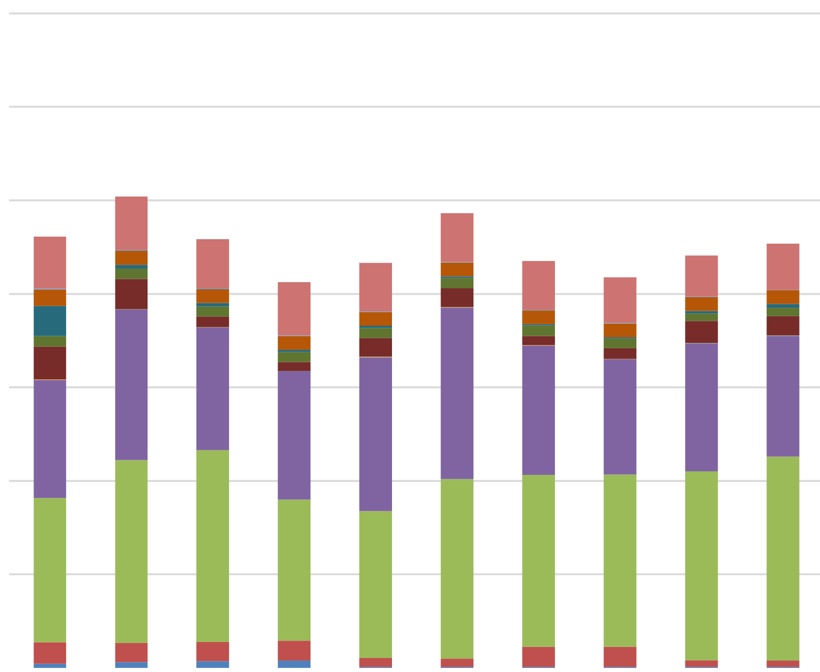
John West and Hilconida P. Calumpong (Co-lead member), Georg Martin (Lead member)

Seaweeds are a group of photosynthetic non-flowering plant-like organisms (called macroalgae) that live in the sea. They belong to three major groups based on their dominant pigmentation: red (Rhodophyta), brown (Phaeophyta) and green (Chlorophyta). Seaweeds were traditionally and are currently still used as food in China, Japan and the Republic of Korea. About 33 genera of seaweeds, mostly red and brown, are harvested and farmed commercially (McHugh, 2003), although close to 500 species in about 100 genera are collected and utilized locally (Mouritsen, 2013). Currently about 80 per cent of total seaweed production is for direct human consumption, eaten dried or fresh for its nutritional value or for flavouring (see Kilinc et al., 2013 for a comprehensive listing of nutrients and compounds) in the form of sushi, salad, soup, dessert and condiments, and the remaining 20 per cent is used as a source of the phycocolloids extracted for use in the food, industrial, cosmetic, and medical industry (Browdy et al., 2012, Critchly et al., 2006, Lahaye, 2001, McHugh, 2003, Mouritsen, 2013, Ohno and Critchley, 1993), as well as for animal feed additive, fertilizer, water purifier, and probiotics in aquaculture (Abreu et al., 2011, Chopin, 2012, Chopin et al., 2001, Chopin et al., 2012, Fleurence et al., 2012, Kim et al., (2014), Neori et al., 2004, Pereira and Yarish, 2008, 2010, Rose et al., 2010). Carrageenan and agar are extracted from red seaweeds, and alginates and fucoidan are extracte, -2(a)10.a5m redddd, since 2003, except in 2007 when China exceeded Chile's production by 1 per cent. Norway and Japan have maintained their position as third and fourth top producers, respectively, since 2003.

Three countries posted only one year's production in 10 years (Namibia in 2003 with 408 tons, Samoa in 2004 with 478 tons, Senegal in 2012 with 1,028 tons. India posted 1 ton of production in 2004 to 2008, except in 2005 when it posted 2 tons of production).



The bulk of seaweeds produced worldwide come from aquaculture. The FAO (2014) reported that the production of aquatic seaweeds from mariculture, reached 24.9 million tons in 2012, valued at about $6 billion United States dollars. The red, brown and green seaweeds constitute about 88 per cent (21 million tons). About 96 per cent (23.8 million ton

