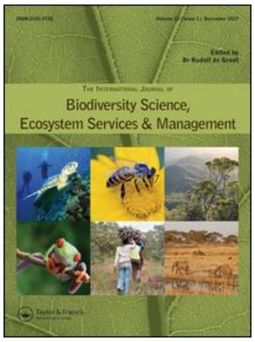

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REVIEW ARTICLE

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Island ecosystem services: insights from a literature review on case-study island ecosystem services and future prospects

Mario V. Balzan[a,b], Marion Potschin-Young[b,c] and Roy Haines-Young[b,c]

[a]Institute of Applied Sciences, Malta College of Arts, Science and Technology, Paola, Malta; [b]Centre for Environmental Management, School of Geography, University of Nottingham, Nottingham, UK; [c]Fabis Consulting Ltd., Barton In Fabis, Nottingham, UK

ABSTRACT
Small islands are of special interest for sustainable development because of their unique characteristics and vulnerabilities. They are ecologically fragile, have limited resources, are susceptible to natural disasters and climate change. This study reviews the literature on island ecosystems, their contribution in the delivery of five key Island Ecosystem Services (IES) and acting pressures and trade-offs associated with IES management. From a set of 1630 potential relevant papers, 273 were selected for analysis. Most of the selected papers focused on cultural IES, in the form of recreation, eco-tourism and gene pool protection. However, provisioning and regulating IES were also well represented in the literature. Most of the studies discussed different management strategies and pressures arising from human use of IES. A small subset investigated the links between island biodiversity and IES, and the contribution of IES to human well-being. This review highlights knowledge gaps in the literature and identifies the need to develop approaches for IES assessments that are informed by local knowledge and which make use of empirical and spatial data for management that maximises the potential of island ecosystems to deliver IES whilst reducing trade-offs.

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Introduction

Small island developing states and islands supporting small communities are recognised as a special case for sustainable development in the United Nations (UN) Agenda 21[1] because of their relatively small populations and open and highly sensitive economies, limited natural resources, restricted usable land area, isolation from and yet dependence on external market, high cost of transportation, susceptibility to natural disasters and climate change, constrained adaptation capacity and limited development options (Nurse et al. 2001). At the same time, island ecosystems provide valuable provisioning, regulating and cultural ecosystem services to island communities and visitors (Wong et al. 2005; Nunes et al. 2014). The important contribution of ecosystems to the well-being of island communities was reviewed in the Millennium Ecosystem Assessment, which assessed the diverse roles that ecosystem services play in island systems and the links to human well-being (Wong et al. 2005).

Ecosystem services are the direct and indirect contributions of ecosystems to human well-being (De Groot et al. 2010a). This definition implies a dependence of human societies on well-functioning ecosystems, and therefore sustainable management and conservation is critical. The ecosystem services concept offers an opportunity to unravel the complex pathway linking ecosystem structure and ecological processes to human well-being, in 'socio-ecological systems'. These include both the ecological and human-dimensions, and are also comprised of social practices, governance and institutional structures, technology and the values of nature for humans (Potschin and Haines-Young 2017). Hence the ecosystem services concept provides a suitable framework to tackle complex problems related to sustainable resource use and has the potential to become an important tool in policy and decision-making, across various sectors and ecosystems (Grêt-Regamey et al. 2016; Burkhard and Maes 2017), to implement management interventions that can improve human prosperity and biodiversity conservation whilst achieving sustainable development (Wood and DeClerck 2015).

The Barbados Programme of Action[2] (1994), the Mauritius Strategy of Implementation[3] (MSI; 2005) and later the Small Island Developing States Accelerated Modalities of Action – or SAMOA Pathway (2014)[4] set out objectives and strategies for the sustainable development of Small Island Developing States (SIDS). The MSI puts in place measures for building resilience in SIDS to address increasing social, economic and environmental vulnerability from exogenous and endogenous sources. The SAMOA Pathway reaffirms the special case for

CONTACT Mario V. Balzan mario.balzan@mcast.edu.mt
Supplemental data for this article can be accessed at here

sustainable development of SIDS, recognises the challenges faced by these in meeting their goals in all three dimensions of sustainable development and acknowledges the need to support and invest in these nations so they can achieve sustainable development. The SAMOA Pathway also recognises the extraordinary biodiversity of SIDS, its value in providing ecosystem services, the grave threats faced by island biodiversity and ecosystem services and strongly supports efforts to conserve biodiversity and to ensure its sustainable use and the fair and equitable sharing of the arising benefits.

Challenges in achieving sustainable development are particularly exacerbated in small island states by the need for defined socio-economic and environmental objectives, monitoring and availability of good quality data at the local scale, the revision of decision-making processes to fully integrate environmental objectives and to ensure horizontal coherence across sectoral policies (Hirano 2008; Roberts 2010). Nonetheless, small islands are diverse with a broad range of characteristics and consequently these will determine the choice of methods used in ecosystem services investigations in island environments. The most influential factors in accurately carrying out and interpreting ecosystem services valuations for SIDS include high dependence on rural and subsistence-based livelihood, common property and open-access resources, weak governance and institutions, sources of vulnerability, and poverty, health, education, migration and other defining socio-economic conditions (Nunes et al. 2014). The socio-economic and environmental isolation of islands strengthens the communities' dependence on ecosystem services (Balzan et al. 2016), especially in SIDS where the rural household subsistence normally depend on the use of common property areas. Intensive management of these and their subsequent degradation is a major problem (Nunes et al. 2014). The vulnerability to natural hazards and climate change also poses a threat to the long-term sustainability (Hess 1990; Nurse et al. 2001, 2014). Therefore, balancing socio-economic benefits with environmental pressures is considered as a key challenge for island communities (Van Der Velde et al. 2007).

This study carries out a literature review relating to five key island ecosystem service (IES): food and water provisioning, erosion and pollination regulation and recreation and eco-tourism. In island environments, particularly in the context of heavy reliance on subsistence agriculture and the agricultural sector, food provisioning services can be vital in terms of the economy and food security (FAO 2004) and are highly valued by island populations (Kenter et al. 2011; Butler et al. 2014). Degradation and the loss of this service might negatively influence the ability of island populations to ensure their food security. Similarly, freshwater is an important and scarce resource on many small islands, making water provisioning and water quality regulation key IES. Islands' cultural ecosystem services in the form of recreation and eco-tourism are highly valued by tourists and locals, and contribute directly to the economy of islands. Erosion control and pollination regulation IES were also investigated in this review, given the important role these play in the delivery of food provisioning IES, whilst recreational and eco-tourism IES play an important role in structuring islands' landscapes and in islands' economies.

The aim of this study is therefore to review current published scientific research relating to the identified five IES in order to (1) analyse the current state of research on IES, (2) identify drivers and pressures affecting IES and island communities and (3) identify knowledge gaps. To accomplish these objectives, we reviewed literature on selected IES and identified methods used for the biophysical assessment of ecosystem services, and their valuation, analysed drivers and pressures associated with the management of the selected IES and interactions with other services through synergies and trade-offs.

Methodology

The research approach was based on a literature review relating to the five key IES themes: food and water provisioning, erosion and pollination regulation and recreation and eco-tourism IES. Whilst it was not possible to cover all the diversity of IES within one study, the selected services encompass the three ecosystem services sections (provisioning, regulation and maintenance and cultural) identified within the Common International Classification of Ecosystem Services (CICES, V4.3, see Haines-Young and Potschin, 2013). The choice to focus on selected ecosystem services allowed us to analyse literature on these services across the cascade model (De Groot et al. 2010a; Potschin and Haines-Young 2016), linking biodiversity and ecosystems to ecosystem services flow, to benefits to human well-being and the values assigned by society. It is by reference to these values that people and societies manage drivers of change, which give rise to pressures, on ecosystems in a societal feedback loop that links value to ecosystems within the cascade model (Nassl and Löffler 2015; Potschin and Haines-Young 2016). Quantitative statistical and qualitative content analysis techniques were used to analyse the literature relating to island ecosystems and their services. The methods used are described in more detail in this section. The IES selected for this study are, with the exception of cultural IES, predominantly terrestrial ecosystem services. However, coastal and marine ecosystems provide valuable services and benefits to island communities. The current status of research on marine and coastal ecosystem services have recently been reviewed by Liquete et al. (2013), where food provisioning, and in particular fisheries, were the most studied ecosystem services while water purification and coastal protection were the most studied regulatory ecosystem services. Cultural ecosystem service studies are contrastingly poorly represented in marine and coastal ecosystem services research, and the focus of these studies is often primarily focused on local and regional socio-cultural or economic assessments of coastal ecosystems, giving rise to significant gaps in research (Martin et al. 2016; Garcia Rodrigues et al. 2017).

