for areas where there were little data available.

Total Ecosystem Function Map: Quartile
The quartiling approach weighted data overlap within each ecosystem function with a score of one to four, with a four having highest overlap. Combining the 19 quartiled ecosystem function layers, the highest total achievable is 76 with 68 being observed. High function overlap is represented by dark blue on the map and includes islands, elevated areas and upper catchment reaches, healthy streams, and largely natural areas. Areas of high and low function overlap were similar to the Presence/Absence method, however, more defined given the larger data range. For example, rather than the whole of Moreton Island being high as in the Presence/Absence method, the eastern fore dunes and western ecosystems are providing more functions as well as the southern tip that mostly supports wetland communities.

Some data layers were used in a large number of ecosystem function maps and so contributed more to the total ecosystem

function map than others. In particular, woody vegetation, remnant vegetation, good grass cover, wetlands, and deeper soils appeared in a number of layers as shown in the results.

Table 3. Number of ecosystem function overlaps by the % of SEQ area.

Number of overlapping ecosystem functions	% of SEQ area with overlap
0	0.42
1	17.32
2	9.75
3	0.92
4	8.85
5	1.90
6	2.83
7	12.93
8	2.05
9	1.74
10	1.67
11	2.30
12	2.54
13	3.15
14	5.90
15	2.63
16	3.62
17	5.86
18	10.70
19	2.92

Table 4. Number of data sets overlapping by the % of SEQ area.

Number of overlapping data sets	% of SEQ area with overlap
0	0.421
1-10	51.667
11-20	13.992
21-30	12.969
31-40	10.591
41-50	8.503
51-68	1.856

Table 4 shows that the maximum number of data overlaps occurring in this Total Ecosystem Function map was 68, with a peak at 11-20 data sets overlapping.

DISCUSSION

The method applied demonstrated that is was possible to spatially locate where ecosystem functions are derived and show by way of data overlap a rough measure of relative significance. Reviewing literature and interpreting the available data sets allowed the spatial identification of the processes and components of ecosystems that are providing ecosystem functions across the SEQ region, and therefore have the potential to provide high amounts of specific or multiple ecosystem services.

The review of available data indicated that although there were significant gaps in required information, there were sufficient data sets available for the mapping. When required and possible, new data sets were developed to fill these gaps. As most of the newly derived data sets contributed to four or more function maps it is evident these new data sets played a significant role in bridging these gaps, making a powerful contribution to presenting the individual functions. While there were not sufficient data to indicate the magnitude of the functions provided there was sufficient research or general principles in the literature to establish the rationale for using particular data sets for each function.

Fifteen (15) of the ecosystem function layers had greater than 40% of their mapped area (the SEQ region) covered with two or more data sets. No ecosystem function maps had an overlap of data areas cover greater than 70% of the mapped area. These results indicate the importance of the individual data layers and the need to use multiple surrogates to get the most comprehensive coverage of areas and to represent all the different pathways in which the same ecosystem function can be performed. With only a few exceptions, the areas that had the highest data overlap in the individual function maps all occupied only a small fraction of the total area.

Research into whether higher data overlap equates to a higher magnitude of actual ecosystem function has recently been conducted (S. Maynard R. Runting, M. Petter, S. Mooney, and A. Davidson, Synthesizing expert knowledge and GIS data sets to support an ecosystem services assessment framework, *unpublished manuscript*). Results indicate a strong relationship between high amounts of data overlap and magnitude of function, however, there can be no doubt that a lack of data will lead to less data overlaps occurring when using this method. This can be seen by the results for coastal and marine areas. Hotspots of coastal and marine ecosystem function have been identified but because of data gaps these areas have less total ecosystem function overlap than terrestrial areas. So, in addition to the maps providing some representation of ecosystem function, they also represent the state of our knowledge in these areas that can guide priorities for further data acquisition.

Also, lack of data overlap does not always indicate a lesser importance. The specific component of an ecosystem or pathway to that specific function (represented by a single data set) may be the most ecologically significant to maintaining that function in real world processes. This highlights the need for weighting of individual data layers and/or ecosystem functions in the context of the specific use intended (e.g., weighting the gas regulation function higher when applying to climate change mitigation and adaptation strategies).

Some data sets were used in a larger number of ecosystem function maps (i.e., vegetation data sets such as good grass cover, detected woody vegetation, and wetlands) and so contributed more to the Total Ecosystem Function map.

When reviewing the two Total Ecosystem Function maps, Method B (Quartile) preserved high overlaps within ecosystem functions but lost areas with low data availability. Method A (Presence/Absence) was less sensitive to data gaps but failed to preserve information about high overlap areas within individual ecosystem functions. Consultations with decision makers and community ranked Method A as being more balanced and understandable. Ideally an overlap method that combines the strengths of both approaches is required.

It is important to recognize the limitations of GIS mapping. Among these limitations are biases in the geographic and temporal coverage of the data and in the types of data collected (Millennium Ecosystem Assessment 2005, Troy and Wilson 2006, Maynard et al. 2010). Data availability for some subregions in SEQ is greater than for others (e.g., marine areas), and there are differences between data availability for the various types of resources (e.g., biodiversity). Steps have been identified and others are being undertaken to narrow these differences. For example, to overcome the paucity of marine data one interim step would be to split all sea areas into at least three separate layers, benthic, pelagic, and sea surface in recognition of their distinct roles and the essentially three-dimensional nature of the ocean.

CONCLUSION

The Millennium Ecosystem Assessment (MA) applied expert judgment to existing knowledge held by scientists, practitioners, and communities to address policy-relevant questions at global and subglobal scales (Millennium Ecosystem Assessment 2005). The SEQ project focused on local and regional scales and faced many of the same challenges identified in the broader-scale MA, i.e., data availability; bridging scales and knowledge systems of stakeholders; and ensuring the resulting products were sufficiently place-based and credible to meet the needs of decision makers.

The data sets that were applied and the resulting maps produced have been peer reviewed by the Steering Group, through an open forum of interested persons and organizations, predominantly SEQ stakeholders (the Working Group), and national and international conferences (Maynard et al. 2010). Overall the method produced maps that, when reviewed, were regarded as credible and useful. The mapping has helped strengthen government policy with respect to ecosystem services.

Ecosystem services and the SEQ Ecosystem Services Framework have been incorporated into the statutory planning document for the region: the SEQ Regional Plan 2009 – 2031.

Policy 4.3 (page 71) discusses the need to "Protect, maintain, and enhance the capacity of the region's ecosystems to supply ecosystem services". The ecosystem function maps are integral to the identification and measuring of ecosystem services to support this policy.