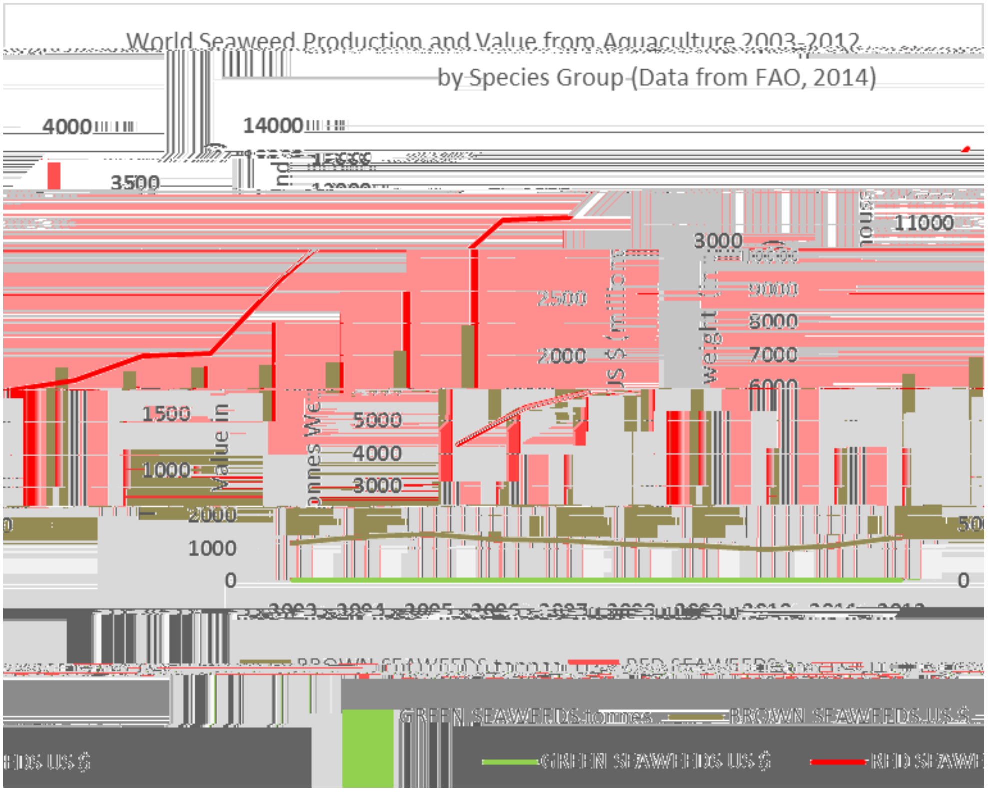


Figure 3. World aquaculture production from 2003-2012 by species groups in tons wet weight and total value in United States dollars per group. (Unidentified aquatic plants excluded.) Green algae production is minimal, as shown in this graph. Data from FAO 2014.

Harvests from wild populations are affected by overexploitation and climatic changes.

France, the brown kelp, *Laminaria digitata*, which is heavily harvested for commercial uses, is reported to be on the verge of local extinction. The already reduced reproductive potential of the kelp due to dwindling population and harvesting-induced ecosystem changes may be exacerbated by climate-caused increase in sea temperature (Brodie et al., 2014, Raybaud et al., 2013). Two other kelp species, *Laminaria ochroleuca,* a warm-temperate perennial, and *Saccorhiza polyschides*, a wide-ranging cool- to warm-temperate annual, have somewhat higher temperature tolerances for sexual reproduction than other kelps (Pereira et al., 2011); however, *Saccorhiza* outcompetes *L. ochroleuca* in shared habitats. Brittany is the northern limit of *L. ochroleuca*'s range. Since 1940, *L. ochroleuca* has been found on the coasts of southern England, which is apparently indicative of a slow northward extension of warmer waters. Anticipated increasing ocean temperatures in the future in the boreal region may result in *L. ochroleuca* possibly replacing *L. hyperborea* (Brodie et al., 2014). On the other hand, the kelp *Ecklonia maxima* is extending eastward on the tip of South Africa because of a northward intrusion by cooler inshore water (Bolton et al., 2012); this could greatly benefit the whole ecosystem and provide more food for the abalone industry there. All this is quite a contrast from southward intrusion patterns by warm water on the east and west coasts of Australia, causing extensive retreat of kelps and fucoids (another group of brown algae) southward from their previous northern-most limits (Wernberg et al., 2011, Millar, 2007).

Seaweed farming and culture are seriously affected by diseases. *Ice-ice* disease has impacted the farming of the kappa-carrageenan-producing *Kappaphycus alvarezii,* commercially called “cottonii”. Another species, *Eucheuma denticulatum,* commercially called “spinosum,” is *ice-ice*-resistant, but contains iota-carrageenan which fetches a much lower price on the world market (Valderrama, 2012). This problem may be a result of the low genetic variation in *K. alvarezii,* all of whose cultured stocks around the world have a similar mitochondrial haplotype, which is not the case for *E. denticulatum* (Halling et al., 2013; Zuccarello et al., 2006). Significant diseases affecting cultivated kelps (e.g., *Saccharina japonica*) include green-rot, white-rot(6(201h)102(8) profits due to high shipping costs. This disadvantage is exacerbated by the dependence of farmers on processors for the procurement of their farming materials and their lack of farm-management skills. In addition, food safety issues can sometimes affect markets and prices. This is because seaweeds are efficient nutrient extractors (Kim et al., 2014) and may accumulate compounds that pose harm to human health (Mouritsen 2013; see also Chapter 10).

Despite the long history of utilization, it is reported that kelp-dominated habitats along much of the NE Atlantic coastline have been chronically understudied over recent decades in comparison with other regions such as Australasia and North America. For example, McLaughlin et al. (2006) noted that information on the distribution and biomass of commercial seaweeds in Northern Ireland is lacking. Smale and Wernberg (2013) highlight the changing structure of kelp forests in the North- East Atlantic in response to climate- and non-climate-related stressors, which will have major implications for the structure and functioning of coastal ecosystems. This paucity of field-

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