Literature search strategy

Our literature search was conducted between September 2014 and March 2015 using Web of Science (Clarivate Analytics, US). To identify relevant publications, we used the search string 'island* AND ecosystem*' together with IES specific terms on the article title, abstract and keywords. No restriction on publication date was set. We recognised that there might be publications covering similar issues that do not use the term 'ecosystem services' (Liquete et al. 2013). Thus the keywords used in the search strings for each thematic area were designed to be as general as possible. The search criteria were developed on the basis of a pilot study conducted between August and September 2014 which showed that many papers investigating islands' ecosystems and their services did not use the term 'ecosystem services' and that several studies investigated the ecology and biogeography of islands. Table 1 indicates how the search criteria were constructed, and lists the terminology adopted by three widely used ES nomenclatures (MA,[5] TEEB[6] and CICES[7]) for the IES considered in the present study.

Selection criteria

The literature search was carried out in two stages involving (a) the screening of the title, abstract and keywords and (b) a full paper analysis. Our initial search identified 1630 papers as potentially relevant. The first selection provided a general characterisation of the literature. Each paper was considered as relevant if it met at least one of the following selection criteria used at this stage:

- Considered the importance of biodiversity components in the delivery of IES;
- Considered human and natural drivers of change affecting islands' ecosystems and communities;
- Considered trade-offs and bundles of IES;
- Quantified market and/or non-market values of IES;
- Investigated indigenous knowledge, perceptions or stakeholder involvement in the management of island ecosystems and their services; or,
- Analysed the management of ecosystems and ecosystem services, including through policy-making.

The screening process identified 470, which were included in the study for full text reading and further analysis. In this second stage, three new selection criteria were added:

- the full text of the article should be available in English;
- the paper should be a peer-reviewed publication; and
- the paper should not investigate the autoecology of islands' species.

Table 1. Correspondence of key island ecosystem services used in this paper with previous classifications.

Search terms	MA	TEEB	CICES	This paper
island* AND ecosystem* AND erosion	Erosion regulation	Erosion prevention	Mass stabilisation and control of erosion rates	Erosion prevention
island* AND ecosystem* AND crop* AND cultivat* island* AND ecosystem* AND livestock	Food	Food	Terrestrial plant and animal	Food provisioning
island* AND ecosystem* AND freshwater	Freshwater	Water	Potable water Water flow regulation; Water quality regulation	Freshwater provisioning
island* AND ecosystem* AND pollinat*	Pollination	Pollination	Pollination and seed dispersal	Pollination
island* AND ecosystem* AND eco-tourism island* AND ecosystem* AND recreation	Recreation and eco-tourism	Recreation and tourism	Recreation and community activities	Recreation and eco-tourism
island* AND ecosystem* AND cultur* value*	Cultural diversity	Inspiration for culture, art and design	Experiential use of plants, animals and land-/sea-scapes in different environmental settings Physical use of land-/sea-scapes in different environmental settings	
island* AND eco-tourism	Recreation and eco-tourism	Opportunities for recreation and tourism	Recreation and community activities	

The second round of analysis identified 273 papers as being relevant for this study (Supplemental data Appendix A).

Data collection

Data relating to 17 variables were extracted from the 273 specific studies identified during the second round of analysis. Data collection was carried out in two stages. In the first stage, we recorded information about the general characteristics of the study, and in particular the following features were extracted:

(1) Year of publication;
(2) Country in which the islands are located;
(3) Identity of the island or archipelago;
(4) Size of island: small islands (<10,000 km^2); large islands (>10,000 km^2); various (from Hess 1990);
(5) Ocean in which the island is located;
(6) Adjacent seas or other water bodies;
(7) Article type: original or review;
(8) Type of analysis: quantitative, qualitative, conceptual, mixed;
(9) Type of habitat analysed: agroforestry; beaches; coastal; coral reefs; cropland; estuaries; forest; heathland; lake; mangroves; marshland; open ocean; orchard; polar; rivers; scrubland; seagrass; shores; temperate forests; tidal marsh; tropical forests; tropical dry forest; tropical rain forest; urban; wetland; woodland; various;
(10) Ecosystem type considered (from the Millennium Ecosystem Assessment, 2005) – marine; coastal; inland water; forest; dryland; island; mountain; polar; cultivated and urban; and
(11) IES considered:
   - none;
   - IES directly considered in this review: food provisioning; freshwater provisioning; pollination; erosion prevention; recreation and tourism;
   - Extended review of IES: raw materials; nutrient cycling; maintaining soil fertility; climate regulation; disturbance prevention; cognitive development; cultural heritage; gene pool protection;
   - various (>3 IES).

Studies considering more than one IES and those including IES different from the five originally selected for this study (extended review of IES in 11) were also included in this study in order to capture any potential trade-offs and synergies.

In the second stage of the Data Collection, the studies were characterised according to objectives of the study and information extracted was used to determine whether each study investigated the following variables:

(12) The link between biophysical ecosystem structure and island ecosystem function or service;
(13) Economic valuation of IES;
(14) Traditional ecological knowledge and stakeholders' perceptions and values;
(15) Drivers and pressures acting on island ecosystems and ecosystem services;
(16) Link between management and IES delivery, associated benefits and sustainability; and
(17) Interactions (trade-offs and bundles) between ecosystem services.

For studies that investigate drivers and pressures acting on island ecosystems and their services, a subsequent step was carried out to identify the drivers and pressures analysed in each study, and namely: habitat loss and degradation, overexploitation, water pollution, erosion, climate change, demographic changes, alien species, socio-cultural changes, resource use and availability, natural phenomena, soil quality degradation, diseases and overgrazing.

Data analysis

We used descriptive statistics to calculate the number of publications for each category for the variable identified in the Data Collection section. In order to analyse the relationship between the drivers, pressures, habitats and IES, we created matrices linking these variables, in which each cell recorded the sum of the number of links from the final selection of studies. Hierarchical clustering on the Euclidean distance between the rows and columns of the matrices was then carried out to group drivers and pressures according to the number of links with habitat and IES data recorded from this literature review (Garcia Rodrigues et al. 2017). This analysis was carried out using the heatmap.2 function from gplots package (Warnes et al. 2016). To analyse the linkages between IES identified from the literature review, a matrix linking different IES categories was created. Each cell contained the number of links identified from the literature between two IES categories. Subsequently, a network was created using the igraph (Csardi and Nepusz 2006), and visualised using the qgraph package (Epskamp et al. 2012). All analyses were performed using The R Software (R Core Team 2016).

Results

The number of papers discussing IES has increased reaching a peak in 2010 (Figure 1a). The selected studies were widely distributed across the five oceans (Figure 1b), with 56 countries represented. However, the islands of the Pacific Ocean (116) and Atlantic Ocean (85) were considered more frequently (Supplemental data