Other applications of the Framework and mapping products are as a Guiding Principle supporting the SEQ Natural Resource Management Plan 2009 – 2031 (Department of Environment and Resource Management 2009); Local Government Planning Schemes, Community Plans, Biodiversity and Nature Conservation Plans, and Water Resource Strategies. The method described for mapping ecosystem functions was used to generate two data sets for the SEQ State of the Region Report, one a map of ecosystem functions in 1991 and the other a change in ecosystem function map from 1991 to the present (Queensland Government 2008). Other potential applications include climate change mitigation and adaptation strategies and guiding the development of a regional offsetting program.

The project was limited in financial resources but fortunate to have some sound data sets and previous literature to draw upon, as well as expert and local knowledge. It is recognized that the SEQ region is relatively data rich, but key ingredients have been identified that would be required to apply this methodology to other regions, at the state-level or nationally.

The Framework remains nonprescriptive so stakeholders are able to apply the information to their management practices within their own capacities. Future work by SEQ Catchments will use these ecosystem function layers as feedstock for the production of ecosystem service maps.

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Table A1.1. List of Ecosystem Functions and their descriptions as incorporated into the SEQ Ecosystem Services Framework

Function Categories	Ecosystem Function	Description - ecosystem processes and components (Ecological Complexity)
Regulating Functions Maintenance of essential ecological processes and life support systems.	**(1) Gas regulation**	Relates to the influence of natural and managed systems in relation to biogeochemical processes including greenhouse gases, photo-chemical smog and volatile organic compounds (VOCs).
	(2) Climate regulation	Influence of land cover and biological mediated processes that regulate atmospheric processes and weather patterns which in turn create the microclimate in which different plants and animals (incl. humans) live and function.
	(3) Disturbance regulation	The capacity of the soil, regolith and vegetation to buffer the effects of wind, water and waves through water and energy storage capacity and surface resistance. The soil profile stores water and reduces runoff. Vegetation enhances infiltration and provides surface resistance. Degraded soils and landscapes have a reduced capacity. Soil properties (e.g. depth, surface texture) and vegetation structure are important.
	(4) Water regulation	The influence of land cover, topography, soils, hydrological conditions in the spatial and temporal distribution of water through atmosphere, soils, aquifers, rivers, lakes and wetlands
	(5) Soil retention	Minimising soil loss through having adequate vegetation cover, root biomass and soil biota.
	(6) Nutrient regulation	The role of ecosystems in the transport, storage and recycling of nutrients.
	(7) Waste treatment and assimilation	The extent to which ecosystems are able to transport, store and recycle certain excesses of organic and inorganic wastes through distribution, assimilation, transport and chemical recomposition.
	(8) Pollination	Pollination is critical to the reproduction of most wild plants and the production of food for consumption by animals and humans. Pollination is the interaction between plants and (1) biotic vectors e.g. insects, birds and mammals and (2) abiotic vectors e.g. wind and water in the movement of male gametes for plant production. Pollination and seed dispersal are linked.
	(9) Biological control	The interactions within biotic communities that act as restraining forces to control population of potential pests and disease vectors. This function consists of natural and biological control mechanisms.
	(10) Barrier effect of vegetation	Vegetation impedes the movement of airborne substances such as dust and aerosols (including agricultural chemicals and industrial and transport emissions), enhances air mixing and mitigates noise.
Supporting Functions Providing habitat (suitable living space) for wild plant and animal species at local and regional scales.	**(11) Supporting habitats**	Preservation of natural and semi natural ecosystems as suitable living space for wild biotic communities and individual species. Natural ecosystems are a storehouse of genetic information generated through evolutionary process. This function also includes the provision of suitable breeding, reproduction, nursery and refugia and corridors (connectivity) for species that are harvested or otherwise valued.
	(12) Soil Formation	Soil formation is the facilitation of soil formation processes. Soil formation processes include the chemical weathering of rocks and the transportation and accumulation of inorganic and organic matter.
Provisioning Functions Provision of natural resources.	**(13) Food**	Biomass that sustains living organisms. Material that can be converted to provide energy and nutrition. Mostly initially derived from photosynthesis.
	(14) Raw materials	Biomass that is used for any purpose other than food (excluding mining resources).
	(15) Water supply	The role of ecosystems in providing water through sediment trapping, infiltration, dissolution, precipitation and diffusion.
	(16) Genetic resources	Self maintaining diversity of organisms developed over evolutionary time (capable of continuing to change). Measurable at species, molecular and sub molecular levels. These processes are increasingly paralleled by human intervention.
	(17) Provision of shade and shelter	Relates to vegetation that ameliorates extremes in weather and climate at a local landscape scale. Shade or shelter is important for plants, animals and structures.
	(18) Pharmacological resources	Natural materials that are or can be used by organisms to maintain, restore or improve health. (Natural patterns can be copied by humans for synthetic products).
Cultural Functions Providing life fulfilment opportunities and cognitive development through exposure to life processes and natural systems.	**(19) Landscape opportunity**	The inspiration and motivation, traditional owner and other cultural, historical and aesthetic values; health enhancement; sense of place; amenity; recreational, scientific and educational opportunity, provided by the extent and variety of natural features and landscapes.

APPENDIX 2

Table A2.1. Data sets used and a description of the contribution of each data set to a component of ecosystem function.

Data set	Data Set Reference	Rationale	Comments
Gas Regulation			
Good Grass Cover	Scarth et al. (2006)	Grassy vegetation plays a role in evaporation and thermal balance (Reynolds and Frame 2005).	Future versions could include shallow seas to acknowledge role in the regulation of oxygen, carbon dioxide, methane, and also trace gases such as methyl sulphides which are very important for cloud formation, and gases of iodine and selenium which is the main distribution network for those micro nutrients to go inland (Neil Tindale *pers. comm.*, 2007). Further investigations will occur into how soil impacts on gas regulation, particularly on carbon sequestration. Agricultural lands could also be included particularly where these soils are under trees and good grass cover.
Woody Vegetation	(Department of Natural Resources and Mines 2005)	Trees contribute to the improvement of air quality (Krieger 2001). Other scientific information suggests that streams are very important sites for carbon sequestration and for nitrogen regulation.	
Woody Vegetation on Streams	Mooney and Petter (unpublished manuscript)		
Wetlands		Wetlands contribute to the process of carbon sequestration by removing CO_2 from the atmosphere (Whiting and Chanton 2001).	
Shallow Sea	Mooney and Petter (unpublished manuscript)	Gas exchange of CO_2, O_2, and CH_4 occurs between the atmosphere and the ocean's surface (Scholes et al. 2003).	
Sea Surface	Mooney and Petter (unpublished manuscript)		
Tidal Zone	Mooney and Petter (unpublished manuscript)	Tidal zones contribute to gas regulation (Batker et al. 2005).	
Climate Regulation			
Good Grass Cover	Scarth et al. (2006)	The presence or absence of groundcover influences climate regulation and temperatures near the ground (Geiger 1965).	Aspect, hill slope, shade, and onshore sea breezes would have been included if data was available. Veg

