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# Comparisons between East-Asian isoyake and deforestation in global kelp systems

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**Abstract:** Seaweed deforestation (isoyake) is a conspicuous phenomenon in many temperature/polar regions of the world and often results in strong ecological and economic impacts to local human communities. The study of isoyake in East Asia (especially in Japan) has a long history, however the resulting literature is generally inaccessible to researchers that do not speak Asian languages. This study integrates knowledge of the causes and consequences of isoyake in East Asia into an emerging global model of the causes of deforestation in non-Asian kelp systems. Isoyake in southern regions of East Asia result from a concurrence of increased herbivory by fish and sea urchins of sub-tropical origin with periods of decreased seaweed production due to poor oceanographic conditions. Such processes are similar to those that cause deforestation in other warm-temperate kelp systems (*e.g.* southern California and northern New Zealand) and may be enhanced during periods of ocean warming. Alternatively, isoyake in northern regions of East Asia result primarily from uncontrolled sea urchin grazing; inherently low kelp productivity in these regions cannot balance the high rates of kelp consumption. As such, these regions appear similar to other high latitude/low productivity kelp systems in which large enduring sea urchin barrens often exist in the absence of external controls on sea urchin abundance (*e.g.* predation or harvesting by humans). Therefore, the diversity of causes of isoyake in East Asian systems appears to encompass the full range of deforestation processes described for high- to low-latitude kelp systems worldwide. The unique situation in which high seaweed and herbivore diversity coincide with high variability in oceanographic processes appears may make East Asian seaweed systems more vulnerable to perturbation than other temperate kelp systems.

## Introduction

Seaweed forests are well recognized to provide essential habitat and energy to nearshore areas worldwide (Mann 1973, Dayton 1985, Barnes and Hughes 1988, Duggins *et al.,* 1989, Schiel & Foster 2006, Graham *et al.,* 2008), with subsequent enhancement of local biodiversity, productivity, and human economies (Steneck *et al.,* 2002, Graham *et al.,* 2007, Kang *et al.,* 2008). This is particularly true for systems founded by kelps, large brown algae in the order Laminariales, which have some of the highest productivities known amongst marine autotrophs (Mann 1973, Jackson 1977, North 1994, Graham *et al.,* 2007). When kelps disappear, either naturally or due to human activities, the ecological and economic consequences can be severe (Steneck *et al.,* 2002, Graham 2004). As such, there is growing interest in understanding general processes driving kelp deforestation at a global scale.

Conspicuous seaweed deforestation was first described in Japan in the 1800s and named *isoyake* (Fujita, this issue). Over the last 100+ years an extensive literature has developed in Japanese, and later Korean and Chinese, scientific journals fueled by public and private interests in ecology and resource use of coastal seaweed forests. Most of this literature is in Asian languages and has

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been generally inaccessible to English-speaking researchers since the first description of kelp deforestation in non-Asian systems (reviewed in Lawrence 1975). As such, isoyake research in East Asia has had little impact on the understanding of the causes of kelp deforestation worldwide. The goal of this paper is to discuss the ecology of East Asian isoyake in light on a new model explaining variability in kelp deforestation at a global scale (Graham *et al.* in prep.).

## Dynamics of East-Asia kelp systems

Seaweeds are important taxa throughout East Asia, however, kelps are only important in the warm- and cold-temperate regions of Japan, South Korea, China and Russia (Lüning 1990). Isoyake has been described from each of these regions, although the ecology of isoyake clearly differs between warm- and cold-temperate systems, and it is useful to treat these separately.

In warm-temperate East Asian kelp systems, isoyake can be observed in southern Japan (Honshu, Shikoku, Kyushu; Fujita, this issue), South Korea (Kang, this issue), and China (Duan and Ming, this issue). Kelp productivity is moderate in these regions relative to other kelp systems worldwide (Graham *et al.* in prep.), with the dominant taxa being *Eisenia bicyclis* and *E. arborea, Ecklonia cava,* and *Undaria pinnatifida* (Lüning 1990). These kelps appear to have adapted to high seasonal variability in oceanographic conditions driven by fluctuations in the strength and direction of the Kuroshio and Japan currents. As such, these systems naturally degrade during late summer and autumn due to regional ocean warming (Yokohama *et al.,* 1987, Haroun *et al.,* 1989). In recent decades, continued ocean warming has resulted in greater stress to the kelps (Serisawa *et al.,* 2004). Further, sub-tropical sea urchins (Terawaki *et al.,* 2001, Steneck *et al.,* 2002, Tamaki *et al.,* 2005) and herbivorous fish (Masuda *et al.,* 2000, Yamauchi *et al.,* 2006) have become common in southern waters of East Asia during warm seasons, devastating local kelp forests. Although predation in Asian kelp systems is poorly studied, there currently are no known conspicuous predators on sea urchins and herbivorous fish in the region. Isoyake caused by herbivory occurs on both natural and artificial reefs, and appears to be most common in regions of low water motion.

