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Review

# Review of the composition and current utilization of *Calanus finmarchicus* – Possibilities for human consumption

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ABSTRACT

*Background:* The continuous high expectations on the world's fisheries to provide products for human consumption is leading to increased overexploitation of fishing stocks. This unsustainable exploitation desperately calls for other suitable resources that can relieve the pressure on the fisheries. The utilization of *Calanus finmarchicus* has been proposed as a suitable alternative. There is, however, still a question of both ecological and economical sustainability of such exploitation.
*Scope and approach:* This review describes currently utilized marine resources, and compares the suitability of *C. finmarchicus* as a useful alternative for those resources. Additionally, the review describes the life history and chemical composition of *C. finmarchicus*. Current utilization of *C. finmarchicus* is also described, along with industrial methods used to derive various products from *Calanus*, as well as a discussion of other potential products from the resource.
*Key findings and conclusions:* *C. finmarchicus* can potentially be considered an alternative marine resource as it has a unique lipid composition, is rich in antioxidants, and contains diverse enzymes. However, the question of sustainable catching remains unanswered and must be addressed before *C. finmarchicus* can be considered for utilization.

## 1. Introduction

The fisheries of the world are under constant expectations to provide food and other commodities. The demands for fish and fish based products have been ever growing, as can be seen in the increasing number of fully exploited, and overexploited fish stocks (FAO, 2016). In 2013, 68.6% of all fisheries were declared being within a sustainable level of exploitation, and 31.4% being over-exploited. Of the 68.6%, only 10.5% were classified as being under-fished, whereas 58.1% were classified as fully fished (FAO, 2016). First and foremost, the fish is utilized for human consumption, either directly as food, (approximately 87% in 2014), or indirectly as fish feed (9.4% in 2014) intended for aquaculture, which in turn is destined for human consumption (FAO, 2016). As well as being utilized as food there are many other highly sought after products processed from fish and other marine sources. These include enzymes, fish oils, chitin, carotenoids, and other biologically active compounds (Ambati, Phang, Ravi, & Aswathanarayana, 2014; Boettger & Hertweck, 2013; FAO, 2016; Salem Jr & Eggersdorfer, 2015; Tocher, 2015; Younes & Rinaudo, 2015).

The utilization of underexploited marine sources, such as crustaceans, zooplankton, and algae, have been studied to relieve the pressure off the currently fully exploited fisheries (Olsen, 2011). Zooplankton are crucial vehicles of transporting carbon (energy) from primary producers (phytoplankton) to upper trophic levels. Along with this energy transport zooplankton provide higher trophic levels with the essential n-3 long-chain (LC) polyunsaturated fatty acids (PUFAs) that they have obtained from the primary producers. Lipid-rich zooplankton in particular, have come under increased scrutiny as they potentially represent an underutilized resource of oils rich in eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) (Olsen, 2011). *Calanus finmarchicus* is one of the most abundant zooplankton in the North Atlantic Ocean and has a range of potentially useable attributes (Melle et al., 2014). These attributes include a unique lipid composition, as well as the presence of proteolytic, and lipolytic enzymes, as well as astaxanthin, and chitin (Bergvik, Leiknes, Altin, Dahl, & Olsen, 2012; Olsen, 2011; Solgaard, Standal, & Draget, 2007). The distribution of *C. finmarchicus* spans from Gulf of Maine to the Norwegian Sea, representing substantial fraction of the zooplankton biomass across the North Atlantic (Melle et al., 2014; Pedersen, Tande, & Slagstad, 2001). *C. finmarchicus* has twelve different developmental stages, six naupliar

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**Fig. 1.** Illustration of *C. finmarchicus* (Hlíðberg, 2002).

stages and six copepod stages. Lipid accumulation starts at the third copepod stage and the lipids accumulated are wax esters, stored in a conspicuous oil sac (Falk-Petersen, Mayzaud, Kattner, & Sargent, 2009). During the winter *C. finmarchicus* enters diapause at depths of > 500 m. During diapause the metabolism is reduced and fueled by the stored wax esters (Falk-Petersen et al., 2009; Hirche, 1996).

This review explores the marine nutrient resources currently being utilized, with a special focus on the copepod *C. finmarchicus* as a feasible alternative and additional marine resource (Fig. 1).

## 2. Current marine nutrient resources

### 2.1. Marine oils

The global demand for fish oil is increasing every year. This demand has been brought on by the growing knowledge of the health benefits of fish oil consumption. The human health benefits include a reduced risk of cardiovascular disease, aid in the development of the eyes and brain and reduced inflammation (Calder, 2012). Traditionally most of the fish oil produced is utilized for aquaculture feed (71% in 2010), with around 1 million metric ton produced annually. However, fish oil production is estimated to rise 10% in the next ten years (FAO, 2016). With the current fish resources exploited to their fullest, other innovative means are being studied to increase marine oil production (Tocher, 2015). These include lab-grown microalgae, and genetically modified terrestrial plants capable of producing long-chain n-3 fatty acids (Pike & Jackson, 2010). The highly sought after fatty acids in fish oil are EPA and DHA (Pike & Jackson, 2010; Tocher, 2015). Stearidonic acid (SDA) is an n-3 fatty acid that is synthesized from alpha-linolenic acid (ALA) with the aid of delta-6 desaturase, and is as such, a precursor of EPA and DHA. SDA has been hypothesized to be a superior EPA and DHA precursor compared to ALA, as it would eliminate the need for D-6-Desaturase, which is a desaturase enzyme involved in the conversion of ALA to SDA, whose presence in humans is thought to decline with age (Calder, 2012).