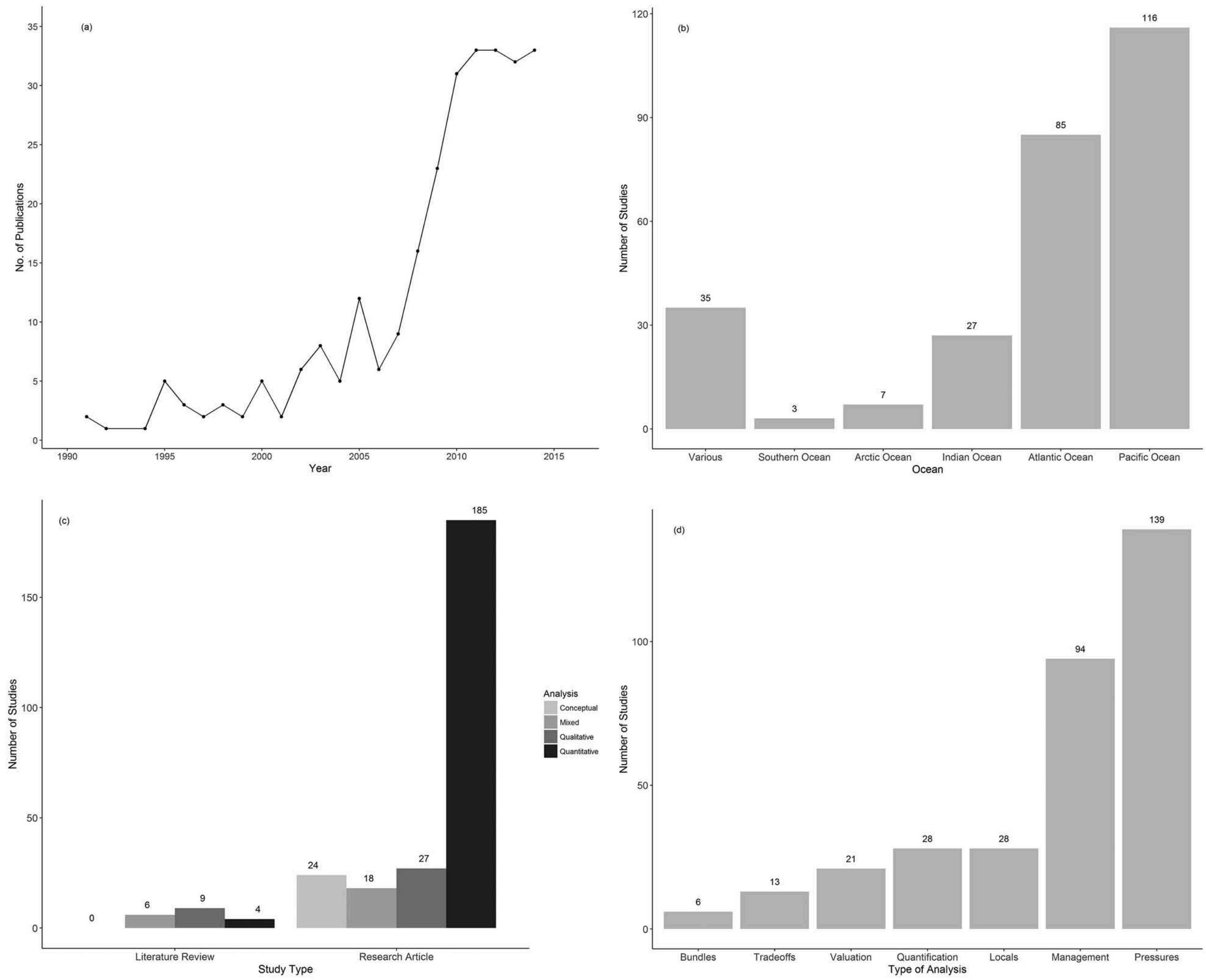

Figure 1. Data analysis of the selected 273 studies on IES. (a) Number of publications per year. (b) Number of studies for each ocean. (c) Number of studies according to the type of analysis. (d) Number of studies according to the type of study.

Appendix B). The majority of the papers were research articles (254) and most of them presented quantitative analysis of ecosystems and services attributes (185) (Figure 1c). Most of the papers (139) considered the pressures acting on island ecosystems and IES. In descending order, the other themes considered were the management of islands' ecosystems and IES (94), biophysical quantification (28), local knowledge and stakeholder involvement (28), IES valuation (21), IES trade-offs (13) and bundles (6) (Figure 1d). Papers dealing with a range of island ecosystems were in the majority (Figure 2). Many studies did not identify specific island ecosystems, treating the island as one ecosystem (152).

Studies including coastal (66) and marine (13) ecosystems accounted for the highest number of studies including stakeholders' ecological knowledge or stakeholder participation, and these made up 12% and 38%, respectively, of all studies in those habitats. For terrestrial island habitats, even lower proportions were recorded supporting the earlier observations that ecosystem service research with stakeholder involvement and social science techniques are underrepresented in existing literature (Seppelt et al. 2011; Liquete et al. 2013).

Publications dealing with drivers and pressures acting on island ecosystems were in the majority, and they accounted for the majority of the papers dealing with coastal (39), urban (4), forest (15), cultivated (12) and dryland (5) ecosystems. Even though this cohort had a global distribution (Supplemental data Appendix C), most of the studies dealing with drivers and pressures were from small islands located within the Atlantic Ocean and the Pacific Ocean (Table 2). Water pollution and habitat loss and degradation were identified as the most studied pressures on large islands' ecosystems, whilst change in the habitat quality and the introduction of alien species were the most frequently recorded pressures in small islands. Pressures that impact similar set of habitats were grouped using matrices linking the drivers and pressure with habitats (Figure 3a) and with IES (Figure 3b). Habitat loss and degradation was strongly associated with coastal habitats, and to a lower extent with cultivated, forest and inland water ecosystems. Alien species and water pollution have been analysed as drivers mainly in inland water, and studies dealing with erosion

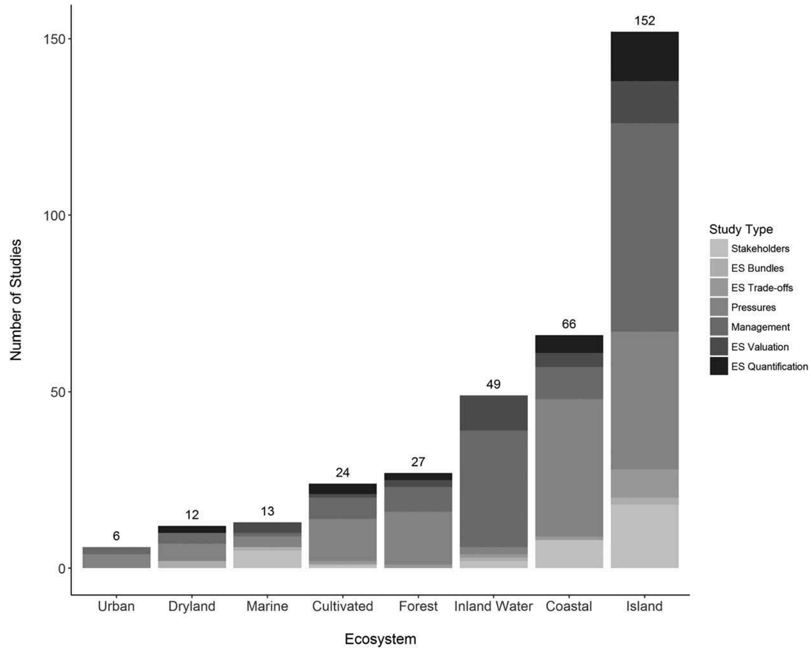

Figure 2. Number of studies in different ecosystems and according to the type of study.

were mainly from forest and coastal habitats (Figure 3a). Two main sets of clusters primarily affect ecosystem services, with the main cluster of drivers and pressures including erosion and habitat loss and degradation. These were strongly linked with recreation and tourism, gene pool protection and erosion prevention IES. The other drivers and pressures were grouped in a second cluster, where the strongest links were recorded between alien species and erosion prevention, gene pool protection and water purification IES, whilst recreation and tourism IES were associated resource use and cultural change (Figure 3b).

The papers investigating recreation and eco-tourism IES (84) were the most prevalent within the data set (Figure 4a). This contrasts with results from global reviews of ecosystem services, in which regulating services were always the most frequently studied group (Martínez-Harms and Balvanera 2012; Schägner et al. 2013). Whilst we carried out a literature search for five case studies of IES, the final data set contained several publications that also investigated other IES. Gene pool protection, defined as the maintenance of nursery populations and communities, was in fact the second most prevalent IES even though none of the search terms targeted this IES. A network analysis was thus carried out to investigate the links between these services (Figure 4b). Strong linkages were recorded between gene pool protection IES and the other services investigated in this literature review, supporting the notion that island biodiversity contributes significantly to the well-being of inhabiting communities. Weaker links were recorded between other IES because few studies investigate how these co-vary across spatio-temporal scales or the management of multiple IES.