Data set	Data Set Reference	Rationale	Comments
Woody Vegetation	Scarth et al. (2006)	Trees create an area where climate regulation occurs under the canopy (Geiger 1965).	mapping was used as a surrogate. There is evidence that modified systems such as cropping/irrigated land can have a cooling effect (Abel et al. 1997), as can water bodies and dams (Park 2001). The good grass cover and woody veg layers have been used as surrogates for climate regulation. This is distinct from gas and CO^2 regulation (Sturges et al. 2001), and other elements of climate regulation which are covered by other functions.
Rainfall	Mooney and Petter (unpublished manuscript)	Rainfall is an indicator of climate variability (Lough 1994).	
Sea Surface	Mooney and Petter (unpublished manuscript)	Oceans play a key role in the global carbon cycle and climate regulation (Chisholm et al. 2001).	
Disturbance Regulation			
Mangroves, Samphire and Salt Marshes	EPA (Young and Dillewaard 1999)	Mangroves provide buffers to floods and storm surges and protect coast lines from erosion (Tomlinson 1994). Mangroves provide storm protection (Bennett and Alcamo 2004). Salt marshes provide protection against disturbance events (Laegdsgaard 2006).	Evidence from the Millennium Ecosystem Assessment Report on Ecosystems and Human Well-Being suggests that reefs provide storm protection and can reduce impacts of hurricanes and tidal waves (Bennett and Alcamo 2004).
Good Grass Cover	Scarth et al. (2006)	Contributes to dune and bank stabilization (United States Army Corps of Engineers 1989).	
Land Below 5 Metres HAT	NASA Shuttle Radar Typography Mission (Rabus et al. 2003), with DNR&M for use in this project (P Scarth 2007, pers. comm., 22 March).	Coastal areas within this layer have been exposed to disturbances in the past. For example, there is geological evidence that a large tsunami previously hit the south east coast of Australia (Dawson and Shi 2000), indicating that this area is prone to possible further disturbances.	

Data set	Data Set Reference	Rationale	Comments
Coastal Dunes	Mooney and Petter (unpublished manuscript)	Dunes provide protection from coastal erosion processes including wind, waves and storm surges (Zimmermann et al. 2005).	
Floodplain and Coastal Deposits	Mooney and Petter (unpublished manuscript)	Floodplains reduce flooding by spreading and slowing stream flows (Murphy and Nance 2000), and absorbing and holding water during storms. This also recharges local aquifers, reducing downstream flooding (Rapport et al. 1998).	
High Rainfall	Mooney and Petter (unpublished manuscript)	High intensity rainfall leads to runoff, which can lead to flooding and cause erosion (Suppiah and Hennessy 1998). Therefore high intensity rainfall is representative of areas where disturbances are likely to occur.	
SEQ Water Bodies	Department of Environment and Resource Management (DERM 2008)	Lakes and dams store water and can reduce flooding by taking on excess flood waters and runoff thereby reducing their impact (Neal et al. 2007).	
Woody Vegetation	DNR&M (2005)	Trees provide disturbance regulation by providing shelter from strong winds and conserving soils (Abel et al. 1997).	
Woody Vegetation Less than 5 Metres HAT	Mooney and Petter (unpublished manuscript)		
Woody Vegetation on Slopes			
Woody Vegetation on Streams			
Wetlands	DERM (2008)	Wetland vegetation reduces the flow of floods and the wetlands store additional water flows (United States Environmental Protection Agency 2006).	
Islands	DERM (2008)	Islands can buffer mainlands from disturbances such as tsunamis (Hanson et al. 2002).	

Data set	Data Set Reference	Rationale	Comments
Sand and Mud banks	Mooney and Petter (unpublished manuscript)	Sand and mud banks provide protection from coastal erosion during wind, waves and storm surge events (Zimmermann et al. 2005).	
Tidal Zone	Mooney and Petter (unpublished manuscript)	Disturbances along coastal communities are likely to occur in tidal zones (below HAT) (McInnes et al. 2003).	
Water Regulation			
Good Grass Cover	Scarth et al. (2006)	Grass slows down water flows (Land Stewardship Project 2004).	
Good Quality Agricultural Land	Department of Primary Industries (DPI) and Department of Housing, Local Government and Planning (DHLGP, 1993).	Good Quality Agricultural Land includes soils of either high moisture content or high water holding capacity (Department of Primary Industries and Department of Housing, Local Government and Planning1993). Therefore this land provides the function of water regulation by absorbing excess water during high or extended rainfall periods or during flooding.	
Woody Vegetation	Scarth et al. (2006)	Plants absorb water from the soil and convert it into gas (transpiration), reducing soil water levels (Murphy and Nance 2000).

Plays a very important filtering role. | |
Woody Vegetation on Slopes	Mooney and Petter (unpublished manuscript)		
Woody Vegetation on Streams	Mooney and Petter (unpublished manuscript)		
Floodplain and Coastal Deposits	SEQ Geological Units Database: DNR&M (2002)	Floodplains regulate stream flow and can reduce flooding by slowing stream velocity during peak flows (Murphy and Nance 2000).	
Sand, Gravel above 5 Metres HAT	DNR&M (2002)	Sand and gravels are highly porous and can store and transmit water (Murphy and Nance 2000).	

