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Land based and marine based bioresources for feed production in Norway

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SAMMENDRAG/SUMMARY:

Rapporten gir en oversikt over norske ressurser som kan nyttes i fôrproduksjon i Norge. Vi ser på dagens arealbruk innen jordbruket (jordbruksareal og utmarksbeite), skogbruk og høsting av ressurser fra havet, samt dyrking av marine organismer. Vi ser også på alternative måter å nytte ressursene for å produsere fôrmidler.

This report provides an overview of resources for feed production from Norwegian bioresources. We look at present use of agricultural land, outfield pasture, forestry production and processing and present harvesting of bioresources from the ocean, as well as cultivation of marine organisms. We also look alternative uses of resources to produce feed.

LAND/COUNTRY: Norway

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Preface

This report is a delivery from the NFR-project Susfeed (326825), work package 1, task 1.1. We describe the use of bioresources and identify the potential use of bioresources for feed production. The chapters about land-based resources is written by project participants from NIBIO while marine based resources are described by project participants from SINTEF O.

Chapter 2 and 3 is written by Grete Stokstad, chapter 4 is written by Gry Alfredsen, and chapter 5 is written by Stine Holmen Ask, Andrea Viken Strand and Maitri Thakur.

Ås, 18.12.23

Grete Stokstad

Content

1 Introduction

The main objective of the Susfeed-project is "*to develop knowledge about how biological resources for feed production can be produced, distributed, and used in a way that contributes to the development of sustainable and high-value agricultural and aquacultural sectors*."

This report is a delivery under sub-objective 1.:

"*Provide a comprehensive knowledge base about feed production from Norwegian bioresources, including identifying potential use of land for bioresources, keeping track of the geographical distribution and potential volumes*."

In this report, we describe Norwegian bioresources and how they are used. Chapter 2, 3 and 4 deals with land-based bioresources, while chapter 5 is concerned with marine-based bioresources.

With respect to land-based resources, this report focusses on land resources that are used for agricultural production and forestry. Although theoretically possible, these two kinds of land use are not necessarily interchangeable. While agricultural land may be used for forest production, only minor parts of forested areas are suitable for being converted into agricultural land. It takes several years to establish a tree crop on previous agricultural land, and it is costly, and sometimes not legal, to convert forested land to agricultural land. Thus, both agricultural and forested land can be considered as a limited resource.

The growing conditions for agricultural land differ due to spatial variations in climate, geology, soils and topography. In particular, differences in the length of growing season and temperature limit the farmers' choice of crop types to be cultivated. Thus, in chapter 2 we list the most common crop alternatives and describe their different requirements with respect to soil, climate, and use.

The report also includes a chapter on outfield grazing. Outfield pastures comprise both forested land and large mountainous areas above the present tree line. Grazing animals are essential for the utilization of outfield pastures, but livestock numbers are limited by the availability of agricultural land. While sheep and cattle live on resources naturally available on outfield pastures during the summer months, they also need feed produced on agricultural land for the winter months. To some degree, outfield pastures are also linked to the management of forested land. The example of outfield pastures makes clear that the utilization of a land-based resource often is dependent on the use of other land-based resource.

The processing of wood is today a centralized activity. Although some local sawmills are still in operation, the large bulk of timber is sent to a few processing facilities. The processing of round timber results in several residue products, some of which could be used for feed production. Some residue products are valuable inputs in other products (meaning that they have a high alternative value), while others may be valued less and are potential sources for feed production at affordable prices. This is discussed in chapter 4.

Marine resources are also valuable feed resources which have been or can be used as a feed resource both within the agricultural and aquacultural sector. In chapter 5, we summarize the potential marine feed resources in Norway including fish, zooplankton, macroalgae, microalgae, low-trophic organisms and hetero- and chemoautotrophic organisms. Where possible, the biochemical contents of lipids, proteins, and omega-3 fatty acids (EPA and DHA) have been included.