Most of the papers considered more than one ecosystem type, in the sense that they dealt with 'whole islands', suggesting interdependence and that ecosystem service delivery may depend on various ecosystems (see Figures 2 and 5). However, in those papers where a specific focus was identified, coastal ecosystems were the most frequently considered, with shore and coral reef habitats most often discussed. Studies carrying out biophysical assessment of IES (28) or the valuation of IES (21) were relatively evenly distributed between different IES categories (Figure 6). The studies investigating recreational and eco-tourism IES were the most common (16), followed by those investigating gene pool protection (10). The small number of papers that quantify the contribution of biodiversity to ecosystem services suggests an important knowledge gap, a situation that is also reflected in the literature (De Groot et al. 2010b).

Only a relatively small fraction of the studies actually quantified the contribution of ecosystems to the delivery of IES and its value to society (Figure 6). Most of the studies discuss different management strategies and pressures arising from human use of these services. This indicates the need for increasing scientific evidence that identifies the importance of biodiversity components in underpinning the delivery of the services in small islands, and which may be used within management plans and strategies. Previous research provides evidence of generally positive association between biodiversity and ecosystem services, allowing researchers to identify key biodiversity attributes that improve ecosystem service delivery (Harrison et al. 2014). However, studies that quantify the link between biodiversity and IES represented a small proportion

Table 2. Drivers of change according to island size and the ocean in which the island is located.

	Habitat loss and degradation	Overexploitation	Water pollution	Erosion	Climate change	Demographics	Alien species	Cultural change	Resource use	Natural phenomena	Soil quality degradation	Disease	Overgrazing	Total
Large Islands (>10,000 km^2)	9	1	10	4	2	0	6	0	0	2	0	0	1	35
Small Islands (<10,000 km^2)	37	3	9	22	5	1	32	3	6	3	3	1	0	125
Arctic Ocean	0	0	4	0	1	0	0	0	0	0	0	0	0	5
Atlantic Ocean	15	0	3	13	4	0	9	2	3	3	3	1	0	56
Indian Ocean	4	0	2	2	0	0	1	0	1	0	0	0	0	10
Pacific Ocean	25	4	9	11	2	1	22	1	2	2	0	0	1	80
Southern Ocean	0	0	1	0	0	0	0	0	0	0	0	0	0	1
Various Oceans	2	0	0	0	0	0	6	0	0	0	0	0	0	8

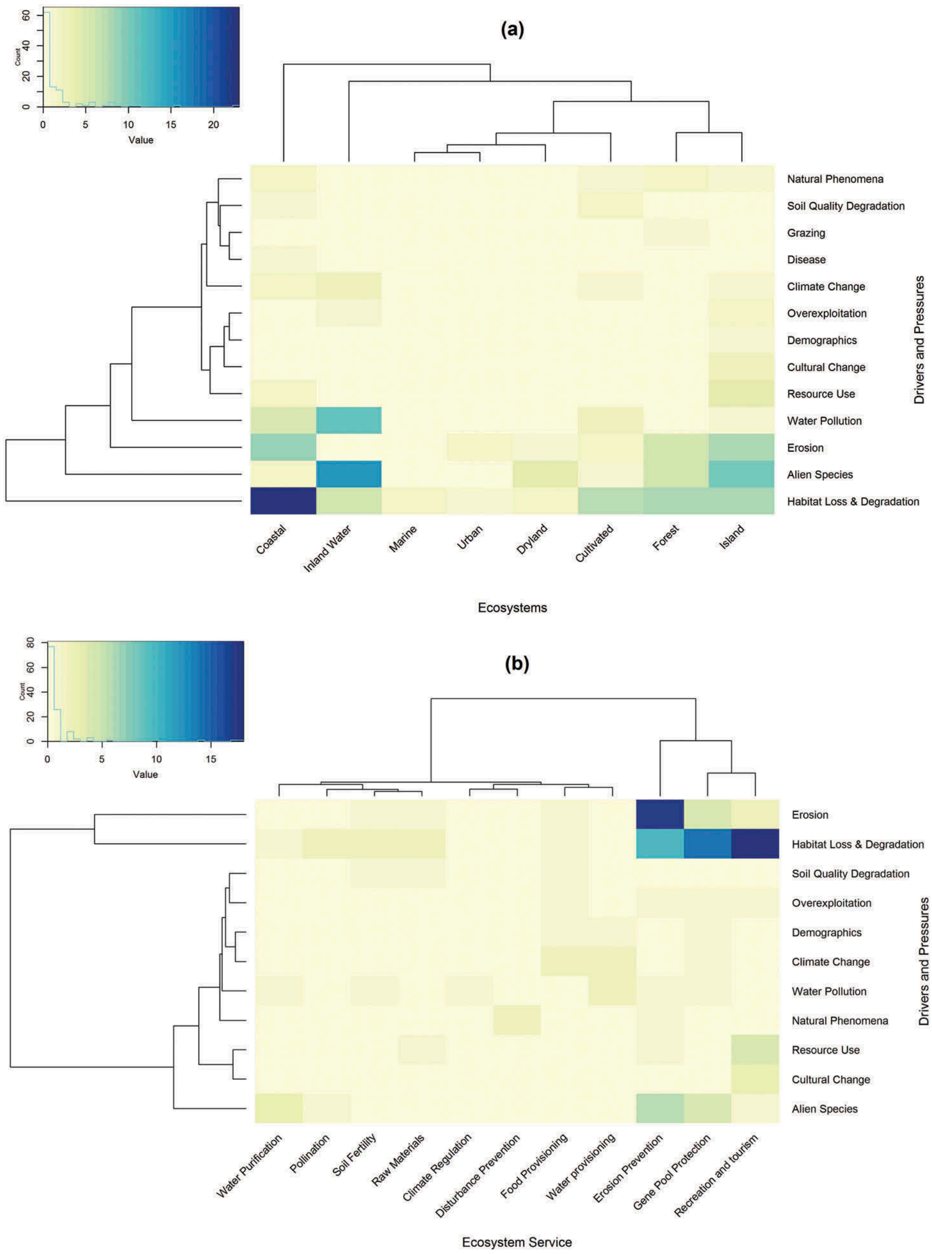

Figure 3. Pressures associated with (a) island ecosystems and (b) ecosystem services. Dendrograms represent similar pressures grouped by hierarchical clustering on the Euclidean distance between the rows and columns of the bipartite matrix by the pressures' categorisation.

of the literature identified in this review. Our results also suggest poor coverage in the literature of the social dimension of ecosystem services; studies investigating indigenous knowledge, human perception and participation in decision-making were mostly associated with cultural themes. No studies investigating the social dimension were found for erosion prevention and pollination. Similarly, very few valuation studies were found. This supports the findings of Liquete et al. (2013), who also detected that studies on valuation methodologies, the analysis of beneficiaries and hence the contribution of ecosystem services to human well-being were under-represented in the marine and coastal literature.

Present focus of studies on island ecosystem services themes

The studied IES are analysed here in more detail in order to assess the present focus of the literature, and to identify drivers and pressures that impact on IES and affect human well-being.

Agriculture and food provisioning

Despite the common challenges of size and isolation, there are some marked differences between islands in terms of the status of agriculture in their economies, with the poorer group having a significant