Data set	Data Set Reference	Rationale	Comments
Wetlands	Environmental Protection Agency (EPA 2008)	Wetland vegetation reduces the flow of floods and the wetland stores additional water flows (United States Environmental Protection Agency 2006).	
Soil Retention			
Good Grass Cover	Scarth et al. (2006)	Groundcover reduces soil erosion (Prosser et al. 2000)	This function refers to the rate at which soil moves around the landscape as opposed to its rate of natural formation.
Woody Vegetation	Scarth et al. (2006)	Forested areas have soils with high stability, soil health, and infiltration rates, and low erodibility (Young 1989).	
Vegetation on Slopes	Mooney and Petter (unpublished manuscript)	Vegetation on slopes reduces erosion rates (Prosser et al. 2000)	
Vegetation on Streams	Mooney and Petter (unpublished manuscript)	Streams with vegetation on surrounding banks are much less prone to erosion than bare stream banks (Beeson and Doyle 1995).	
Nutrient Regulation			
Biodiversity Planning Assessment	Environmental Protection Agency (EPA 2002)	The BPA layer represents areas of remnant vegetation. Remnant native vegetation provides a variety of important ecosystem functions, including nutrient cycling (Parkes et al. 2003).	Southern Moreton Bay is highlighted as an important area for nutrient regulation due to the location of these ecosystems and related biophysical factors. The Wader Habitat layer could also be included in the nutrient regulation function as supported by de Groot et al. (2002: 399)"migration (of birds, fish and mammals) plays an important role in the distribution of nutrients between ecosystems".
Mangroves, Samphire and Salt Marshes	EPA (Young and Dillewaard 1999).	Mangroves are sites of high nutrient cycling (Tomlinson 1994). Salt marshes are nutrient cycling sites (Broome et al. 1988).	
Fish Habitat Areas	(Queensland Fisheries Service-Marine Habitat 2000)	Areas of fish habitat are nutrient cycling sites (Broome et al. 1988).	
Good Grass Cover	Scarth et al. (2006)	Grasses and plants contribute to nutrient cycling in soils (Murphy and Nance 2000).	
Good Quality Agricultural Land	DPI and DHLGP (1993).		
Woody Vegetation	Scarth et al. (2006)		

Data set	Data Set Reference	Rationale	Comments
Managed Forests	Queensland Land Use Mapping Project (QLUMP) (Witte et al. 2006)		
Low Nitrogen, Phosphorus, Total Suspended Solids	WBM Oceanics (2005)	Low levels of nutrients indicate areas where nutrient cycling is occurring (Bormann and Likens 1967).	
Floodplain and Coastal Deposits	DNR&M (2002)	Floodplains are sites where nutrient cycling occurs (Tockner et al. 1999).	
Streams	WBM Oceanics, (2004)	Nutrient cycling occurs in streams (Newbold et al. 1981).	
Woody Vegetation on Streams	Mooney and Petter (unpublished manuscript)	Grasses and plants contribute to nutrient cycling in soils (Murphy and Nance 2000). Nutrient cycling occurs in streams (Newbold et al. 1981).	
Wetlands	EPA (2008)	Wetlands are nutrient cycling sites (Corstanje et al. 2007).	
Shallow Seas	Maritime Safety Queensland (MSQ 2007) US National Geospatial Intelligence Agency (USNGIA 2005)	Nutrient cycling occurs in Shallow Seas (Sturges et al. 2001). Tidal and wave action in combination with export of organic matter, may moderate the accumulation of ephemeral algae and, thus also, render some rocky shore communities relatively resistant to nutrient enrichment (Kraufvelin 2007).	
Sea Surface		Nutrient cycling occurs at the sea surface (Sturges et al. 2001).	
Waste Treatment			
Mangroves, Samphire and Salt Marshes	EPA (Young and Dillewaard 1999)	Mangroves are valuable sites for waste treatment (de Lacerda 2002).	This map focuses on the capacity of the natural systems to assimilate waste which is regarded as excess

Data set	Data Set Reference	Rationale	Comments
Good Grass Cover	Scarth et al. (2006)	Plants provide the ecosystem service of eliminating contaminants from soils (Cunningham et al. 1995).	nutrients rather than the amount of waste processing being carried out as a result of pollution activities. However for example, in wetlands the process of natural water purification that removes pollutants and pesticides from waters is a method of waste treatment or waste assimilation which can be described as an ecosystem function (Cork et al. 2001).
Woody Vegetation	Scarth et al. (2006)	Plants absorb nutrients in waste products, primarily through the roots, and transform the soluble chemical elements, (including water contaminants), into plant tissue (Getter 1999).	
Low Nitrogen, Phosphorus, Total Suspended Solids	WBM Oceanics (2005).	Low levels of nutrients indicate areas where natural waste treatment is effectively occurring (Bormann and Likens 1967).	
Floodplain and Coastal Deposits	MSQ (2007) USNGIA (2005)	Filtration is among the most important ecosystem functions provided by floodplains (Shelton et al. 2001) and is a form of waste treatment.	
Low Total Nitrogen	WBM Oceanics (2005).	Nutrient levels can indicate either good or poor ecosystem health (Bunn et al. 1999), low total nitrogen indicates good ecosystem health, and therefore that waste treatment is naturally occurring in that area (Bormann and Likens 1967).	
Low Total Phosphorus	WBM Oceanics (2005).		
Low Total Suspended Solids	WBM Oceanics (2005).		
Streams		Streams and rivers are areas of natural waste assimilation and treatment (Velz 1970).	
Woody Vegetation on Streams	Mooney and Petter (unpublished manuscript)	Plants provide the ecosystem service of eliminating contaminants from soils (Cunningham et al. 1995).	
Wetlands	EPA (2008)	Wetlands have a higher rate of biological activity than most ecosystems therefore they can transform many of the common pollutants that occur in conventional waste waters into harmless by-products or essential nutrients that can be used for additional biological productivity (Kadlec and Wallace 2008).	

Data set	Data Set Reference	Rationale	Comments
Shallow Seas	MSQ (2007)	Ocean ecosystems provide waste assimilation and treatment of water (Lochte et al. 2003).	
Sea Surface	USNGIA (2005)		
Pollination			
Biodiversity Planning Assessment	EPA (2002)	Pollination occurs in areas of remnant vegetation. Remnant vegetation is of high importance to native pollinators (Cunningham et al. 2002).	Future versions will assess the pollination role of fish habitat areas, coral generation areas and areas for generating important shellfish species. A 1-5 kilometre buffer around vegetation was adopted based on the advice from invertebrate and pollination experts regarding the likely ranges of vertebrate and invertebrate pollinators, including native bees (1km), European bees, birds, small gliders (5km) and bats (15, to 50 during drought conditions) (Committee on the Status of Pollinators in North America 2007).
Good Grass Cover	Scarth et al. (2006)	Pollination occurs on grasses and groundcover (Friedman and Harder 2004).	
Wetlands	EPA (2008)	Pollination occurs in wetlands (Cronk and Fennessey 2001).	
Vegetation Corridors	EPA (2002)	Pollination occurs in vegetation (Dafni 1992).	
Heath lands	EPA (2005)	Pollination occurs in heath lands (Dafni 1992).	
Wet Forests		Pollination occurs in forests (Dafni 1992).	
Vegetation Tracts	Mooney and Petter (unpublished manuscript)	Pollination occurs in vegetation (Dafni 1992).	
Biological Control			
Biodiversity Planning Assessment	EPA (2002)	The larger the area of remnant vegetation, the more possibilities native, vulnerable or threatened species have combating against edge effects, predators, meaning the population has a higher resilience (Murcia 1995).	Future versions will develop a surrogate map that reflects plant diversity based on the assumption that higher plant diversity provides more habitat opportunities for beneficial species for pest control.
Vegetation Corridors	EPA (2002)		
Vegetation Tracts	Mooney and Petter (unpublished manuscript)		
Good Grass Cover	Scarth et al. (2006)		
Islands		Distance from mainland protects from exotic and predator species invasions.	

