Climate Risk Management 1 (2014) 25–38

Contents lists available at ScienceDirect

Climate Risk Management

journal homepage: www.elsevier.com/locate/crm

Dynamical seasonal ocean forecasts to aid salmon farm management in a climate hotspot

Claire M. Spillman [a], Alistair J. Hobday [b,*]

[a] Centre for Australian Weather and Climate Research (CAWCR), Bureau of Meteorology, GPO Box 1289, Melbourne, VIC 3001, Australia
[b] Climate Adaptation Flagship, CSIRO Marine and Atmospheric Research, Hobart, TAS 7000, Australia

ARTICLE INFO

Article history:
Available online 9 December 2013

Keywords:
Seasonal forecasting
Climate variability
Climate change
Aquaculture
Atlantic salmon
POAMA

ABSTRACT

Marine aquaculture businesses are subject to a range of environmental conditions that can impact on day to day operations, the health of the farmed species, and overall production. An understanding of future environmental conditions can assist marine resource users plan their activities, minimise risks due to adverse conditions, and maximise opportunities. Short-term farm management is assisted by weather forecasts, but longer term planning may be hampered by an absence of useful climate information at relevant spatial and temporal scales. Here we use dynamical seasonal forecasts to predict water temperatures for south-east Tasmanian Atlantic salmon farm sites several months into the future. High summer temperatures pose a significant risk to production systems of these farms. Based on twenty years of historical validation, the model shows useful skill (i.e., predictive ability) for all months of the year at lead-times of 0–1 months. Model skill is highest when forecasting for winter months, and lowest for December and January predictions. The poorer performance in summer may be due to increased variability due to the convergence of several ocean currents offshore from the salmon farming region. Accuracy of probabilistic forecasts exceeds 80% for all months at lead-time 0 months for the upper tercile (warmest 33% of values) and exceeds 50% at a lead-time of 3 months. This analysis shows that useful information on future ocean conditions up to several months into the future can be provided for the salmon aquaculture industry in this region. Similar forecasting techniques can be applied to other marine industries such as wild fisheries and pond aquaculture in other regions. This future knowledge will enhance environment-related decision making of marine managers and increase industry resilience to climate variability.

Introduction

Aquaculture is seen as an important element in future food security, particularly given projected declines in the availability of wild fish, and the growing human population (Bell et al., 2009; Merino et al., 2012). Future production is uncertain, however, as climate change will further threaten sustainable fisheries and aquaculture production in some regions, while presenting opportunities in others (Brander, 2007; Hobday et al., 2008; Cochrane et al., 2009; Bell et al., 2011). One widely farmed species considered vulnerable to rising ocean temperatures is Atlantic salmon (*Salmo salar*; Battaglene et al., 2008;

* Corresponding author. Tel.: +61 362325310.
E-mail address: alistair.hobday@csiro.au (A.J. Hobday).

2212-0963
http://dx.doi.org/10.1016/j.crm.2013.12.001

Lorentzen, 2008), which is farmed in high latitude coastal waters of both hemispheres (Gross, 1998) and often grown close to its thermal limits.

One important location for salmon aquaculture is Tasmania, Australia. The industry has grown from establishment in 1984 to now represent Australia's most valuable seafood industry (DPIPWE, 2013). It is an important regional employer, worth hundreds of millions of dollars to Tasmania's economy, with additional growth planned for the next decade. Several companies farm salmon in a range of Tasmanian locations; south-east Tasmania accounts for up to 50% of the annual production. Salmon are produced in land-based hatcheries, grown in ponds for 6–12 months, and then moved to coastal sea cages for the final two years of production. While in sea cages, the fish are subject to the local environmental conditions. Fish health and growth are both strongly influenced by ocean temperatures, with salmon in Tasmania grown in waters approaching their upper thermal limit in summer (Battaglene et al., 2008). Under climate change however, thermal tolerances are predicted to be exceeded more frequently, which could lead to degraded fish health, increased disease outbreaks and mortality (Battaglene et al., 2008). This increase in water temperatures is influenced by both general ocean warming, as well as the increased poleward extension of warm water currents from the north (Ridgway, 2007; Wu et al., 2012).