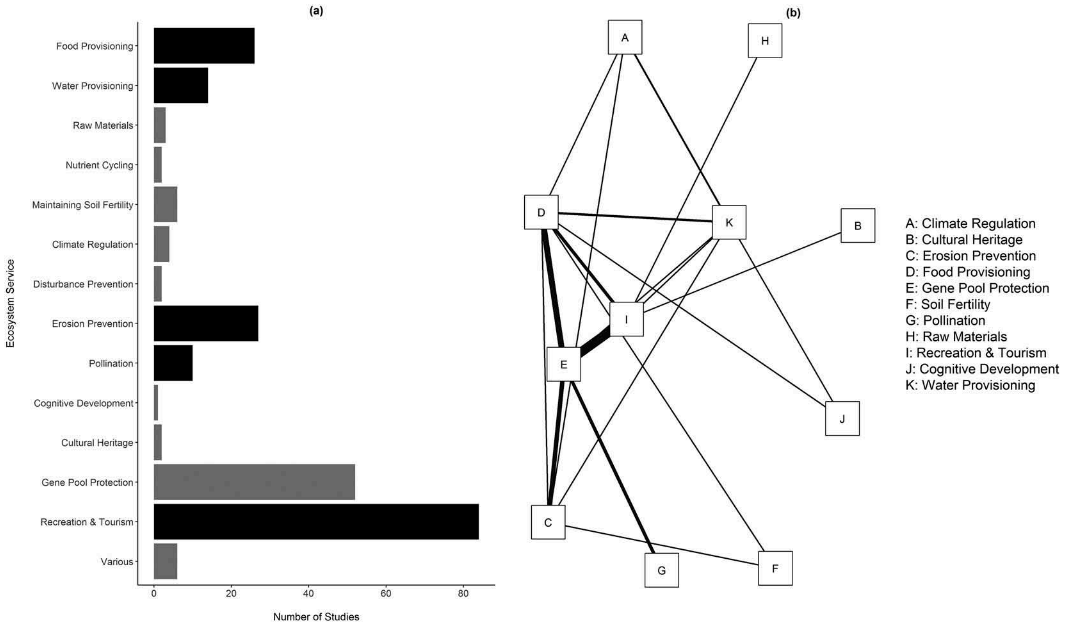

Figure 4. (a) Frequency distribution of studies investigating islands ecosystem services and their benefits. Black bars indicate IES investigated in this literature review. (b) A network diagram showing the linkages between different IES identified in this study.

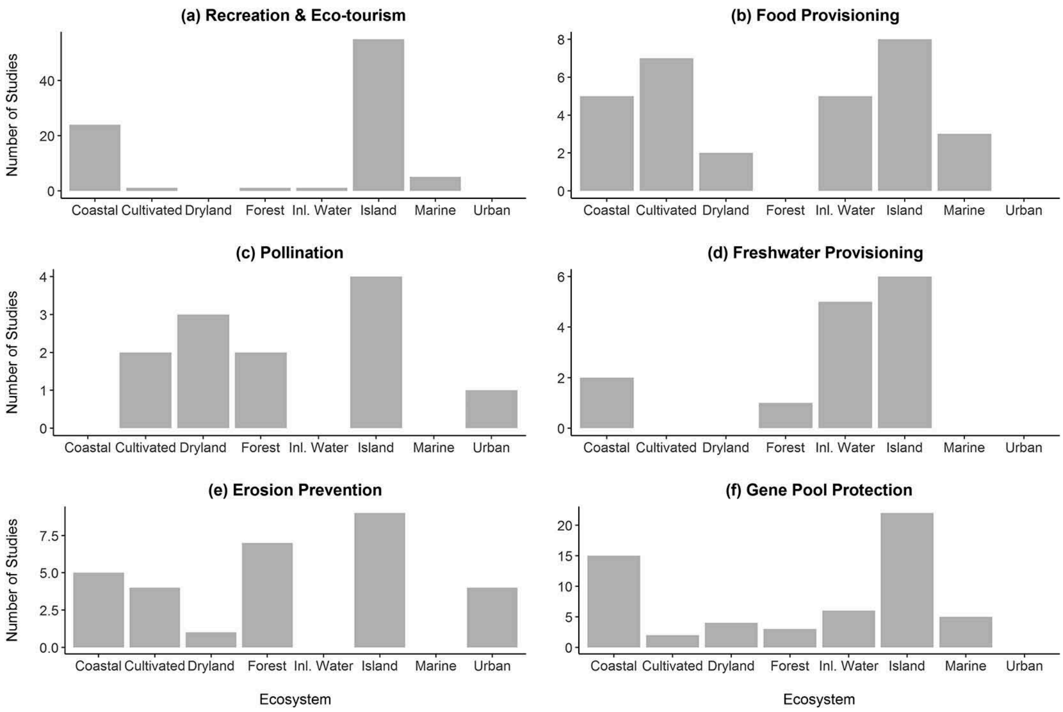

Figure 5. The number of studies per ecosystem type for studies investigating (a) recreation and eco-tourism, (b) food provisioning, (c) erosion prevention, (d) water provisioning and quality regulation, (e) pollination and (f) gene pool protection IES. Gene pool protection IES have been included here given the prevalence of studies investigating this service.

agricultural sector while in the richer group its contribution is more limited (FAO 2004). These extremes therefore face quite different challenges in terms of the management of land and ecosystem services. For example, improved garden and agricultural production and the maintenance of freshwater resources were the highest ranked management strategies in island communities with a strong dependence on local food production (Kenter et al. 2011; Butler et al. 2014). In contrast, on small Mediterranean islands, particularly in areas where agricultural land is unproductive, there is abandonment. Agricultural abandonment is associated with an increase in soil organic carbon (Vaccari et al. 2012) and in the flow of services from the expansion of forest (Aretano et al. 2013). However, abandonment is not always beneficial for ecosystem services and increased woody plants cover and the loss of open habitats

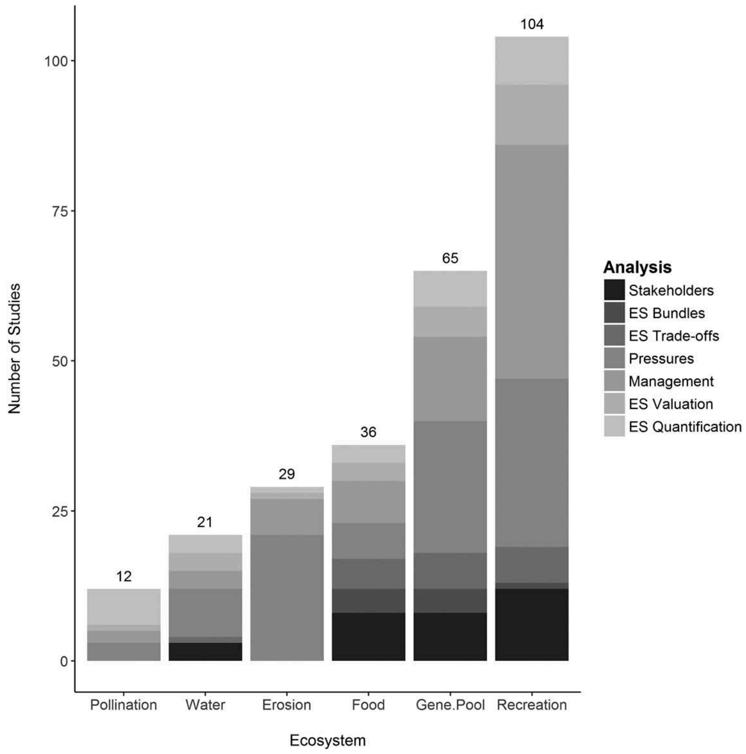

Figure 6. Frequency of different study types for the identified IES. Gene pool protection IES have been included here given the prevalence of studies investigating this service.

may lead to ecological shift in local communities and can have a negative impact on species of conservation value (Sokos et al. 2013).

The loss of biodiversity from traditionally species-rich agroecosystems is one of the most rapidly emerging threats to food and livelihoods in SIDS (UNEP 2014). Agricultural biodiversity is being eroded by increased monoculture, monetisation and urbanisation. The significance of such changes are often overlooked because mainstream conservation often concentrates on endemic or charismatic species and intact ecosystems, and many small islands have little natural, unmodified habitat left (Thaman 2008). Agricultural intensification for export has been found to be associated with an increase in the import and usage of agricultural chemicals. This in turn has led to public concerns related to health issues and increasing pressure to freshwater ecosystems (Van Der Velde et al. 2007; Tashiro et al. 2013). In contrast, small-scale food gardening has been found to contribute to more sustainable forms of development by reducing economic vulnerability and promoting food security (Thaman 1995, 2008). In a study carried out in the island of Dominica, locals were willing to pay more for organic and locally grown produce, and the conversion of the island to an 'organic island' with its associated benefits (Boys et al. 2014). Food gardens and their associated cultural services were also highly valued on Pacific islands (Kenter et al. 2011; Butler et al. 2014). Studies show that traditional agricultural practices, such as crop rotations and legume row plantings within olive trees and orchards in the island of Crete, are important for the maintenance of soil fertility (Nikolaidis 2011).

