Social and Ecological Interactions in the Galapagos Islands

Stephen J. Walsh
Carlos F. Mena · Jill R. Stewart
Juan Pablo Muñoz Pérez *Editors*

Island Ecosystems

Challenges to Sustainability

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The Galapagos Islands are a “living laboratory” for the study of evolution, environmental change, and conflicts between nature and society. Free of human predators for almost all its history, these islands have developed some of the most unique life forms on the planet, adapted to their harsh surroundings and living in ecological isolation. It was not until Charles Darwin’s famous visit in 1835, which helped inspire the theory of evolution that this Archipelago began to receive international recognition. The Galapagos Archipelago encompasses 11 large and 200 small islands totaling approximately 8,010 sq. km. This series will focus on the entire island archipelago, and it will emphasize the study and documentation of human-environment interactions on the four inhabited islands in the Galapagos: Isabela, Santa Cruz, San Cristobal, and Floreana. Together they constitute a well-defined “natural laboratory” for the study of human-environment interactions as they vary in fundamentally important ways.

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Editors

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Foreword: World Summit on Island Sustainability

It was 4 pm on an overcast day, and I found myself sitting on the soft, cool sand of Playa Mann surrounded by dozens of snoozing Galapagos Sea Lions. I was entranced watching the dominate male patrol his shore, swimming back and forth in front of the beach. He was big and loud and taking his job very seriously. Then, two young women who had been laying on the beach, walked to the shoreline to dip their toes into the refreshing water, but he was NOT having it. He quickly swam over, waddled out of the ocean like a lightning bolt (which was incredible because of his girth) and let out a sound I can only compare to an old rusty tuba being played by a strong wind gust! Needless-to-say, the two ladies headed back to their beach towels very quickly, but the other sea lions, including females, young males, and many nursing babies on the beach, weren't even phased. Then off to my right, I caught a glimpse of a marine iguana slowly making its way out to sea to feed (oh my gosh!). Its salt crusted head swaying right to left with every step. It was then I saw the rocks in the distance were not speckled with bright colors, but it was a huge collection of Sally Lightfoot Crabs looking for their next snack. And this was within the first 30-minutes of putting my bags down after arriving on San Cristobal Island, Galapagos Archipelago of Ecuador.

The Galapagos Islands are one of the most spectacular places on our planet. Anyone who loves nature dreams of visiting them and I was grateful to be experiencing this incredible, historic, and special place myself. I was reminded that while islands make up a small percentage of the Earth's total area, they are home to a large percentage of the world's biodiversity including many threatened and endangered species. And while there is still a lot of work to be done, Galapagos has become a beacon of light for science, discovery, and successful conservation.

I am part of a family that has been forging conservation, especially in our ocean, for three generations and counting. My grandfather-in-law, Jacques Cousteau pioneered underwater exploration. You see, he fell in love with the sea and wanted to send more time under water, so he co-invented the Aqua-Lung, a device we refer to today as SCUBA. Then he wanted to share this fabulous water world with everyone he could, so he made underwater cameras, outfitted an old wooden hulled minesweeper, and set off on adventures around with world with his family in tow.

Cousteau became an international household name with his eponymous TV series, *The Under Sea World of Jacques Cousteau.* While they set out to show the beauty and wonder of the ocean, they also endeavored to share the truth about the degradation of the environment that they witnessed on their adventures. Indeed, Jacques and his son Philippe Sr. are considered two of the founders of the modern environmental movement.

When Jacques was born in 1910, there were 1.6 billion people. Today, its estimated that we have over 7.5 billion people on earth and we will most likely reach 9 or 10 billion by the middle of this century. Today, our world is facing an onslaught of severe problems: excess carbon, biodiversity loss, a warming and more acidic ocean, food shortages, sea-level rise, floods, droughts, fires… the list goes on and on. And many island nations are at the front lines of these battles. Just in my lifetime, we have lost HALF of all the biodiversity on our planet… imagine that, in just 40 years, half of the wondrous diversity of nature has disappeared. With this constant torrent of bad news, it is very easy to get upset, anxious, and even downright depressed. But there is HOPE.