Data set	Data Set Reference	Rationale	Comments
Barrier Effect of Vegetation			
Woody Vegetation	Scarth et al. (2006)	Woody vegetation impedes the movement of airborne substances such as dust and aerosols, enhances air mixing and mitigates noise (Bolund and Hunhammar 1999).	The challenge in defining this function spatially confused the issue, so rather than the focus being on the protection from more noise, the map would identify the assets that generate the noises pleasing to humans such as surf, wind, etc. This approach appears to be supported by Bolund and Hunhammar (1999).
Supporting Habitats			
High Ecosystem Values Aquatic	Moreton Bay Waterways and Catchments Partnership (MBWCP 2005)	Areas with high invertebrate and fish diversity. Moreton Bay is internationally recognised for its high ecosystem values which are essential to maintain habitat for high biodiversity (South East Queensland Healthy Waterways Partnership 2007).	A habitat was deemed to be "supporting" if it possessed enough vegetation or other natural features to sustain some degree of ecosystem function. This is the broadest possible interpretation and is the function map that comes closest to nature conservation mapping whereas the remaining functions are more closely related to anthropocentric service provision. This function is a supporting function for the other functions and therefore services. In summary this map illustrates a broad range of ecosystems with relevant diversity and complexity that can sustain
Biodiversity Planning Assessment	EPA (2002)	The BPA identifies habitat areas in SEQ for a number of species (EPA 2002). Remnant vegetation provides habitat for native species (Parkes et al. 2003).	
Mangroves, Samphire and Salt Marshes	EPA (Young and Dillewaard 1999)	Mangroves are habitat to number of fauna (Tomlinson 1994). Saltmarsh habitats are recognised for their importance to migratory waders under the Ramsar convention, but it is increasingly evident that they are also important to a variety of commercially valuable fish and native mammal species (Laegdsgaard 2006).	

Data set	Data Set Reference	Rationale	Comments
Core Habitat	EPA (2002).	The EPA coordinated expert panels and information to determine the habitat areas in SEQ that are core habitat for endangered, vulnerable and rare (EVR) taxa (EPA 2002).	ecosystem functions that provide a vast range of ecosystem services. This results in the use of a large amount of data.
Fish Habitat Areas	Queensland Fisheries Service - Marine Habitat (2000).	Fish habitat areas are recognized as important areas in SEQ (South East Queensland Healthy Waterways Partnership 2007).	The woody vegetation layer could be included with remnant vegetation masked out to avoid doubling up with layers such as the BPA.
Grey Nurse Shark Habitat	EPA (2006b)	Listed by the EPA as a marine species of conservation significance (EPA 2006b).	
Marine Park Conservation Zone	Queensland Government (1997)	The 'Marine Parks Zoning Plan 1997', identifies important habitat areas in Moreton Bay (Queensland Government 1997).	
Marine Park Habitat Zone	Queensland Government (1997)		
Priority Taxa Non-remnant	EPA (2007b)	Plants provide habitat for fauna (Morrison et al. 2006).	
Reefs	EPA (2006b)	Reef and rocky reef habitats have very high biological importance, and are habitat to numerous fauna (Roberts et al. 2002).	
Rocky Reefs			
Seagrass		Seagrass beds are important habitat areas (Butler and Jernakoff 1999, Coles et al. 2004).	
Special Biodiversity Values	EPA (2002)	Areas of high biodiversity provide habitat for species (Brooks et al. 2002).	
Threatened Species Habitat	EPA (2002)	Data illustrates the habitat areas in SEQ for EVR species (EPA 2002). Remnant vegetation provides habitat for species (Parkes et al. 2003).	
Woody Vegetation on Streams	Mooney and Petter (unpublished manuscript)	"Natural riparian zones are some of the most diverse, dynamic, and complex biophysical habitats on the terrestrial portion of the planet" (Naiman and Décamps 1997, 622).	
Wader Habitat and Roosts	EPA (2006b)	Important Wader habitats are present in the Moreton Bay area (Clouston 2002).	

Data set	Data Set Reference	Rationale	Comments
Wetlands	EPA (2008)	Wetlands provide a wide variety of habitats for fish, invertebrates, amphibians, reptiles, mammals, and birds (Cronk and Fennessey 2001).	
Vegetation Corridors	EPA (2002)	Vegetation corridors/tracts provide important habitat for native fauna species (Bennett 1990). Plants provide habitat (Morrison et al. 2006).	
Vegetation Tracts	Mooney and Petter (unpublished manuscript)		
Shallow Seas	MSQ (2007) USNGIA (2005)	A variety of fish species occur in shallow sea waters (Warburton and Blaber 1992).	
Sand and Mud banks		Sand and mud banks are habitat areas (Lloyd and Cook 2002).	
Sea Surface		The Moreton Bay area is habitat for many marine species (Queensland Government 1997).	
Soil Formation			
Biodiversity Planning Assessment	EPA (2002)	Vegetation contributes to soil formation (Jenny 1994).	Jenny (1994, 148) states "from the viewpoint of soil formation, the most important classes of vegetation are forests, grasses, and desert shrubs. Jenny (1994, 141) quotes Joffe (1949), stating "without plants, no soil can form." However, it is highly debated among soil scientists as to whether organisms and vegetation actually contribute to the formation of soil (Jenny 1994, 141). "In all studies of soil-climate relationships, vegetation is treated as a dependent variable rather than as a soil-forming factor" (Jenny 1994, 141).
Mangroves, Samphire and Salt Marshes	EPA (Young and Dillewaard 1999: 12/6).	Mangroves and salt marshes are places where sedimentation occurs and soils are deposited (Rogers et al. 2005).	
Good Grass Cover	DNR&M (2005).	Site where soil formation occurs (Jenny 1994).	
Good Quality Agricultural Land	DPI and DHLGP (1993).	Contributes organic matter (Schnitzer and Khan 1978) and soils are deposited here (Phillips et al. 1999).	
Floodplain and Coastal Deposits	MSQ (2007) USNGIA (2005)	Weathered soils are transported and deposited here (Gerrard 1992).	
Woody Vegetation on Slopes	Mooney and Petter (unpublished manuscript)	Contributes organic matter which is important in soil formation (Schnitzer and Khan 1978). Site where soil formation occurs (Jenny 1994).	