2 Agricultural land in Norway and production of feed crops

2.1 Agricultural land and growing conditions across Norway

2.1.1 Soil and climate

Agricultural land in Norway is mapped in the National Land Resource Map AR5. AR5 separates agricultural land into three classes depending on the lands' potential use. Fully cultivated land can be tilled, while surface cultivated land cannot be tilled due to shallow soil. However, the crop can be harvested with the use of machines. Infield pastures are areas where neither tilling nor harvesting with machines is possible due to the steepness and/or shallow soil with stones and bedrock.

Table 1. Classes of agricultural land in Norway

Type of agricultural land	Area	Share of land area of Norway
Fully cultivated	8 801 76.5 hectares	2.70 %
Surface cultivated	324 76.,8 hectares	0.10 %
Infield pasture	2 216 05.5 hectares	0.70 %

Source: "Arealressurskart AR5" from 2020, NIBIO

In Table 2, the agricultural land is divided into categories based on soil type and other factors which make the use of machinery difficult, such as slope, high occurrence of coarse material in the topsoil, stones and bedrock. It is also assumed that soil types that require drainage have a drainage system and areas with soil types that need irrigation are irrigated. Table 2 shows that Vestlandet is a region with a large share of land with moderate to great restrictions, while Østlandet and Innlandet have the lowest share of land in these categories.

Table 2. Land quality of fully cultivated and surface cultivated land with respect to use of the agricultural land for crop production. ("Driftstekniske begrensninger")

	Class 1 No restrictions and flat		**Class 2** No restrictions and sloping terrain		**Class 3** Moderate restrictions		**Class 4** Great restrictions		**Sum**	
	daa	%	daa	%	daa	%	daa	%	daa	%
Østlandet	1 009 300	42	572 000	24	706 800	30	105 900	4	2 394 000	100
Innlandet	581 500	30	688 400	36	539 000	28	123 400	6	1 932 300	100
Sørlandet og Rogaland	297 400	27	279 900	25	402 200	36	136 300	12	1 115 800	100
Vestlandet	133 500	12	177 100	16	597 300	53	218 900	19	1 126 700	100
Trøndelag	390 200	26	397 100	26	628 900	42	98 200	6	1 514 400	100
Nord-Norge	244 700	25	120 500	12	469 900	48	135 600	14	970 800	100
NORWAY	2 656 600	29	2 234 900	25	3 344 100	37	818 400	9	9 054 100	100

From: Lågbu, R., Nyborg, Å., & Svendgård - Stokke, S. (2018). Jordsmonnstatistikk Norge. NIBIO rapport 4(13) S.28

The need for drainage depends on soil type and slope of the fields. In total, 47 % of the cultivated land in Norway is expected to be naturally drained (Lågbu et al. 2018), this share is highest in Innlandet (70 %) and lowest (21 %) in the region consisting of Vestfold, Akershus and Østfold, where clay dominates.

2.1.2 Differences in climatic conditions across Norway

The length of the growing season varies across Norway and is a central factor that limits farmers' crop choice. The map to the left in Figure 1 shows the spatial variation in the length of the growing season in Norway. The length of the growing season was calculated as the number of days between the dates that mark the start and end of the season. The start date is defined as the first day after 1. April without snow cover and a 7-days average temperature (day and night) above 5 °C. The end date is defined as the first day where the 7-day average temperature is below 5 °C (see: https://www.nibio.no/tema/jord/jordkartlegging/jordsmonnkart/vekstsesongens-engde?locationfilter=true). Figure 1 illustrates that the growing season follows both a latitudinal and altitudinal gradient, meaning that the growing season gets shorter the further north the agricultural land is located, but also is curtailed as elevation increases.

Precipitation is another important factor that influences farmers' crop choice. The second map in Figure 1 illustrates the spatial differences in precipitation across Norway. While the harvest of crops within the western part of Norway can be challenging due to rainy weather, droughts are more common in the south-eastern parts.