Nature has an incredible ability to restore itself. And while I have witnessed this in many places on my adventures, one very unlikely place stands out. It all started in the middle of the Pacific Ocean during the Cold War when the United States detonated 23 nuclear bombs on a small chain of islands around Bikini Atoll. The largest of these bombs was a hydrogen bomb called Castel Bravo, detonated on March 1, 1954, with 1000 times more power than the bombs dropped on Hiroshima or Nagasaki. The heat from the blast registered almost as hot as the surface of our sun. So hot in fact, the sand at the blast site on Bikini Atoll turned into glass. And every living thing for miles around, above and below the surface, died instantly.

So, when I went to film the sharks of Bikini Atoll… I had no idea what to expect. But it turned out to be one of the most spectacular ecosystems I have ever seen. Slipping into the water, I was immediately surrounded by 70 grey reef sharks, massive groupers the size of German shepherds, and giant clams the size of coffee tables. The entire ecosystem wasn't just surviving, it was thriving. In just 60 years, Bikini went from nuclear waste to a pristine environment. This was because the land of the islands is still radio-active, thus no one goes there, and the area has turned into a de facto Marine Protected Area. When talking with a scientist there, they said if we compare the effects of nuclear fallout and the effects of human presence on our natural world… humans are worse. Ouch.

But in the same way humans have the power to destroy nature, we also have the power to rebuild it. We know how to do it, we have the tools, we just need the will. Because when we do, nature benefits, but so do people and as my grandfather-in-law once said, "to build environmental sustainability, we must build human sustainability."

About an hour and a half north of Cabo San Lucas at the bottom of the Baja Peninsula is a town that embodies just this. Cabo Pulmo is a small community of dusty dirt roads and small humble homes. Not unlike dozens of similar communities you might find up and down the peninsula, and yet Cabo Pulmo, as unlikely as it may seem, is a shining beacon for ocean conservation. Thirty years ago, the

patriarch of this small community, a man named Juan Castro was worried. The fishing that had sustained his community for generations was declining. Every day they had to venture further and further offshore to find fish with no guarantee of success. Like any good father, Juan worried for his ability to feed his family and the future of his children.

Then, one hot summer day, a group of tourists drove up from Cabo offering him money to take them out on his boat. Much to his surprise they did not want to fish, instead they had come to scuba dive. When they returned to the surface, one of the divers tossed his mask to Juan and invited him to look underwater. This was a pivotal moment and changed Juan forever because despite growing up next to the ocean, he had never looked beneath the surface.

The beauty he witnessed gave him an idea, and after years of work, he convinced the local community to join him in a crusade to create a Marine Protected Area in their local waters. Fast forward 20 years and the 70 square kilometer no-take marine reserve in Cabo Pulmo is a paradise unlike anything in the Sea of Cortez. With upwards of a 1000% increase in living creatures in the area, even for someone like me – who has been diving all over the world, it is magical. And when you talk to Juan and his children and grandchildren, you hear a common refrain that they are proud of what they have achieved. Not because of the recovery of the reef (though that matters too), they are most proud because in the words of one of his sons Mario… they have something that they can pass on to their children that will only increase in value.

It's these stories of success that give me hope. As you will learn in the chapters to follow, scientists, researchers, and local people have made fascinating discoveries and found viable solutions for many of the problems we face. Humans have a steadfast drive to survive and when we come together and work WITH nature, incredible things can happen.

While nature has islands, knowledge does not. And knowledge is best shared.

Journalist, Adventurer & Ocean Advocate Ashlan Cousteau
EarthEcho International,
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Preface: Galapagos Science Center and Island Sustainability

Overview Statement

On June 26, 2022, a group of scientists from around the globe convened at the Charles Darwin Convention Center in the Galapagos capital of Puerto Baquerizo Moreno. They arrived on San Cristobal Island to participate in the *2022 Galapagos World Summit on Island Sustainability*, hosted for over four days by the USFQ-UNC Chapel Hill, Galapagos Science Center.