In recent studies, where subjects (humans) were supplemented with SDA and compared to ALA, the increase in EPA was twice as high when supplemented with SDA compared to ALA supplementation (Calder, 2012). While ALA is also an essential n-3 fatty acid and found in many common foods, it is a relatively poor precursor for EPA in humans (Calder, 2012). Today the daily recommended consumption of EPA and DHA in many countries ranges from 250 to 1000 mg (Salem Jr & Eggersdorfer, 2015). Salem Jr and Eggersdorfer (2015) estimated that the current 200.000 metric tons of available EPA and DHA for human consumption falls well short of the worldwide human requirements, which they estimate at 1.3 million tons. This shortage calls for new sources and a great deal better utilization of lipids from marine products currently harvested.

### 2.2. Astaxanthin

Astaxanthin is a naturally occurring carotenoid and is one of the most commonly used carotenoid in the world. Astaxanthin is a very potent antioxidant that has been shown to have several health benefits, such as anti-lipid peroxidation, being anti-inflammatory, preventing cardiovascular disease, having anti-diabetic activity, and anticancer activity (Ambati et al., 2014). In aquaculture it is mainly used to give the fish a reddish color, whereas its antioxidant properties are sought after when used as a human food supplement, and as a food ingredient (Ambati et al., 2014; Higuera-Ciapara, Felix-Valenzuela, & Goycoolea, 2006). Synthesized astaxanthin occurs in its free form when produced, and it has been demonstrated to be a weaker antioxidant compared to naturally occurring astaxanthin (Capelli, Bagchi, & Cysewski, 2013). Moreover, the cost of production of natural astaxanthin is much higher than that of synthetic astaxanthin, which has resulted in the aquaculture sector using almost exclusively synthetic astaxanthin (Nguyen, 2013). However, some aquaculture producers utilize naturally derived astaxanthin, as it adheres to the rules of organic production, hence allowing for the production of organic products (Hynes, Egeland, Koppe, Baardsen, & Kiron, 2009). Currently, natural astaxanthin is mostly derived from algae and yeast, but astaxanthin is also present in high amounts in many types of zooplankton, such as krill and the copepod species, including *C. finmarchicus* (Ambati et al., 2014; Pedersen, Vang, & Olsen, 2014).

### 2.3. Proteins as feed

Along with the increasing demand for seafood for human consumption, more pressure is being placed on the fisheries, not only to provide fresh fish to meet this demand, but also to provide a significant portion of proteins and lipids needed as fish feed in aquaculture (FAO, 2016). Successful attempts have been made by using plant-based proteins and lipids, mostly from soy and wheat for aquaculture purposes (Draganovic, Goot, Boom, & Jonkers, 2013). However, there are several drawbacks in using plant-based proteins in aquaculture, as many plant-based proteins lack the essential amino acids, free amino acids, and have low digestibility (Krogdahl, Penn, Thorsen, Refstie, & Bakke, 2010). Therefore, there is a need for new sources of protein, which are more suitable for aquaculture and for further potential use for human consumption.

### 2.4. Enzymes

Today marine enzymes are used in a wide variety of industries, which is owed to their incredible diversity. This diversity in enzymatic properties is due to the harsh environments which the organisms experience, where they deal with the different challenges by for example, creating enzymes to be able to operate in e.g. high or low temperatures, high pressure or salty conditions (Trincone, 2011). Examples of the diversity of enzymes derived from the marine resources are an amylase that is capable of producing ethanol in saline conditions isolated from marine bacterium and an alcohol dehydrogenase isolated from marine archaeon capable of functioning in high-temperature and -pressure environments to mention few (Egorova & Antranikian, 2005; Matsumoto, Yokouchi, Suzuki, Ohata, & Matsunaga, 2003). In 2013, the industrial enzyme market was estimated at 4.8 billion USD, and was expected to rise to 7.1 billion USD by 2018 (Dewan, 2014). Marine enzymes are also often employed to produce secondary metabolites, that also possess biological activities themselves (Boettger & Hertweck, 2013).

Marine enzymes are mostly harvested from waste and/or by-products of marine sources, and do therefore not add pressure on the current fisheries. However, only a small percentage of marine waste and by-products are used for this purpose, making it an underutilized resource, which could help relieve the current need for enzymes.