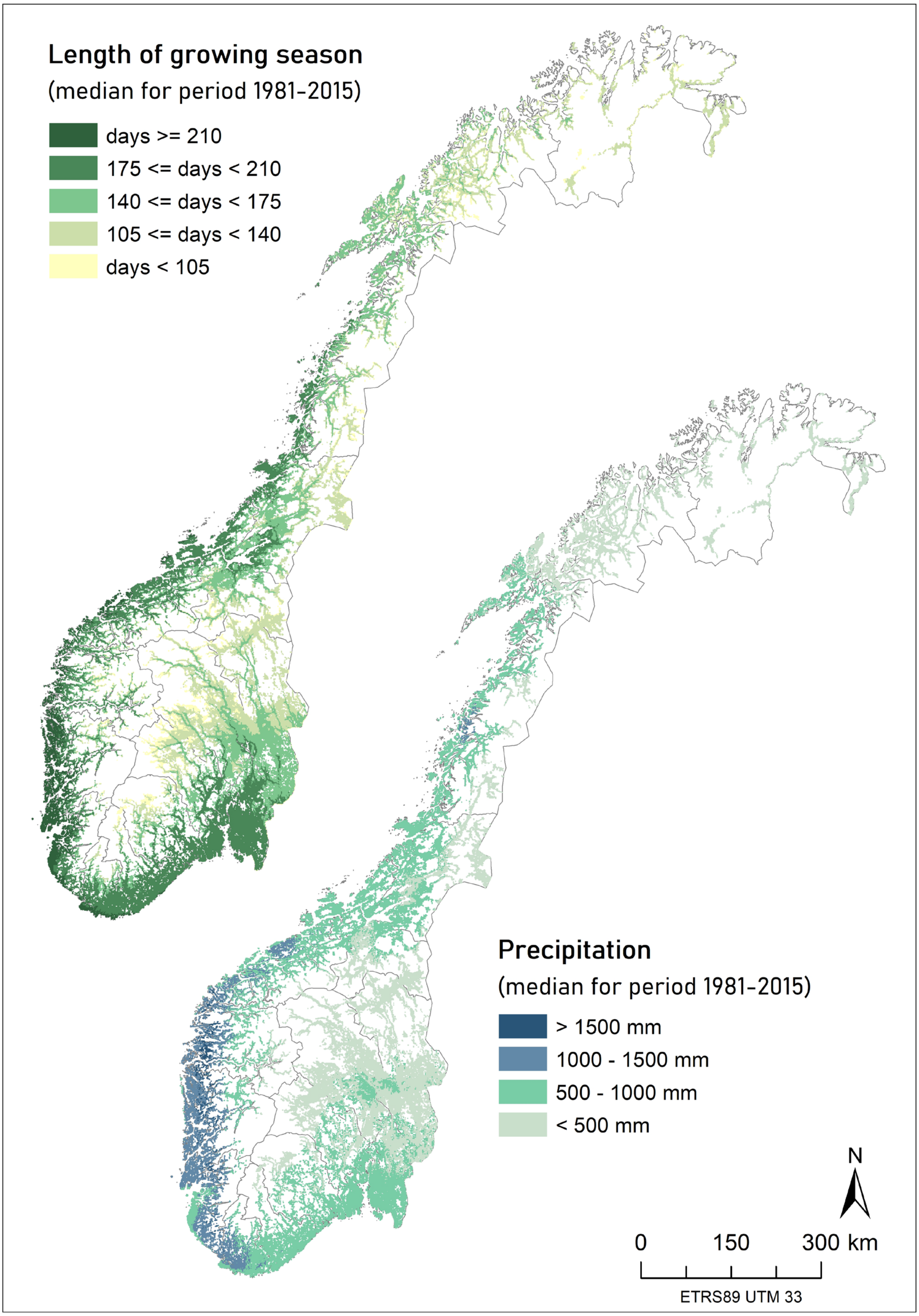

Figure 1. Annual length of growing season (median value over 35 years, 1981-2015) and median precipitation across Norway.