The event was significant if for nothing more than it represented the first full-scale global science conference hosted on San Cristobal since the archipelago closed to visitors at the onset of the COVID-19 pandemic in February 2019.

But the timing could not have been more appropriate. By June 2022, Galapagos and other island systems around the world were seeing tourism economies that had lain dormant during the pandemic begin to revive, reintroducing familiar stresses to fragile archipelagos.

The topic of the summit was island sustainability – a comprehensive examination of the threats to island ecosystems and strategies and solutions for their sustainable management and growth. Launched with an inspirational welcome from EarthEcho International's Ashlan Cousteau, the event brought together speakers with unique perspectives from locations such as French Polynesia, the Caribbean, the Hawaiian Islands, Guam, Australia, Chile, New Zealand, and the USA to discuss common challenges and to learn from one another.

While the Galapagos Islands are well-known for the endemic fauna and flora that inspired Darwin's *On the Origin of Species*, the focus of the conference was much broader than the preservation and study of unique species and habitats. The summit examined the topic of island sustainability comprehensively, exploring the unique role archipelagos play as geographically isolated systems to understand interactions between humans and the natural world and the larger forces facing the planet itself. With the global pandemic subsiding – and faced with the mounting threats of global climate change and human impacts on the planet – the discussion could not have been more-timely, nor held in a more appropriate place.

The work of the scientists who contributed to the 2022 Galapagos World Summit is contained in the pages of this publication, collected under appropriately broad sections that address the general foci of island sustainability. These range from the unique challenges to sustainability in island ecosystems to the critical role of social sub-systems in island communities and the attributes of terrestrial and marine subsystems. It embraces the interdisciplinary nature of sustainability research and concludes with thoughts on the future of Earth's archipelagos.

The magnet that drew these scholars to this remote corner of the world was the Galapagos Science Center – the only university-owned research center in Galapagos. A partnership of the University of North Carolina at Chapel Hill and Universidad San Francisco de Quito, this modern three-story laboratory facility is located at the foot of the volcanic hill that rises behind Playa Mann on San Cristobal Island. Opened in 2011, the 20,000 square foot facility houses four specialty labs outfitted separately for the study of terrestrial ecology, marine ecology, microbiology and genetics, and GIS and data science. It maintains a full-time staff of 15 employees under the leadership of co-directors from USFQ and UNC-Chapel Hill.

The vision for the Galapagos Science Center was the product of the close relationship and collaborative work of Dr. Steve Walsh at UNC-Chapel Hill and Dr. Carlos Mena at USFQ – and relationships of all kinds have proven the key to the GSC's success.

USFQ and UNC-Chapel Hill combined resources to construct and launch the center, which has grown steadily since its founding into a highly successful platform for scientific work in Galapagos. Unlike one-off research engagements where scientists visit, collect their samples and data, and depart, the GSC has embedded itself in the community and established a close *working relationship with the Galapagos National Park and Marine Reserve.*

Together, the Park and the GSC have developed a streamlined permitting process for scientists working through the Galapagos Science Center. The GSC has sought to align its work with the Park's needs and priorities and, where mutually beneficial, dedicated its own resources to support the Park's work. A joint initiative led through UNC and USFQ genetics and microbiology faculty and developed in consultation with the Ecuadorian authorities has established a GSC biobank and launched a DNA sequencing and storage project in the islands.