Data set	Data Set Reference	Rationale	Comments
Wetlands	EPA (2008)	Weathered soils are transported and deposited here (Richardson and Vepraskas 2001).	Future versions will investigate the role of micro-organisms and invertebrates in soil formation and consider the inclusion of dry sclerophyll ecosystems.
Food			
Broad Agriculture	QLUMP (Witte et al. 2006)	Agriculture provides food products for humans such as wheat and beef (Kokic 1993).	This function is interpreted literally as those areas where humans and other animals obtain food in terms of supply. In the SEQ context, hunting natural game apart from fishing does not provide a significant amount of food for human consumption. The most significant game meat industry for human consumption is kangaroo. Traditional Owners would value bush foods and natural areas higher. In a divergence from biophysical and topographic interpretation of ecosystem function, this map relies on land use mapping as a surrogate for food provision. This map requires further thought particularly the contradiction between food for animals and food as a service for humans. However the MEA identifies biodiversity as a source of ecosystem goods such as food (Bennett and Alcamo 2004).
Mangroves, Samphire and Salt Marshes	EPA (Young and Dillewaard 1999: 12/6).	Mangroves are important areas of food sources for many animals (EPA 2007a).	
Good Quality Agricultural Land	DPI and DHLGP (1993).	Good quality agricultural lands are areas of high soil fertility and provide the bulk of fresh food (M. Petter *pers com*, 2008).	
Grazing	QLUMP (Witte et al. 2006)	An area where livestock graze for food.	
Intensive Agriculture	QLUMP (Witte et al. 2006)	Food growing and food production for human consumption (M. Petter *pers com*, 2008).	
Marine Park Habitat Zone	Queensland Government (1997).	A food source area for marine species and birds (EPA 2006c).	
Reservoirs	Dep. of Natural Resources and Water (DNR&W 2006)	The damming of rivers for water supply has created food sources and habitats for fish species and water birds (Arthington and Pusey 2003).	
Seagrass	EPA (2006b)	An important food source for many marine animals (Schneider and Mann 1991), and to marine biota along the Queensland coast (Coles et al. 2004).	
Water Bodies	DNR&W (2006)	Mostly farm dams which cattle use as their water supply.	

Data set	Data Set Reference	Rationale	Comments
Shallow seas	MSQ (2007) USNGIA (2005)	Photosynthesis provides food for autotrophic organisms (Garrison 2007).	
Tidal Zone		A variety of marine species feed in tidal zones (Pihl 1985).	
Raw Materials			
Woody Vegetation	Scarth et al. (2006)	Woody vegetation (trees and shrubs) planted for wood production (Kavanagh et al. 2005).	Hunting for skins or furs is not a significant part of mainstream culture in SEQ which leaves areas of timber as the principle raw material to map.
Managed Forests	QLUMP (Witte et al. 2006)	Australian forests are available for timber harvesting (Department of Agriculture Fisheries and Forestry 2003).	
Plantations	QLUMP (Witte et al. 2006)	Australia's plantations are an important source of hard and softwood supplies (Department of Agriculture, Fisheries and Forestry 2005).	A layer illustrating areas of private farm forestry would enhance this map.
Vegetation Corridors	EPA (2002)	Woody vegetation (trees and shrubs) planted for wood production (Kavanagh et al. 2005).	
Water Supply			
High Ecosystem Values (Aquatic)	(MBW&CP 2005)	Good ecosystem health requires adequate water supply to maintain that ecosystem's health (Gleick 1996).	The layers used to produce this map are considered indicators of a catchment in good health and functioning well to supply water. These areas are largely unmodified by human practices and can therefore be expected to be playing a very important water supply role. The MEA provides evidence that terrestrial plants provide water quality through the biological processes they undergo (eg. during evapotranspiration) (Bennett and Alcamo 2004).
FLAG lowup	(Roberts et al. 1997)	Areas where groundwaters are likely to accumulate (Roberts et al. 1997).	
Good Quality Agricultural Land	DPI and DHLGP (1993).	Good quality soils have high water content and retention capacity (Arshad and Martin 2002) or may occur above groundwater reserves.	
High Density of Headwater Streams	Mooney and Petter (unpublished manuscript)		
Low Nitrogen, Phosphorus, Total Suspended Solids	WBM Oceanics (2005).	Cleaner water is more likely to contribute to water supply (M. Petter *pers com*, 2008).	

Data set	Data Set Reference	Rationale	Comments
Rainfall	Mooney and Petter (unpublished manuscript)	Rainfall and runoff flows into reservoirs and dams (M. Petter *pers com*, 2008).	
Reservoirs	DNR&W (2006)		
Sand and Gravel Geology Above 5 Metres HAT	DNR&M (2002).	These areas have the capacity to store fresh water (Milly and Dunne 1994).	
Water Bodies	DNR&W (2006)	Rainfall leads to runoff which flows into reservoirs and dams contributing to water supply (M. Petter *pers com*, 2008).	
Streams	DERM (2008)		
Genetic Resources			
Core Habitat	EPA (2002).	Provides habitat areas to maintain genetic diversity (Corvalán et al. 2005). The preservation of habitats is related to the availability of genetic resources (Lowe et al. 2005).	The preservation of habitats is related to the availability of genetic resources (Lowe *et al*. 2005: 255). High species diversity maintains genetic diversity (Corvalán et al. 2005).
Fish Habitat Areas	Qld Fisheries Service -Marine Habitat (2000).		
Grey Nurse Shark Habitat	EPA (2006a)		
Moreton Bay Marine Park Conservation Zone	Marine Park Zoning Plan (Queensland Government 1997).		
Priority Taxa Non Remnant	EPA (2007b)	High species diversity maintains genetic diversity (Corvalán et al. 2005).	
Reefs	EPA (2006b)	Australian reefs are among the richest in the world for genetic resources (Volkman 1999).	
Rocky Reefs			
Seagrass		Important food source which maintains genetic diversity (Corvalán et al. 2005). Occurs along the Queensland coastline (Coles et al. 2004).	
Special Biodiversity Values	EPA (2002)	Biodiversity is a source of ecosystem goods such as genetic resources (Bennett and Alcamo 2004).	

