CORPUS PUBLISHERS

Environmental Sciences and Ecology: Current Research (ESECR)

ISSN: 2833-0811

Volume 7 Issue 1, 2026

Article Information

Received date : March 09, 2026

Published date: March 16, 2026

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DOI: 10.54026/ESECR/10120

Keywords

Conservation; Ecosystem Services; Productive-Matrix Marine Refuges (PMMR)

Opinion Article

Toward Regenerative Coexistence in Chilean Norpatagonia: Marine Refuges within Intensively used Seascapes

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Abstract

Aquaculture has transformed the seascapes of Chilean Nor Patagonia into intensively used socio-ecological systems where conservation has been largely displaced. Yet resilient kelp forests and associated biodiversity continue to sustain key ecological functions. We argue that long-term viability in the Chiloé Archipelago requires a paradigm shift in which production and conservation are treated as interdependent. The new framework of multi-use protected areas established by Chile's Biodiversity and Protected Areas Service (SBAP) enables conservation to be embedded on intensive-use seascape. We propose a network of Productive-Matrix Marine Refuges (PMMR) that protect ecological remnants capable of stabilizing environmental conditions, enhancing bioremediation, and supporting biodiversity. This network can strengthen ecological resilience across intensively used seascapes and advance a frontier model of nature conservation within highly impacted production landscapes.

Introduction

In Chilean Nor Patagonia, and particularly in the Chiloé Archipelago, aquaculture has produced an intensive-use seascape in which conservation has been relegated to remote and marginal areas of the country. These aquaculture landscapes constitute a complex socio-ecological system inhabited by diverse communities and characterized by overlapping uses that collectively face a governance crisis driven by the fragmentation between economic development and biodiversity conservation. We argue that the future of this region depends on redefining the relationship between production and conservation so that ecological integrity becomes a condition for long-term viability. Despite the intensity of human use, critical biodiversity - including kelp forests, dolphins, and whales - persists and coexists with productive activities. International assessments indicate that marine biodiversity loss poses direct risks to food security, climate resilience, and the economic stability of coastal nations [1]. Accordingly, we propose a new paradigm in which production and conservation are interdependent conditions for long-term viability in Chiloé's aquaculture landscapes. Safeguarding the ecological systems that sustain the industry ensures not only the protection of nature, but also the socioeconomic wellbeing of the region.

The Dilemma of Aquaculture Landscapes and The Role of SBAP

The Chiloé Archipelago is the core of Chile's aquaculture sector - the world's second-largest salmon producer and a global leader in mussel cultivation. Yet this economic prominence coexists with a longstanding deficit in addressing environmental liabilities. The recent establishment of Chile's Biodiversity and Protected Areas Service (SBAP) [2] presents an unprecedented opportunity to develop multi-use conservation areas embedded within productive landscapes, enabling more effective public-private governance and fostering the restoration of marine ecosystems.

Natural Refuges as Providers of Critical Inputs for Production

The performance and resilience of the aquaculture industry depend on ecological variables that only healthy marine ecosystems can provide [1]. We therefore propose the establishment of a network of Productive-Matrix Marine Refuges (PMMR) embedded within intensively used seascapes where aquaculture and other human activities dominate. These refuges would safeguard remaining kelp forests and maintain key ecosystem processes that sustain biodiversity and environmental stability across the seascape. Through primary production, nutrient cycling, and habitat provision, kelp forests can enhance oxygen availability, stabilize environmental conditions, and support diverse microbial communities. These ecological functions contribute to the resilience of the broader seascape while also supporting fisheries, aquaculture, and marine wildlife such as critical habitat for dolphins, and coastal birds.

Kelp forests - in this case *Macrocystis pyrifera* - act as underwater lungs that inject dissolved oxygen into the water column through photosynthesis and generate microclimates that buffer temperature anomalies, thereby reducing physiological stress in fish and mollusks. They also harbor diverse microbiota that serve as biological barriers against pathogens. Moreover, macroalgae and filter-feeding organisms perform natural bioremediation by absorbing excess nutrients (nitrogen and phosphorus), reducing the likelihood of harmful algal blooms.

A Multisectoral Benefit Model

This paradigm shift reframes marine conservation as an integral component of intensively used seascapes rather than an activity confined to remote or isolated areas. Marine refuges embedded within productive landscapes can generate ecological and socio-economic benefits across multiple sectors by safeguarding biodiversity and maintaining key ecosystem processes. Evidence from marine reserve networks shows that protected areas can export larvae and biomass to surrounding waters, supporting adjacent fisheries through spillover effects [3,4]. In Chilean Nor Patagonia, such refuges could strengthen artisanal fisheries by replenishing larvae and biomass in Management and Exploitation Areas for Benthic Resources (TURFs) and other fishing grounds. By sustaining kelp forest habitats and associated biodiversity, these refuges also support wildlife-based tourism and help maintain ecosystem services essential for coastal communities, including food security, cultural identity, and long-term environmental stability.

Conclusion

The central objective is the strategic management of ecological remnants within intensively used seascapes. Priority should be given to identifying kelp forests that have demonstrated exceptional resilience by persisting under conditions of high human use. Some sites may require immediate protection in their current state, while others in degraded areas should be prioritized for active restoration and repopulation efforts. In this context, Chilean aquaculture has the opportunity to lead a transition toward more responsible marine stewardship by supporting the protection and recovery of ecological refuges within the seascapes where the industry already operates. Well-conserved networks of marine refuges can sustain biodiversity, maintain key ecosystem processes, and reinforce the ecological foundations upon which aquaculture and many other marine activities depend. Above all, they contribute to the resilience of the broader seascape that supports diverse economic, social, and cultural livelihoods across coastal communities. Marine refuges should therefore be understood as foundational ecological elements that help sustain biodiversity, ecosystem functioning, and the long-term stability of socio-ecological systems at the seascape scale.

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