The GSC has also deeply embedded itself in the community it serves, offering career and educational opportunities to *local citizens, hiring locally, and contributing actively to public life in the islands.* Each year, a symposium is held at which GSC scientists present their work to the Galapagos National Park, their peers, and members of the local community. When the Covid-19 pandemic reached Galapagos, the islands locked down and tourism that supports their economy suddenly came to a crashing halt. As a key employer in the San Cristobal Island community, the GSC kept its staff on the job and launched the GSC REACCT program, reallocating a share of its budget to fund community projects that both created local jobs and advanced resource conservation and island sustainability goals. Information about some of the GSC's citizen science and sustainability projects, such as the Galapagos Barcode Project, can be found in this volume.

The GSC's attention to local and Park relationships is complemented by the global research partnerships that have been a part of the center since its inception. The International Galapagos Science Consortium was created early on to offer enhanced GSC access and benefits to key global partners and to provide a platform for strategic engagement with faculty and students from around the globe.

The 2022 Galapagos World Summit on Island Sustainability leveraged all of these relationships – local, park, and global – that have made possible the success of the Galapagos Science Center. In the pages that follow, we offer the fruits of that convocation of scholars. We hope that, in the wake of the COVID-19 pandemic, their work may guide others toward a healthy balance between the human and natural world in our planet's precious archipelagos.

Donald Hobart

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Stephen J. Walsh Co-Guest Editor, is the Founding Emeritus Director of the UNC Center for Galapagos Studies and the UNC-USFQ Galapagos Science Center. He is also an Emeritus Distinguished Professor of Geography and is a Research Professor in the UNC Department of Geography. His research focuses on understanding the multi-scale and multi-thematic drivers of land use/land cover change in vulnerable and fragile ecosystems through remote sensing, spatial analysis, and spatial simulation model of "what if" scenarios of change.

Carlos F. Mena Co-Guest Editor, Co-Director of the Galapagos Science Center, Director of the Institute of Geography, and Professor in the College of Biological and Environmental Sciences, Universidad San Francisco de Quito, Ecuador. His research assesses the importance of land use/land cover change on social and terrestrial systems in the Galapagos Islands as well as in the Ecuadorian Amazon.

Jill R. Stewart Co-Guest Editor, is the Philip C. Singer Distinguished Professor, Department of Environmental Sciences and Engineering, University of North Carolina at Chapel Hill, USA. She develops novel techniques to detect and track pathogens in water. She is particularly interested in linkages between ecosystems and human health and well-being.

Juan Pablo Muñoz Pérez Co-Guest Editor, has more than 20 years of experience in diving and surfing in the Galápagos and 10 years of conducting research. Juan Pablo's research focuses on animal movement and ecology, especially sea turtles and other marine animals such as whales and dolphins. Since 2014 he has been a pioneer in investigating plastic pollution in Galápagos with the primary objective of using science to find solutions. Currently, he is completing his PhD at the University of the Sunshine Coast.

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Part I
UNC & USFQ Galapagos Science Center, 10th Year Anniversary

Chapter 1
Connected Places and Social-Ecological Forces that Impact Small Island States and Their Sustainability: An Essay

Stephen J. Walsh and Carlos F. Mena

Introductions

We are motivated by the general concern for the fragility and uniqueness of island ecosystems and the tensions between human-environment interactions, often manifested through economic development, disturbance regimes, and challenges to resource conservation (Baldacchino 2018; Walsh and Mena 2016). Risks to islands, and particularly, Small Island States, are often associated with the intensity and type of environmental and socio-economic processes that impact local island conditions (Gardner and Grenier 2011). For instance, island ecosystems are influenced by the type of economic development associated with residential and touristic processes, such as, population migration, urbanization, deforestation, and agricultural extensification (Brewington 2013). Climate change and the related factors of sea-level rise and changes in the intensity and frequency of ENSO events are confounding processes that further shape island ecosystems (Uyarra et al. 2005). Environmental change, including, coastal erosion, invasive species, and land use dynamics further mediate islands, thereby, necessitating the development of mitigating strategies. Such strategies often involve resource conservation and protected area designation to ensure the wise stewardship of marine and terrestrial sites, with the goal to minimize the social-ecological challenges to the sustainability of island ecosystems (Ernoul and Wardell-Johnson 2013; Ghosh et al. 2001; Walsh et al. 2018).