Particularly important for the salmon farms in the south-east of Tasmania, is the seasonal extension of the warm water East Australia Current (EAC). The EAC is a complex and highly energetic western boundary system off eastern Australia and is dominated by a series of mesoscale eddies (Ridgway and Hill, 2009). Flow is strongest in summer, often seen as a tongue of warm water extending south into waters off eastern Tasmania (Ridgway and Godfrey, 1997). South-eastern Australia, including Tasmania, is a climate change 'hotspot' (Hobday and Pecl, 2013). Average temperatures in this region are projected to be 2.8 °C higher than the 1990–2000 average by 2050 (Hobday and Lough, 2011), due in part to the strengthening of the EAC and increased southward flow (Ridgway, 2007). Interannual variability also can also result in warmer than average conditions, and already impacts the industry in some years. Thus, dealing with impacts of a warmer climate is both a current and a long-term challenge for salmon farmers in this region (Hobday et al., 2008).

The Tasmanian salmon industry has identified that coping with climate variability and change can be facilitated with an improved understanding of the marine environment (Battaglene et al., 2008). Advance warning of both extremely warm or cold water temperatures would give farm managers time to respond and adapt management strategies to maximise production (e.g. balanced nutritional requirements) and minimise mortality (e.g. from disease). For the majority of salmon farm managers, information about the future a season ahead is of primary interest, and allows a range of risk management responses to be implemented. Statistical forecasts have been used by the Tasmanian salmon industry in recent years (Hobday et al., 2011b) and whilst these can be skilful, they do not account for a changing climate, or for unprecedented conditions. Given the observed and projected warming trend in this region, reliance on a statistical or climatological approach will be of limited value in the coming years. Dynamical model predictions offer an alternative as there is no assumption of climate stationarity i.e., models can forecast unprecedented events as they are based on physical principles and are not constrained by historical data.

The use of dynamical seasonal forecasting to provide advance warning of ocean conditions for marine management has increased in recent years. The Predictive Ocean Atmosphere Model for Australia (POAMA), developed by the Bureau of Meteorology and CSIRO, is currently used for management purposes in several marine applications. Real-time forecasts for coral bleaching risk on the Great Barrier Reef are currently produced operationally, providing advance warning to reef managers of potential bleaching risk in the upcoming summer (Spillman, 2011a; Spillman et al., 2012). POAMA forecasts of ocean temperature are also combined with a statistical southern bluefin tuna habitat model, to produce tuna habitat maps for the Australian Marine and Fisheries Authority, which are used in setting management zones (Hobday et al., 2011a). In an aquaculture context, a key need is to evaluate if a coupled ocean–atmosphere forecast model such as POAMA can forecast regional ocean conditions at the seasonal time scale, which can then be downscaled to provide information at the coastal farm scale.

The aim of this study is to first assess the regional skill of POAMA in forecasting ocean temperatures in south-east Tasmania and to establish relationships with salmon farm temperatures in the region. We then assess the skill of the model ensemble mean and probabilistic forecasts. The ensemble mean provides the average conditions based on multiple model realisations (ensemble members), while probabilistic forecasts provide information as to the likelihood of an event occurring. Finally, we demonstrate farm-specific forecast products that are delivered to individual salmon farmers to enhance their climate readiness.

Methods

Salmon farm data

Monthly farm temperature data are available for two farms (Huon and Dover) in south-east Tasmania for 1991–2010 (Fig. 1), the longest temperature time series available. The farms are located in waters less than 20 m in depth, and salmon cages are within 500 m from the coast. Water temperatures are measured many times each day using a data logger in a cage at 5 m depth, and supplied as a monthly average for each location. Each dataset has been scaled by removing the long-term monthly mean ocean temperatures for 1991–2010 (i.e., the climatology) for each farm to create temperature anomalies to