Farming practices play an important role in structuring island landscapes and can impact other ecosystems and their services. Most of the studies (19) retrieved from food provisioning literature searches, or which were carried out in cultivated ecosystems, investigated the pressure and impacts on ecosystems and food provisioning, while a considerable number of studies (16) looked at agricultural management alternatives, with several investigating options for ensuring sustainability. In contrast, few studies (4) carried out a biophysical quantification of food provisioning IES. Several studies investigated the impacts of historic agricultural practices on ecosystems. For example, McCoy and Hartshorn (2007) report how agricultural practices in Hawaii were associated with wind erosion over the period from prehistoric times to the abandonment of many areas in the eighteenth century following European contact. Early settlement on Easter Island (Rapa Nui) was characterised by sustainable land use and traditional agroforestry, but subsequent clearing of woodland on upper slopes resulted in sheet erosion. Agriculture on eroded downslope areas ceased by around AD 1400 and gullying began on Rapa Nui with the increase in sheep numbers in the early twentieth century (Mieth and Bork 2005).

Our review supports the view that the introduction of alien herbivores can impact indigenous island vegetation communities (Figure 3a) and erosion regulation IES (Figure 3b). Overgrazing and trampling by introduced goats (*Capra hircus* L.) in the Canary Islands has affected several endemic plant species (Gangoso et al. 2006). However, the picture is mixed, as illustrated by the study of Fernández-Lugo and De Nascimento (2011) who on another of the Canary Islands (Tenerife) found that grazing had no negative effects on native plant diversity, leading the authors to suggest the promotion of goat grazing as a way to maintain land use, cultural values and species richness. Korsten et al. (2013) found that naturalised geese in New Zealand helped maintain indigenous plant species against the invasion of exotics in wetlands, by restoring the herbivore function lost with the extinction of native avian grazers. In contrast in Lesvos Island, Greece, sheep grazing was found to be a barrier for oak recruitment (Plieninger and Schaich 2011). The impact of livestock introduction on native species is likely to vary according to the grazing intensity as demonstrated by the research of Lorent and Sonnenschein (2009). By modelling the European Commission (EC) Common Agricultural Policy subsidy allocation to sheep and goat breeder in Crete, they demonstrate how subsidies stimulated the growth of herds and this was associated with increased grazing pressure until the carrying capacity of pasture lands was exceeded leading to the loss of vegetation diversity. Restoration of ecosystems, which may include the exclusion of livestock, may be required for the recovery of ecosystem structure and function (Dodd et al. 2011; Whitehead et al. 2013). For example, the restoration of Hawaii's native forest, which has been largely replaced by grasslands for livestock, was associated with an improvement in soil hydraulic properties necessary to distribute infiltrated water faster and deeper, as appropriate for native plant needs (Perkins et al. 2012).

This section has identified key topics and trends from the reviewed literature, and agricultural abandonment and intensification were observed to lead to the loss of biodiversity, IES and, in some cases, the loss of the highly valued food provisioning IES themselves. The impact is context-dependent and is affected by the magnitude of the pressures and the characteristics of the island system.

Pollination

Pollination is important for delivering key benefits in the form of a marginal increase in production of market-based or subsistence crops, fibre, forage, timber and non-timber forest products, and through the reproduction of wild plants that play a role in other ecosystem services (Kremen et al. 2007). A total of 23 studies investigated pollination in small islands. Most considered several island ecosystems (11), while a few focussed specifically on forest (6) and dryland (3) ecosystems. Only two of the studies dealt with cultivated ecosystems whilst no studies investigated crop pollination. The majority (15) investigated drivers and pressures affecting pollination services. Our review suggests that generally the ecology of pollination remains relatively poorly studied, even though many islands are biodiversity hotspots and the conservation of pollinators is important for ensuring the reproduction of endemic plants (Anderson 2003; Potts et al. 2006; Nielsen et al. 2011; Chamorro and Heleno 2012). The value of animal pollinators was emphasised in a study of plant assemblages pollinated by bats by Scanlon et al. (2014), who found that they coincided with habitats valued by humans for medicinal, cultural and economic uses.

Island pollination networks often have high degree of generalisation caused by the asymmetrical plant–pollinator relationships (Cox et al. 1993) and depauperate pollinator fauna on islands compared to continental communities (MacArthur and Wilson 1967). Even relatively large and isolated temperate island groups such as New Zealand have smaller pollinator faunas compared to mainland areas (Lloyd 1985). Pollination interaction webs in the Mauritius were observed to be dominated by a few abundant and generalised species even though several rare and specialised species were also recorded (Kaiser-Bunbury et al. 2009). The loss of a generalist pollinator may therefore be a significant threat for the reproduction and survival of island plant species. Plants on remote islands are also reproductively isolated, have evolved towards dependence on few indigenous pollinators and demonstrate an inability to adjust to the loss of pollinators (Cox et al. 1993). Flying foxes (*Pteropus* sp.) pollinate several plant species in South Pacific Oceanic Islands, and their decline is hypothesised to lead to a cascade of linked plant extinctions. Bird pollination was associated with a higher fruit set for flowers from New Zealand (Anderson 2003), whilst in another study from the island of Lesvos, bee diversity and the provision of pollination services were associated with habitats with high floral diversity and availability of floral resources (Potts et al. 2006).

Threats to plant–pollinator interactions on many islands are mostly driven by alien species and their direct and indirect competition for pollination (plants) and for floral resources (animals) (Kaiser-Bunbury et al. 2010). Two studies from this review investigated the effect of invasive plants on pollination services. The abundance of the invasive *Solanum elaeagnifolium* Cavanilles has a negative impact on pollination services and seed set of the native *Glaucium flavum* Crantz on Lesvos Island, and the presence of the invasive significantly increased pollen limitation (Tscheulin and Petanidou 2013). The invasive *Opuntia* spp. was also found to modify the number of links between plants and pollinators in the Canary and Balearic Islands, but by linking to generalist natives, *Opuntia* spp. remained peripheral and the pollination network was not affected unless invasion is intense (Padrón et al. 2009). Alien plants may be facilitated by generalist pollinators, hence resulting in the integration of the invading plants in resident communities (Kaiser-Bunbury et al. 2010). Similarly, native pollinators might be outcompeted by an invasive pollinator, depending on its exploitative or competitive superiority (Traveset and Richardson 2006). A wide range of potential host plants and the ability to achieve large population sizes are important traits that increase the competitiveness of the invading pollinators (Groom et al. 2014). The introduction of managed species, such as the honey bee *Apis mellifera* and *Bombus terrestris* was observed to result in lower visitation of flowers by native pollinators and the displacement of the latter (Kato and Kawakita 2004; Ishii et al. 2008). The introduced *A. mellifera* were observed to lead to lower nectar-feeding activity and pollination services by two endemic birds in the Mauritius, and to a lower reproductive success of these native birds. Honey bees were also less efficient pollinators; reduced setting of seed in native plants potentially reduced their reproductive success (Hansen et al. 2002). On the other hand, the removal of an invasive nectar thief and arthropod predator, *Vespula pensylvanica* Saussure, in Hawaii resulted in an increase in bee visitation, especially from introduced honeybees, and in an increased fruit production of an endemic tree (Hanna et al. 2013). This finding supports the observation that introduced pollinator species may be acting as a substitute for threatened or extinct island pollinators, and hence the eradication of the newly established species is not always the best strategy for the conservation of plant diversity in island systems. The reintroduction of native species from outlying islands (Abe et al. 2008) or the introduction of functional replacement species (Kaiser-Bunbury et al. 2010) have also been suggested as a potential management strategy.

Pollination IES are susceptible to habitat disturbance (Kaiser-Bunbury et al. 2010), indirectly threatening plant diversity and food provisioning. Small populations in fragmented landscapes are subject to higher competition from invading species for pollinators, and native trees were characterised by pollination limitation and decreased fruit production in La Réunion (Indian Ocean) (Gigord et al. 1999). Higher intensity of land use management is associated with lower pollinator diversity. In a study from South Island, New Zealand, pollinator diversity declined as pollinators with a narrow diet, large body size, solitary behaviour and a preference for non-floral larval food were the first pollinators to be lost (Rader et al. 2014). These observations suggest that more intensively managed or disturbed landscapes are characterised by common or exotic plant species with generalised pollination requirements.

Literature discussing the biophysical processes underpinning pollination IES was poorly presented in this study, while there is some evidence that pollination IES are highly valued by island communities. Habitat loss and degradation and the introduction of alien species were identified as key pressures acting on pollinator diversity and pollination IES.