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Focal areas of island sustainability discourses generally include the importance of self-reliance of islanders and their social-ecological systems, protection and development of human and cultural resources, and the promotion of partnerships between government and non-government organizations to ensure sustainable human-environment interactions as an approach to reduce uncertainty (Pazmino et al. 2018). Critiques of island sustainability often address issues that focus solely on the future, such as, climate change, that may neglect persistent social challenges, including, household livelihood alternatives, healthcare, education, water quality, and food security on islands (Mai and Smith 2015).

As described by Mena et al. (2020), *Sustainability* may be defined as a socio-ecological process used to maintain critical multi-scale functions and corresponding ecosystem services through time, often in response to disturbances imposed by human and/or natural processes. *Sustainable Systems* may require adaptation to accommodate change without permanently transitioning the system into an alternate state, thereby, requiring interventions to restore sites to a previous condition. *Sustainable Development* is a process to improve the quality of life of island people, while maintaining the ability of social–ecological systems to continue to provide valuable ecological services that social systems require, and physical systems depend. In the Galapagos Islands of Ecuador, for instance, the maintenance of amenity resources to support tourism and the quality of life of residents are explicitly linked to ecosystem goods and services, particularly, the accessibility to high-quality natural environments and the terrestrial and marine visitation sites that showcase iconic species and iconic environments (Dong et al. 2009).

Islands – Space and Place

Islands, circumscribed often by irregular coastlines and shaped by complex historical and multi-scale geographies, are strongly influenced by ocean conditions, but so too by the mutual relationships among space, place, society, globalization, and the social-ecological forces of change (Dodds and Royle 2003; Ratter 2018). The general context of islands is that they can be geographically remote or positioned close to the mainland, connected directly or indirectly to the continent and to other islands, singularly located or arrayed in archipelagos, irregular in shape and size, locationally distributed according to the combination of geological, biological, and anthropogenic forces, and varied in their ecological, economic, social, cultural, and topographic settings (Johannes de Haan et al. 2019).

Island vulnerability often is influenced by a collection of factors, for instance, their geographic remoteness, land cover/land use change patterns, intensity and type of human uses, orientation to the ocean, biophysical and social factors of formation and change, terrain configurations, settlement patterns, social and ecological connectivity, disturbance regimes, and the human dimension linked to consumptive behavior, economic development, and conservation management (Royle 2001). Islands are further shaped by their endogenous dynamics including, soil and

freshwater conditions to support residential and transitory populations as well as subsistence and/or commercial agriculture, shoreline conditions to support trade and ocean transport, and settlement patterns and colonial legacies that impact populations as well as tourism (Baldacchino 2018; Stamoulis et al. 2018). Exogenous factors also impact islands, for instance, through situational factors of wind, currents, climate, and migratory pathways of marine species as well as through distant political forces associated with social and environmental policies, economic development programs, and resource conservation initiatives (Esther et al. 2012). From a biological perspective, isolation affects island biota in complex ways, for instance, through the amounts of surrounding landmasses that determine the number of arriving propagules and the over-water distance that may act as dispersal biases that favor arriving species that are good swimmers, flyers, or floaters as well as seeds that can maintain their integrity for relatively long periods of time and under changing environmental conditions (Weigelt et al. 2013). Also, when compared to mainland sites, oceanic islands are known for their high percentage of endemic species, but only moderate levels of species richness, both highly relevant to the global prioritization of tourists as well as conservation efforts.