In cold-temperate East Asia, isoyake can be observed primarily in Japan on the west coast of Hokkaido (Fujita, this issue) and in limited areas on the west coast of Sakhlin Island, Russia (Galanin, this issue). Isoyake is not described for the east coast of Hokkaido. In these regions, the dominant kelps are *Saccharina japonica* and *Undaria pinnatifida.* The west coast of Hokkaido has very low productivity relative to other kelp systems worldwide (Graham *et al.,* in prep.) and isoyake here is caused almost entirely by overgrazing by the sea urchin, *Strongylocentrotus nudus* (Fujita, this issue). The only known control on sea urchin overgrazing in this region is high water motion in shallow water, and harvesting by humans; sea urchin harvesting, however, is only possible outside of isoyake where sea urchin gonads are of marketable quality. In Russia, the observation of isoyake is recent and coincides with declines in kelp farming productivity (Galanin, this issue), potentially due to poor oceanographic conditions.

## Inclusion into a global deforestation model

Japanese researchers have long understood that isoyake results either when oceanographic conditions degrade kelp production entirely or when kelp consumption exceeds kelp production. In addition to creating artificial habitats to compensate for isoyake, researchers have considered ways to either enhance kelp production or hamper kelp consumption. This approach is entirely consistent with new ideas that have emerged from the study of kelp production and consumption in non-Asian kelp systems. Using ecological and oceanographic data, Graham *et al.* (in prep.) found that kelp production potential varies 30-fold between the lowest (Arctic) and highest (west South Africa) productivity regions, driven by global variability in irradiance, ocean temperature, and nitrate concentrations. Furthermore, kelp production potential decreased predictably with increasing latitude and broad-scale enduring sea urchin barrens were restricted to high latitude systems. The conclusion from this study was that high-latitude low-productivity kelp systems were more likely to experience imbalance between kelp production-consumption than low-latitude high-productivity systems. Kelp production potential from southern and northern Japan were well predicted by the global model (Graham *et al.,* in prep.).

An additional conclusion of the global kelp model was that low-latitude systems often have a greater diversity of factors that control herbivory populations. Seaweed diversity in warm-temperate regions is generally higher than high-latitude counterparts, and herbivore and predator populations are also generally more diverse due to proximity to the subtropics. In Japan, the southern islands have a high diversity of kelp grazers including various sea urchins, fishes, and snails, coincident with regionally high diversity of kelps of the genera *Ecklonia, Eckloniopsis, Eisenia, Undaria,* and *Saccharina*; these kelp taxa are complimented by many species of *Laminaria, Agarum* and *Alaria* in the north. Sea urchin diseases are also relatively warm water phenomena (Behrens and Lafferty 2004) and sea urchin fisheries are often well established in lower latitudes. As such, the balance between kelp production-consumption can often be shifted in favor of kelp by a greater diversity of sea urchin controlling factors in low-latitude systems. Again, this perspective well explains many key differences in isoyake between the northern and southern regions of East Asia (Graham *et al.* in prep.), where numerous factors appear to cause and control isoyake in the south, whereas sea urchin harvesting appears to be the only controlling mechanism in the north.

## Conclusions

Despite numerous endemic kelp taxa and high seasonal fluctuations in oceanography, it is clear that East-Asian kelp systems function similarly to other temperate kelp systems worldwide. Shifts in the balance between kelp production and consumption result in kelp deforestation at a variety of temporal and spatial scales. Although grazers can be important components of isoyake throughout East-Asia, deteriorating oceanographic conditions appear to be a primary cause of isoyake in warm temperate regions, with grazers inhibiting the return of kelp to natural abundances. Sea urchins have a much more direct role in the cause of isoyake in northern cold temperate regions, with ocean warming playing a secondary role. However, it is still unknown whether isoyake are relatively naturally states in East-Asian kelp systems, since the only modern control on sea urchin populations appears to be human harvesting, extreme water motion, or high levels of kelp productivity. The absence of important sea urchin predators, besides the sea otter, which has long been extinct from Japan, is conspicuous.

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