Freshwater

The physical characteristics of islands mean that freshwater is often a scarce and vulnerable resource (UNEP 2014). Most studies dealt with island inland water (54), coastal (12) or several island ecosystems (13). This set investigated water provisioning and quality regulation (16), and its links to gene pool protection (13), food provisioning (11), recreation and tourism (3), climate regulation (3), nutrient cycling (2), erosion prevention (1) and cognitive development (1).

A small number of studies (9) either made a biophysical assessment, or valued freshwater IES (3). The former mainly dealt with the role of inland water ecosystems in the supply of freshwater and food, and nutrient cycling. The studies by Benstead et al. (2009) and Raposeiro et al. (2014) quantified nutrient cycling in island streams, and assessed the importance of macroinvertebrates in leaf litter decomposition. Their results suggested that in depauperate and isolated ecosystems, decomposition of plant litter by aquatic macroinvertabrates is negligible. Only few studies, such as those by Butler et al. (2014) and Kenter et al. (2011), investigated the value of freshwater IES to island communities. The latter found people were willing to contribute a relatively high fraction of the household income for these IES. Inland water ecosystems also contribute to food security (Berg et al. 2010; Cleasby et al. 2014; Hossain et al. 2014) and freshwater provisioning (Wong et al. 2005) to island communities. Many small islands rely mainly on groundwater reservoirs, and severe water storages are often experienced on atolls and raised limestone islands where there are no rivers (Wong et al. 2005). The lack of effective water infrastructure coupled with expanding human population and tourism can further amplify freshwater shortage and may result in overabstraction of groundwater storages (Wong et al. 2005; Teh and Cabanban 2007). This is a problem to many small islands which may lead to increased salinity and has important implications to human well-being and food production (Wong et al. 2005). Setegn et al. (2014) modelled freshwater resources in the Rio Cobre watershed of Jamaica, and found ground water contributes more than 42% of the total water yield. These models enabled watershed management scenarios to be developed to explore the impact of land use or climatic changes on freshwater resources. However, none of the studies in this review investigated the contribution of ecosystems to the provision of groundwater, for example through aquifer recharge.

The degradation and scarcity of freshwater resources was identified as an emerging issue for small islands and SIDS, where poor water quality and limited water quantity impact on human health (Postel and Carpenter 1993; Wong et al. 2005; UNEP 2014). Most of the studies (45) dealing with freshwater ecosystems in this review investigated the threats to freshwater ecosystems, including: the introduction of invasive alien species (18), water pollution (18), habitat loss and degradation (6), climate change (4), natural phenomena (2) and population growth (1).

The intentional or accidental introduction of alien species, which interact with native species and modify ecosystems, was identified as an important threat to freshwater resources (Orrù et al. 2010; Nico et al. 2011). Our review found that invasive alien species were shown to impact on freshwater communities through herbivory (Smirnov and Tretyakov 1998) and predation (Capps et al. 2009; Havird et al. 2013), and to result in changes to ecosystem structure and function (Skov et al. 2010; Holitzki et al. 2013) and water quality parameters (Simanonok et al. 2011; Moslemi et al. 2012). Moreover, the persistence of native species in aquatic habitats is associated with its physical condition; many tropical island fauna assemblages in severely altered streams have been found to be dominated by non-native species (Ramírez et al. 2011; UNEP 2014). The construction of dams and increased frequency and severity of droughts, which limit the connectivity of freshwater bodies, has also been observed to have a negative impact on diadromous fishes in tropical islands (Milton 2009; Ramírez et al. 2011) .

Pollution is a significant threat to island freshwater ecosystems. A number of studies identified in this review reported high concentrations of bioaccumulating pollutants, such as mercury, in freshwater ecosystems (Jaffal et al. 2011; Zananski et al. 2011), including in isolated islands in the Arctic and Antarctic regions (Riget et al. 2004; St Louis et al. 2005; Kenney et al. 2012). Agricultural activities are also a source of nutrients (Duwig et al. 1998; Caruso 2002; Corbet et al. 2002) and agrochemicals (Magbanua et al. 2010; Tashiro et al. 2013), which can reduce the quality of freshwater resources. Studies suggest that climatic change may exacerbate problems of freshwater provisioning IES, such as through the thinning of groundwater bodies and the extent and depth of seawater intrusion (Masterson et al. 2013).

Most of the studies in this review investigated island inland water ecosystems and their pressures. Freshwater ecosystems were highly valued for food and water provisioning IES. The limited capacity to provide freshwater IES and a strong demand for these, together with the degradation of freshwater ecosystems were identified as key threats to the sustainable use of freshwater IES.

Erosion control

Our review identified a number of papers dealing with erosion control on islands (Figure 6). The majority of the studies dealt with the issue in the context of coastal and forest ecosystems; only two studies made a quantitative, biophysical assessment of the issue (Boothroyd et al. 2004; Pries et al. 2008). Most of the studies reviewed dealt with drivers and pressures acting on island ecosystems (40) and their management (17).

From historic times, human activities have led to soil erosion. Pollen data from the Faroe Islands indicate that in pre-settlement island landscapes vegetation communities were stable over long periods of time at the landscape scale but displayed small-scale, episodic dynamism (Lawson et al. 2007). Changes attributable to human impacts include the appearance of cereal pollen, expansion of ruderal taxa and the suppression of shrubs and tall herbs, and an increase in the rate of erosion with the introduction of farming activities (Lawson et al. 2007). Similarly, in the central Pacific Cook Islands human-induced effects included major forest clearances and increased erosion of volcanic hillsides and alluvial deposition in valley bottoms (Kirch 1996). Erosion from ploughing and farming, and subsequent land abandonment in the Canary Islands was found to cause an irreversible degradation to the soil water regime, which could hinder ecological succession to the original climax community (Mora et al. 2012). Nonetheless, the effect of farming activities is likely to depend on the agricultural practices and their intensity. Macdonald et al. (1997) describe geomorphic evidence that indicates that sugar cane and cotton plantations in the Virgin Islands did not cause severe erosion but the more recent increase in built-up area and the growth in tourism have increased sediment yields and sedimentation rates.

The introduction of pigs *(Sus scrofa)* to Hawaii and their subsequent feralisation has damaged native plant communities, by facilitating the dispersal of alien plant species, trampling and increased soil fertility; re-establishment of native communities adapted to poor soils is prevented (Nogueira-Filho et al. 2009). It is reported that pig foraging and movement patterns can physically alter the watershed and increase run-off and soil erosion (Nogueira-Filho et al. 2009; Dunkell et al. 2011). The impact of feral sheep has also been reported by Walter and Levin (2008) for the Pacific Island of Socorro, while Freedman (2011) and De Stoppelaire et al. (2004) report on the effect of feral horses on dune formation on Sable Island, Canada. The study by Vacca (2000) on the exploitation of cork-oak forest in Sardinia suggests that controlled grazing pressure can be tolerated by native ecosystems without reducing cork production.

Our review documents how infrastructure development on small islands can exacerbate soil and coastal erosion (e.g. Ramos-Scharrón and MacDonald 2005; Ramos-Scharrón and MacDonald 2007; Goreau et al. 2008; Ramos Scharrón 2010; Ramos-Scharrón 2012). Construction material is, for example, often mined from beaches and coastal reefs in an unsustainable manner (Nunn 2000; Guzmán et al. 2003; Babinard et al. 2014). Similarly, the removal of mangroves along shorelines can increase the threat to human safety from storms as well as impacting water quality and biodiversity (Nunn 2000; Wolanski et al. 2005; Gilman et al. 2008). Burke and Maidens (2004) report that in the Caribbean region two-thirds of the coral reefs are at risk from at least one source of anthropogenic threat and roughly one-third are threatened by coastal development. Nevertheless, climatic change and sea level rise are probably the greatest threat to coral reefs (Gilman et al. 2008). The reduced delivery of erosion regulation services on islands impacts on the delivery of cultural and food provisioning IES but few studies investigated bundles of IES, and despite that we have recorded several studies identifying pressures affecting erosion IES, the impact of the loss of this service on other services and benefits remains poorly studied.