Often the focus on islands is on their complex connectivity among nearby and distant places and the spatiality of islands and the role they play in shaping the evolutionary characteristics of habitats as well as land cover/land use change patterns on islands, mediated by local inhabitants and visitors, including, people, plants, and animals (Pazmino et al. 2018). While accounting for only about 2-percent of the world's land area and formed and continuously shaped by geologic, geomorphic, and biological forces, islands are connected to mainland locations and other islands in strategic ways (Royle 2001). Often borne from the fire of volcanic activity, islands are shaped by indigenous populations, colonial legacies, and migration streams whose contexts are further influenced by social, cultural, economic, geopolitical, and biophysical domains. Further, islands are often influenced through insularity, that is, generation of a local sense of place and an island identity in which inhabitants and their associated political structures become agents of change and conveyors of development (Royle 2001). The complex and precarious nature of small islands are often defined through their limited resources, multi-layered social systems, and the close social interactions among population groups, social externalities, environmental change, and global networks (Ratter 2018). Small islands are also often portrayed as vulnerable to external pressures, ranging from colonization, geopolitical forces, sea-level rise, natural hazards, and resource scarcities, as well as internal pressures, including under-employment, depopulation or over-population, diversification of household livelihoods, and loss of historical identities (Baldacchino 2018).

Islands are also the home to vulnerable iconic species and unique habitats that are the focus of global tourism activities and conservation efforts. Microcosms of larger mainland systems, islands exhibit smaller sizes, crisp boundaries, restricted access, and often historical isolation that make them more manageable to study and more effective to measure the factors that threaten their social-ecological sustainability. Tourism has become one of the most important economic sectors in recent

decades, and island tourism is one of the main components of world tourism. Tourism has become the most important and dynamic driving force of economic change on islands, especially for islands with high amenity resources. Tourism can reduce the seemingly remoteness of islands as islands connect to the world through constructs that shape place and alter the use and imagination of space (Machado and Almeida 2014). Human factors associated with residential populations, migrations, and tourism frequently drive land cover/land use change through direct and indirect ways, even more strongly than ecology and geography. Deforestation, agricultural extensification, and urbanization shape natural and human circumstances that act upon islands by episodic and continuous forces of change. The Human Impact Index, a measure of current threats to islands and mainland sites through development, is significantly higher for islands. Further, land cover/land use change on islands for the year 2021 indicates significantly higher levels as compared to mainland locations.

Tourism is directly influenced by location, which plays a central role in the development of mass tourism on islands. Tourism has led to the restructuring of island economies, for instance, through clustering of accommodations, impact of national and international airports, food imports from the mainland or from other islands, port and harbor development, and community infrastructure development that has tended to reframe economic activities from agriculture, agroforestry, and/or fisheries to the marketing of alternate, exotic products, including, amenity resources and visitation sites that are consumed by resident and tourists. Often higher revenues are generated through the direct employment of residents and/or a migrant work force incentivized to locate on islands by the service industry and its emphasis on island tourism. Placed-based and boat-based tourism are often elements of island tourism, but their impacts on the environment are considerably different as a consequence of their respective demands on the community infrastructure. Island branding often seeks to establish a special niche in tourism, products marketed locally or globally (e.g., coffee), special services rendered (e.g., banking), and even the island's identity, as more international visitors seek to indulge in the island experience, interact with iconic wildlife species, and marvel at special landscapes and/or island cultures. Island challenges to tourism include the possible saturation of an island as a tourist destination, degradation of alternate sources of island revenues, surrendering to tourism as the only island product, and the challenges of securing sufficient and dependable sources of freshwater and approaches for handling associated waste and sanitation demands (Fiorini et al. 2017). Sustainability in the context of tourism is the development and maintenance of islands in a manner that ensures the region remains viable over an indefinite period, does not degrade the environment, and does not prohibit the successful development of alternate activities conducted on islands. Island resilience links to island sustainability in which islanders and government organizations engage local people in the development and management of tourism, strengthens the local capacity and social capital on islands through participatory engagement and the development of innovative mechanism to achieve positive and long-lasting results from tourism that extends throughout the community.