Data set	Data Set Reference	Rationale	Comments
Threatened Species Habitat	EPA (2005)	Areas which maintain genetic diversity through provision of varied ecosystems (Corvalán et al. 2005).	
Regional Ecosystem Variety	EPA (2005)		
Vegetation Corridors	EPA (2002)		
Streams Island Streams	DERM (2008).	Streams provide services such as mitigating drought and floods, detoxifying and decomposing wastes, and maintaining biodiversity (Phillips 2006).	
Sand and Mudbanks	MSQ (2007) USNGIA (2005)	The preservation of habitats is related to the availability of genetic resources (Lowe et al. 2005).	
Vegetation Tracts	Mooney and Petter (unpublished manuscript) derived from SLATS (2003)		
Shade and Shelter			
Woody Vegetation	Scarth et al. (2006)	Woody vegetation consists of trees which provide shade from the sun for many animals (Belsky 1994).	Shelter for mapping purposes was described as shelter provided to animal, plants and/or stock and humans. Abel et al. (1997) list the benefits of shade and shelter. A shelter layer was added by intersecting the Good Grass Cover layer (DNR&M 2007) with the woody vegetation layer (DNR&M 2005), showing shelter provided for stock.
Shelter	Mooney and Petter (unpublished manuscript) derived from SLATS (2003)	Trees provide shelter for stock (Greenslade 1992).	
Pharmacological Resources			
Reefs	EPA (2006b)	Areas of high biological and genetic diversity are	Oceans and areas with special

Data set	Data Set Reference	Rationale	Comments
Rocky Reefs		areas where bioprospecting occurs (Tucker and Farrier 2001).	biodiversity values are highly likely to yield pharmacological resources especially areas such as reefs.
Seagrass		Habitat and food for a number of marine biota (Coles et al. 2004), which are of much interest as pharmacological resources, for example, Cone snails (Chivian 2002). Areas where bio-prospecting occurs (Tucker and Farrier 2001).	The loss of threatened species denies the opportunities for any future use of their genetic resources or any of their pharmacological properties.
Special Biodiversity Values	EPA (2002)	Biodiversity is the fundamental resource for bioprospecting (Hassan et al. 2005). The maintenance of threatened species helps maintain biodiversity.	This includes animal species that can supply useful pharmacological products.
Threatened Species Habitat			
Wet Forests		Many pharmacological resources are found in rainforests, including fungi which have high pharmaceutical potential (Paulus et al. 2006).	
Regional Ecosystem Variety	EPA (2005)	Native Australian species are of interest to bioprospectors (Williams et al. 2001).	
Tidal Zone	MSQ (2007) USNGIA (2005)	Tidal zone algae are used as a pharmacological resource (Reichelt and Borowitzka 1984).	
Landscape Opportunity			
Priority Taxa Non Remnant	EPA (2005, 2007b)	Areas with remaining populations of priority taxa represent a particular type of landscape variety.	Landscape Opportunity is the ability of the different variety and extent of the natural ecosystems to provide the opportunity for a wide range of spiritual, scientific, aesthetic, educational (both formal and informal education) and is a function of the diversity in the landscape, as well as areas of broad landscape and special biodiversity as well as areas of broad extent.
Special Biodiversity Values	EPA (2007b)	Bushland areas in SEQ have been found to have high scenic amenity (Office of Urban Management 2007).	
Specific landscape types (see comments)	Terranean Mapping Technologies (2007)	Specific landscapes provide variety in opportunities across the region. Many of these landscapes have scenic amenity, recreational, cultural and social values. Waterways in particular are essential landscape features (M. Petter *pers com*, 2008).	

Data set	Data Set Reference	Rationale	Comments
Vegetation Corridors	EPA (2002)	Corridors provide essential connections between landscapes and the extensive edges offer a high degree of landscape diversity (M. Petter *pers com*, 2008).	**Specific landscape types included:** Mangroves, Samphire and Salt Marshes Reefs/Rocky Reefs
Good Streams	DERM (2008)	Healthy streams provide recreational and cultural amenity, eg. Water sports, Bird-watching (Bennett and Alcamo 2004) and are identified in the SEQ Regional Plan as having "significant scenic amenity" (Office of Urban Management 2007). Watercourses in SEQ provide scenic amenity (Preston 2001, Office of Urban Management 2007).	Reservoirs Seagrass Water bodies Streams Wetlands Heathlands Islands Island streams
Landscape variety: • Geodiversity • RE Variety	DNR&M (2002) EPA (2005)	The diversity of geological features supports diversity of regional ecosystems (M. Petter *pers com*, 2008).	Midlands Mountains Wet forests
Vegetation Tracts	Mooney and Petter (unpublished manuscript)	Large areas of continuous habitat provide unique opportunities and inspiration (South East Queensland Regional Organisation of Councils 2005).	Sand and Mudbanks Sea Surface Tidal Zone
Scenic Preference	Council of Mayors SEQ (South East Queensland Regional Organisation of Councils 2005)	Areas of high scenic preference (or beauty) provide unique opportunities and inspiration (South East Queensland Regional Organisation of Councils 2005).	

Appendix 3. Figure A3.1- Map of Ecosystem Function 03 (Disturbance Regulation)

Please click here to download file 'appendix3.pdf'.