Whilst most of the studies focused on coastal and forest ecosystems, indicating the critical role played by these in the delivery of erosion control IES, significant pressures acting on this IES dominated the literature. The introduction of alien species, modification of island ecosystems through intensive agricultural practices, and urban and coastal development were identified as key threats to erosion control IES.

Recreation and eco-tourism

Many islands have considerable potential for the delivery of cultural ecosystem services in the form of experiential use of species, habitats and landscapes, and eco-tourism and recreational use of island ecosystems. Indeed, the economies of many islands strongly depend on tourism (Hampton and Jeyacheya 2013). Thus it is not surprising that papers dealing with these issues were the most frequently encountered in our review. Our detailed analysis of these papers suggested, however, that only a small number quantified the contribution of biodiversity to recreation and eco-tourism IES and their value. Instead, most discussed different management strategies and drivers and pressures arising from human activities (e.g. Samways et al. 2008).

Few studies in this thematic area attempted to quantify services. However, the kinds of analysis that can be done are illustrated by Teh and Cabanban (2007) who carried out a biophysical assessment of the Palau Banggi island’s ecosystems to evaluate its suitability for eco-tourism, and Hall and Day (2014) who undertook a study of forest karst in Puerto Rico and its potential to support low-impact recreation and eco-tourism. Studies that mapped preferences for outdoor recreation and perceived values included those of Klain and Chan (2012), Van Riper et al. (2012) and Uyarra et al. (2009). These indicate a significant overlap between perceived value of site for recreation and gene pool protection ecosystem services. Cruz et al. (2011) showed that while eco-tourism was an important outcome from a Special Protection Area set-up according to the EC Birds Directive, other significant outcomes included gene pool protection, freshwater provision and purification, the reduction of floods and landslides occurrence and carbon storage.

Ecosystems that provide cultural ecosystem services are often impacted upon by multiple drivers and pressures that can cause a reduction in the associated benefits (Milcu et al. 2013). Milcu et al. (2013) identified land use/cover change and overexploitation as the most important pressures acting on cultural ecosystem services, and giving rise to ecosystem services trade-offs that affect the final delivery of cultural services. Such pressures would be expected to be exacerbated in small islands with limited land resources. For example, extensive reclamation of habitats such as wetlands and tidal flats in Dongtan, Chongming Island, China, was associated with a reduction in the total value of eco-tourism and recreational services by 62% in 10 years, equivalent to \$855.26M–\$981.85M (Zhao et al. 2004). Trade-offs with recreation and eco-tourism arising from blast fishing, fertiliser runoff, wastewater management, sediments from run-off and coastal construction, damage due to reef walking, boat anchoring and fishing harvest have been reported (e.g. Teh and Cabanban 2007; Hassanali 2013). However, intensive management for recreation and eco-tourism IES can itself cause trade-offs and pressures that lead to reduced delivery of other key IES. In a review of eco-tourism in conservation across continents and habitats, Krüger (2005) found that a large proportion of case studies reported that eco-tourism led to serious habitat alteration and serious trail erosion.

Intense urbanisation along islands' beaches has been observed to cause higher coastal erosion rates (Silva et al. 2009; Shahbudin et al. 2012). Tourism also poses significant demands for energy and freshwater, which may impact on the sustainability of island ecosystems (Teh and Cabanban 2007; Samways et al. 2008).

Studies on recreation and eco-tourism IES were the most abundant in this literature review. This review identified key synergies between recreation and eco-tourism IES and other provisioning, regulating and cultural IES. Trade-offs associated with the use of island ecosystems to deliver other IES (e.g. agricultural and fisheries provisioning IES) were also identified. However, tourism also leads to a number of pressures on island ecosystems, itself creating trade-offs with the delivery of other key IES to island communities (e.g. erosion control, freshwater provisioning and gene pool protection)

Conclusion – identifying gaps and future research

This review identified the importance of ecosystems and the associated IES to island communities and visitors. The results indicate that there is a substantial evidence base that demonstrates that communities in small islands derive significant benefits from these services, enabling them to cope with the unique vulnerabilities and pressures that they face due to their size and isolation. Important knowledge gaps do, however, remain in the literature:

- Cultural ecosystem services associated with small islands have been well researched, and most of the studies look at the links between gene pool protection, recreation and eco-tourism. The focus of most studies was the management of island cultural ecosystem services, which indicates how island ecosystems have been managed and studied with respect to their ability to provide cultural services, while few have studied the underpinning mechanisms responsible for the delivery of these services. Studies carrying out a biophysical quantification of IES were lacking suggesting an important gap in knowledge.
- Although island systems have long been transformed by people, the intensification of use in modern times has been significant and has led to a wide spectrum of pressures on IES. Habitat loss and degradation, the introduction of alien species and coastal and soil erosion were identified as particularly important pressures. In this review, the vulnerability of ecosystem services on islands to climate change was less well studied, even though this has important impacts and may lead to the loss of their adaptive capacity and livelihoods.
- Relatively few studies have investigated the perceptions and traditional ecological knowledge of local people; those that we found were mainly concerned with food and water provisioning and recreation and eco-tourism IES, rather than erosion control and pollination. This literature also suggests that local communities are aware of the pressures arising from human activities and their impact on well-being, since a relevant number of studies look at stakeholder involvement as a method to develop management actions. Within this context, a place-based approach that assesses services as bundles of strong social relevance coupled with an assessment of the management and policy actions needed to sustain them would seem to be a priority.
- Many studies considered multiple island ecosystems, suggesting strong interrelationships between terrestrial, coastal and marine ecosystems and in the delivery of ecosystem services. Pressures that impact on one ecosystem were shown to affect other interrelated ecosystems, while multiple ecosystems appear to contribute to the delivery of specific IES. These results corroborate the view that integrated management approaches are essential. Spatial data should be used to maximise the potential of island landscapes to deliver IES whilst reducing, or dealing with the effects of trade-offs.
- Studies that use empirical or spatial data to assess recurrence across a range of spatial and temporal scales are lacking. Studies that investigate how cultural, provisioning and regulating services co-vary, and the role of ecosystems in the delivery of these services, are important to identify management practices maximising the potential of island landscapes to deliver IES bundles, whilst reducing trade-offs and negative impacts on ecosystems.

The results obtained from this literature review of IES suggest that ecosystem service assessments, and the management of IES, in small islands are likely to be hampered by the relative availability of published scientific information on the mechanisms linking ecosystem structure and function, IES delivery, benefits and values. This study demonstrates a strong prevalence of studies investigating pressures on island ecosystems, and the management of these, but few studies quantify the role of biodiversity in delivering key IES, investigate the value to island communities or involve stakeholders to ground-truth the development of management actions or evaluate the possible management actions.

Given the identified gaps, and the extensive data requirements to assess multiple ecosystem services, the consultation with experts, locals and stakeholders, who through profession or experience have developed sufficient knowledge on the subject, is likely to provide an important starting point for providing a wider picture, developing integrative assessments of IES, focused monitoring and data collection, improved understanding of the synergies and trade-offs between IES and to provide indication of ecosystem management measures that would be favoured by island communities and other stakeholders. These approaches need to consider the special case of small islands, as a result of the common challenges these face, the interrelatedness of island ecosystems and IES, and the significant benefits island communities derive from these ecosystems.

Notes

1. https://sustainabledevelopment.un.org/content/documents/Agenda21.pdf.
2. Produced in Bridgetown, Barbados in 1994 at the first Global Conference on the Sustainable Development of Small Island States, a conference mandated by United Nations General Assembly Resolution 47/189. https://sustainabledevelopment.un.org/conferences/bpoa1994.
3. Mandated by UN GA Resolution (A/57/262), the high level Mauritius International Meeting held in Port Louis, Mauritius in January 2005 served as the culmination of a 10-year comprehensive review of the Barbados Programme of Action for the Sustainable Development of Small Island Developing States. https://sustainabledevelopment.un.org/conferences/msi2005.
4. The Third International Conference on Small Island Developing States was held from 1 to 4 September 2014 in Apia, Samoa. The UN Member States formally adopted the SAMOA Pathway outcome document of the Conference. https://sustainabledevelopment.un.org/sids2014.
5. http://millenniumassessment.org/en/index.html.
6. http://www.teebweb.org/.
7. www.cices.eu.

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