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Review

The physics of open-water shellfish aquaculture

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Abstract

Aquaculture of shellfish species is expanding in many countries. Limitations on, and competition for, inshore water space is making offshore shellfish developments more attractive. Here we review issues relating to the design and mechanics of shellfish longline structures in relation to the offshore marine environment. Two main facets are explored: (i) the effect of the flow (waves and currents) on the farm and (ii) the reverse perspective of the impact of the farm on the flow. Because these systems are relatively new, we first examine similar systems, both natural (kelp beds) and man-made (floating breakwaters, fish farms). Techniques for measuring both the local oceanography and the structural response are listed along with new approaches for measuring important properties. A number of future applied research topics are identified as being a key to advancing the industry, including issues like mooring design, vertical drag coefficients, wave–current interaction, stratification and influence on fauna.

Keywords: Shellfish; Physics; Oceanography; Longline; Mussel farm; New Zealand; Waves; Currents

Contents

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1. Introduction

Shellfish aquaculture has a long history, with many early societies extending their wild harvesting techniques through the introduction of accessible artificial substrata and transplanting of important species. This early development occurred because shellfish larvae have a free-swimming stage. Hence, provided there is a suitable supply of juveniles and nutrients and that the environment is not too extreme, a harvestable crop will result. Given these determinants, provision and development of a suitable substrate is a major factor over which some control can be exerted. Here we review the physical factors associated with open-water shellfish aquaculture. There is inevitably a local bias. However, the New Zealand industry is a useful template as it is well established but still expanding and one that place a high value on environmental sustainability.

Here we define offshore as being exposed to substantial oceanic conditions—mainly in the form of exposure to large waves and storms. As there have been few shellfish developments to date in this environment we consider ‘‘open water’’ shellfisheries—those that are at some distance from shore and require reasonable infrastructure. This broader category includes developments in large bays and coastal inlets.

Many inshore techniques for sustaining shellfish have evolved through individual ingenuity and adaptation. These tend to have regional idiosyncrasies. Within South East Asia the main species grown is *Perna viridis* and open-ocean aquaculture is being trialled in a number of countries including Malaysia, Indonesia, Thailand, Cambodia and the Philippines. The largest producer in the world China (FAO, 2004) grows predominately *Mytilus galloprovincialis.* This species is also grown across much of Europe, the Russian Federation, Brazil and Australia (Gosling, 2003; Buck et al., 2006). *Mytilus edulis* also known as the blue mussel is grown in parts of Europe, North America and Scandinavia. New Zealand, the forth largest mussel producer, grows an endemic species *Perna canaliculus*.

A variety of methodologies have evolved to produce shellfish in large quantities in inshore waters. Rafts and longline techniques have been established in tandem with mooring and harvesting approaches. Strategies have also been developed to deal with things like ice-cover (Drapeau et al., 2006) and large tidal ranges (France). In addition, recruitment is no longer left to chance and collection of juveniles (spat), integration onto the artificial substrate and harvesting are important steps in the evolving methodological development. Intensive farming of inshore locations highlights a range of areas of potential usage conflict (Ridler, 1997): aesthetic value, navigation, nutrient/phytoplankton depletion, space allocation and the likelihood of terrestrially sourced contamination. This combination of issues had led to industry looking to offshore waters for future expansion.

Moving into exposed offshore coastal/ocean waters requires substantial investment in planning and infrastructure. One only needs to look at the oil industry to see the scale required and the importance of good engineering for successful development of infrastructure in the ocean environment. Two complementary facets to the engineering of such marine structures arise. First, the effect of the flow on the structure controls the structural survival and the environment the crop must develop in. Second, the effect of the structure on the flow is also important for correct assessment of environmental impact, especially through its influence on redistribution of waste and nutrient-depleted water. Clearly, there is feedback between the two. Section 2 describes approaches to shellfish aquaculture in open waters, Section 3 describes comparable canopy systems, Section 4 describes the effect of flow on the farm, Section 5 describes the environmental implications of such structures and then Section 3 synthesises the findings.

2. Approaches to open-water shellfish aquaculture

Currently, there are a number of different types of mussel farm design, which vary depending on the water depth, hydrodynamics and the regional style. These include surface and submerged longline farms and raft-based structures (Fig. 1).

The continuous longline technique is becoming a dominant farming style and can be used for any of the main mussel species commercially grown around the