As seen on several occasions around the globe, *nature-based tourism* can rejuvenate a socio-economic system through a destination's social, physical, and natural capital. *Social capital* is the source of cultural and touristic identify of a place, *physical capital* includes the infrastructure, transport, and services offered, and *natural capital* is the source of environmental services provided, such as, access to iconic species and special landscapes and seascapes (Juan et al. 2008). Islands, however, that depend on a specialized environmental niche are vulnerable to environmental change, heighted by social-ecological stressors, such as, climate change and in-migration of population for jobs in the tourism industry (Gil 2003). *Vulnerability* refers to characteristics of a place, person, or group and the situations that influence their capacity to anticipate, cope, resist, and recover from the impacts of disturbances and/or shocks to human and ecological systems. Generally speaking, islands, particularly small islands, are more affected by external pressures and more immediately than larger islands, island archipelagos, and mainland areas. *Coastal Vulnerability Index* that assesses vulnerability by indicators of exposure and coping capacity shows that all Small Island Developing States (SIDS) face a moderate or high risk from factors, such as, sea-level rise, El Nino events, alien species, flooding and erosion, population migration, and environmental degradation. Development challenges applied to small islands include diseconomies of scale, fluctuating commodity prices, difficulties in accessing global markets, lack of adequate infrastructure, and, often, inadequate availability of local labor and high transit costs. In the Galapagos Islands, for instance, the economic benefits of tourism are unequally distributed at the local, national, and international levels (González et al. 2008; Taylor et al. 2008). The inequality in the tourism sector in the Galapagos is supported by tension among local people and government institutions that impact household livelihoods, lack of trust in the permit system imposed by government, and a sense that the process is not fair to all stakeholders.

The geography of islands, particularly, small islands, is closely related to space, place, and time and the on-going context of globalization, and the social-ecological drivers of change. Small islands are bounded spaces that are limited in size, land area, resources, economic and population potential, and political power. Small islands also face specific problems associated with isolation, which impacts the relative accessibility to services and markets, however, exotic branding of islands can reduce the anxiety of marketing single products to the region or world. By far, marketing of special and iconic places through tourism has elevated islands to new financial levels, but not without the expressed concern of over-population, resource exploitation, and diminishing returns on investment over time. Loss of island identity and its "islandness," a term used to embody the essence of island living and the attributes that make an island what it fundamentally represents, hangs in the balance of complex human-environment interactions and understanding and mitigating the threats to island sustainability (Baldacchino 2018; Ratter 2018; Royle 2001).

Island Sustainability

The challenges associated with sustainable management of island ecosystems, the impact of local, regional, and global context linked to endogenous and exogenous forces of change, and complex and multi-scale human-environment interactions necessitates an integrated approach to island studies and the ability to simulate "what if" scenarios applied to islands (Pizzitutti et al. 2017). Island biocomplexity is a term used to describe the study of complex adaptive systems that combine a new island ecology that incorporates human induced change on the environment. Island biocomplexity encompasses the complex interactions within and among ecological systems, physical systems on which they depend, and human systems with which they interact (Walsh et al. 2019). Island ecosystems are complex adaptive systems because their macroscopic properties emerge from the interactions among the individual components of the ecosystem (Pizzitutti et al. 2014). Global changes, including the forces associated with tourism, migration, and land cover/land use change, exert exogenous pressures on island ecosystems, but their systems have their own spatially contingent endogenous dynamics (Miller et al. 2018). Development of quantitative and spatial simulation models can help to understand the forces and elements influencing the specific patterns of tourism growth (Miller et al. 2010). Simulation models suggest that the type of tourism determines the pattern of tourism growth and the characteristics of the post-stagnation phase in the absence of policy changes. The simulation models are designed to consider social and ecological threats to diverse and fragile island settings, informed through multi-scale and multi-thematic geospatial data. Often, the models are designed to improve the decision-support systems to examine various elements of tourism management (Pizzitutti et al. 2014; Walsh and Mena 2016). Participatory approaches integrate the views of multiple stakeholders and to build an understandable, graphical representation of the impacts of tourism and resident populations on complex human-environment interactions. Dynamic systems models rely upon data to specify rules to model behavior, complex relationships, and rates of exchange that are derived through statistical functions specified in theory or practice (Thanh and Carl 2015). Figure 1.1 is a conceptual representation of the concepts and perspectives that shape island sustainability and influence the development of dynamic simulation models to understand the implication of policy, disturbances, development, and social-ecological pattern-process relationships on island futures (Zhang and Walsh 2018).