APPENDIX 4

Figure A4.1. Output Map of Total Ecosystem Function - Simple Overlap
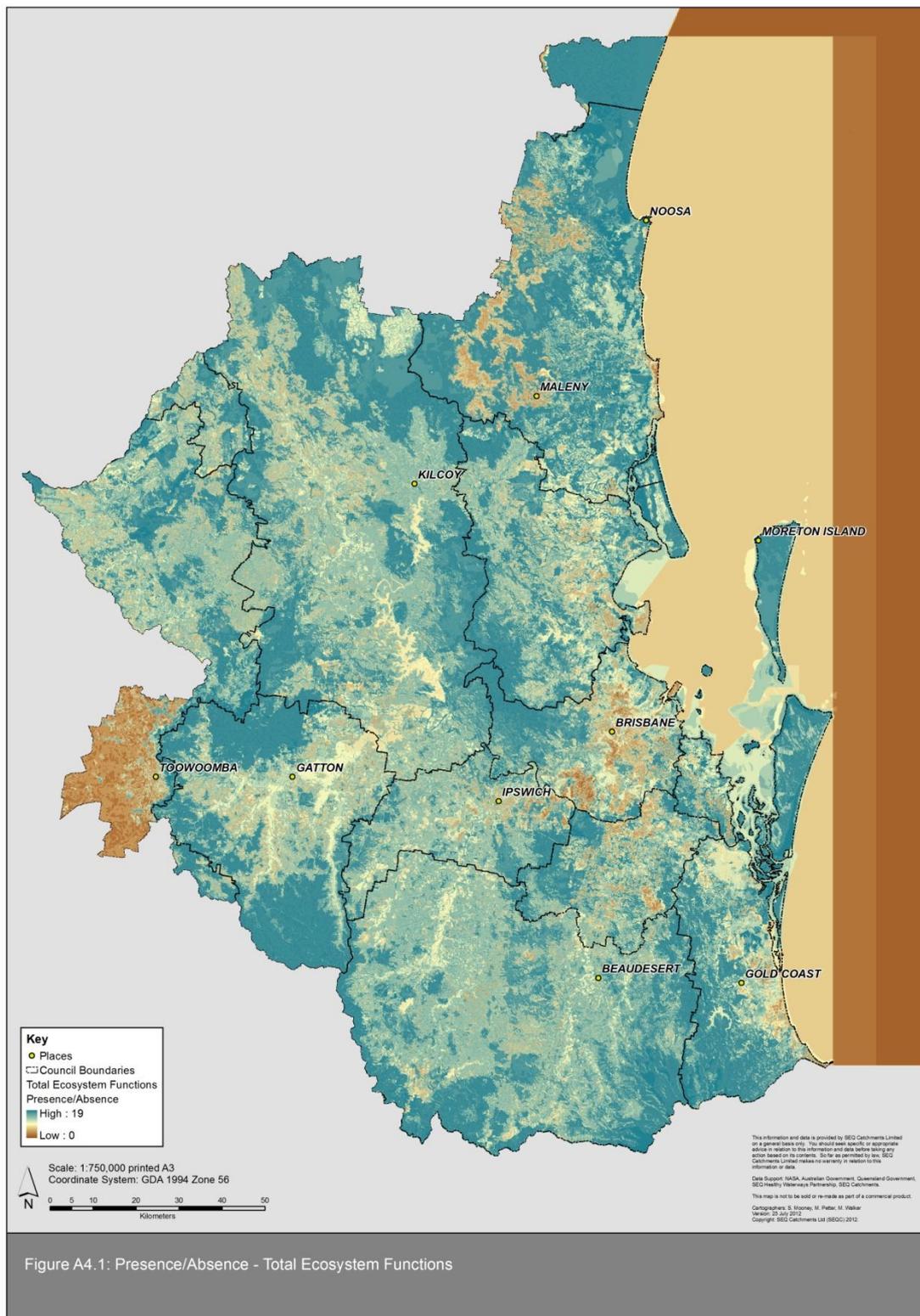

Figure A4.1: Presence/Absence - Total Ecosystem Functions

APPENDIX 5

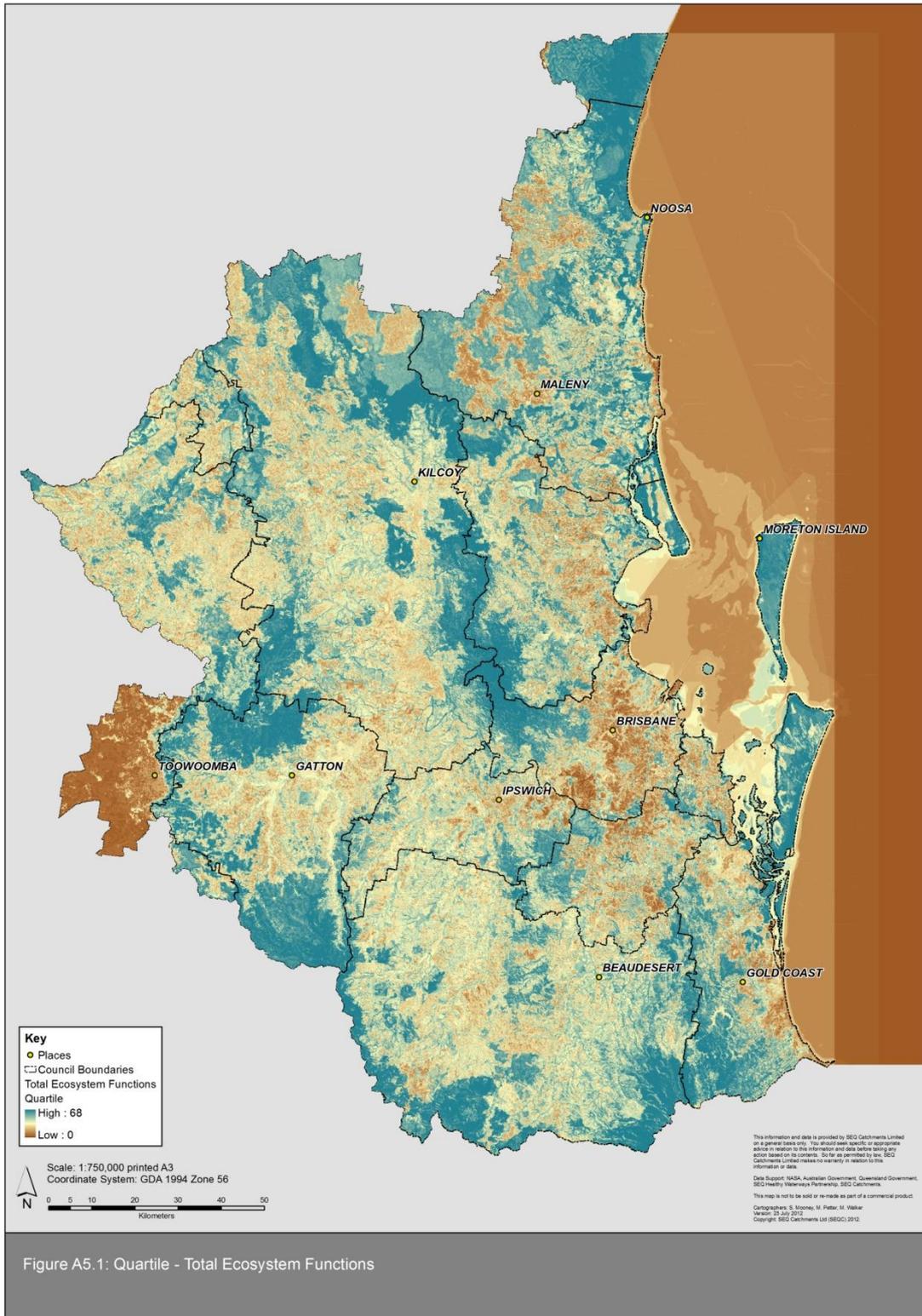## Figure A5.1. Output Map of Total Ecosystem Function - Quantile Overlap

Figure A5.1: Quartile - Total Ecosystem Functions