Concluding Thoughts

People are an important driver of change on islands, for instance, through urbanization, tourism, fisheries, agriculture, and the influx of people and products from mainland settings. The introduction of invasive species, depletion of natural resources, and excessive reliance on terrestrial and marine assets may jeopardize the

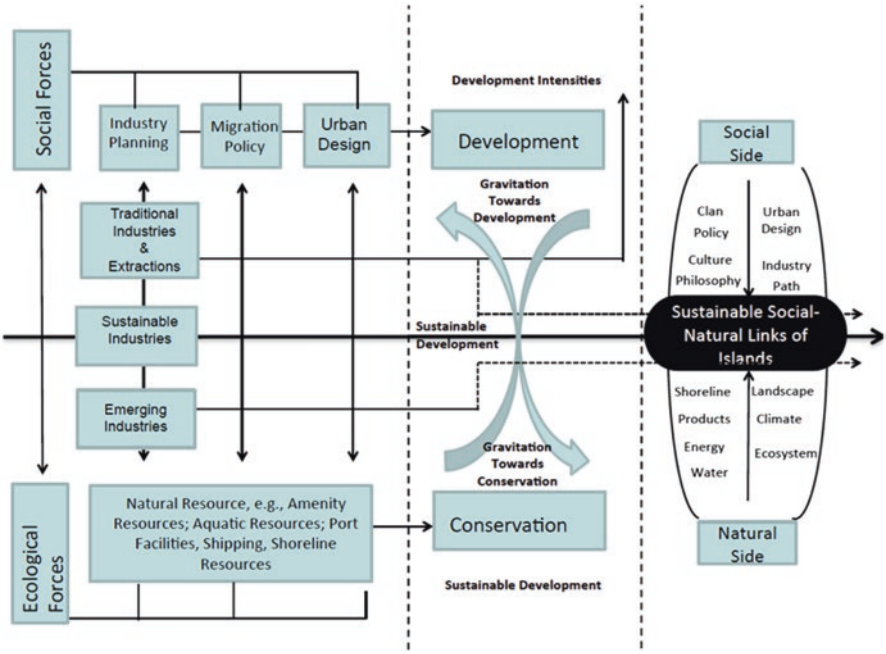

Fig. 1.1 Conceptual representation of an economic development and a resource conservation gradient, shaped by social and ecological forces of change and the characteristic elements of each (Zhang and Walsh 2018)

long-term provisioning of ecosystem goods and services which local residents, tourists, and human-environment interactions depend. Small islands, in particular, and their social-ecological systems, are threatened by forces of globalization, natural hazards, and the worsening impacts of climate change. Shaped by geographic isolation and unique environments, cultural diversity and biological endemism of islands are at risk from the very forces that encourage tourism and the associated development brought to their shores (Shi et al. 2004).

As in colonial periods, islands continue to be exploited through resource extraction and production, now linked to the niche tourism marketing of iconic species, amenity resources, and island identities. Tourism development makes islands attractive to migration from within and outside the region. Often placed-based vs. boat-bases tourism impacts the environment through excessive use, but also moves revenues to off-island locations and entrepreneurs. As outposts of globalization, islands are constantly in motion from social and ecological perspectives, changing the discourse about islands and their ability to seize opportunities and to protect themselves from threats to their sustainability. Often with limited political power, islanders may find it difficult to address the complexities of contemporary life and to prepare for alternative futures among the intrinsic challenges to islands. Embracing the island experience is often craved by populations that are economically enabled to relocate to islands and to realize the benefits of "islandness," a