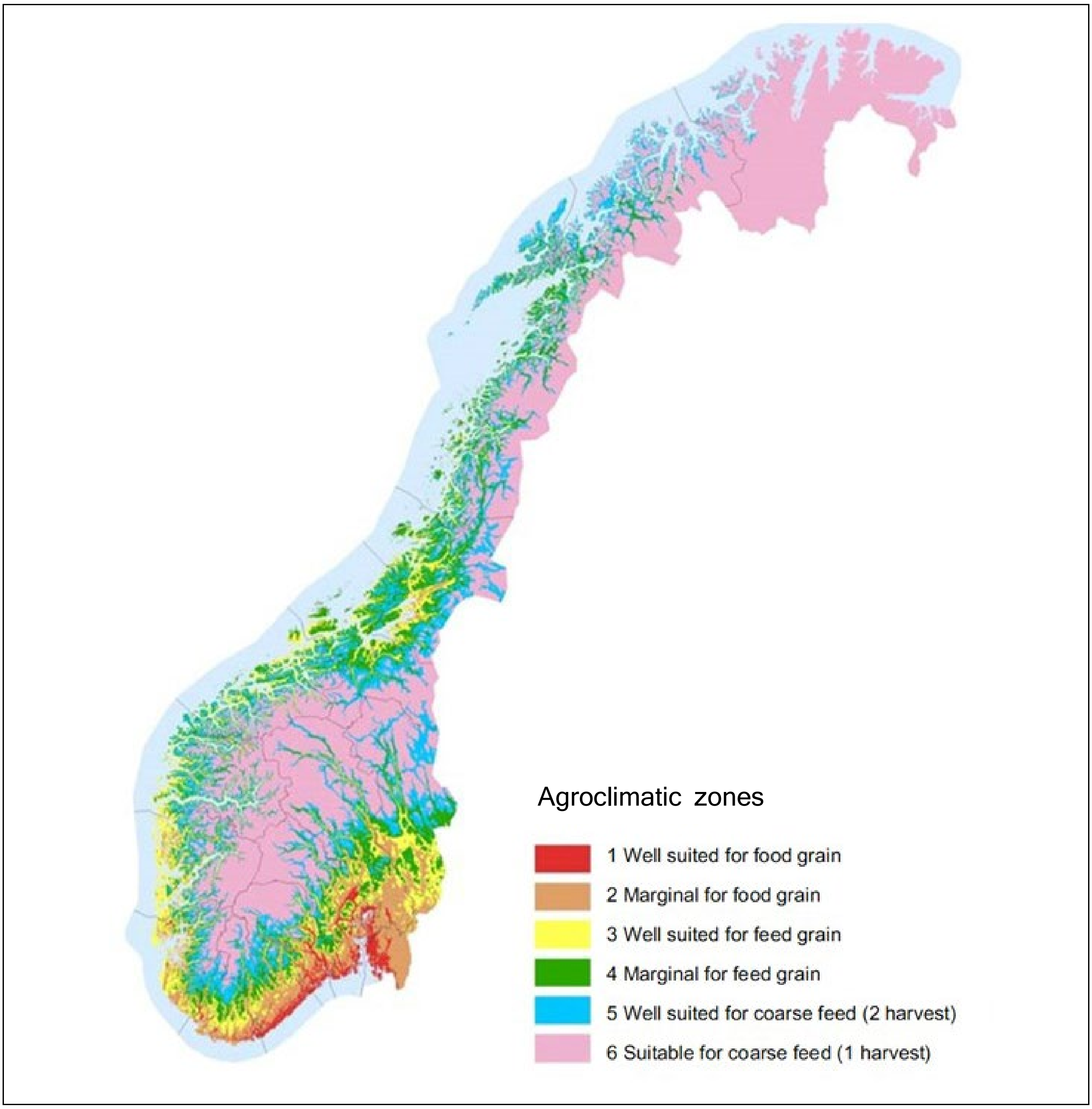

Figure 2. Agroclimatic zones, from Uleberg & Dalmannsdotter (2018). NIBIO Rapport 4(75).

Figure 2 is an illustration of the agroclimatic zones in Norway. Feed production is possible all over the country. Successful harvest of grain and other crops with a longer growing season is limited to the agroclimatic zones 1-3.

AR5 maps the area that is, or easily can be used for agriculture. There are also forested areas and marshes that could be turned into agricultural land by removing trees (including roots) and trenching. The amount of this area is illustrated in Figure 3 where present and potential new agricultural land is measured for the different climatic zones. The best growing conditions are in zone one, while zone six has the shortest growing season. Zone six covers the mountain areas and a large part of northern Norway (see Figure 2). Figure 3 shows that a major part of the potential agricultural land in Norway is located in climatic zones with a shorter growing season.

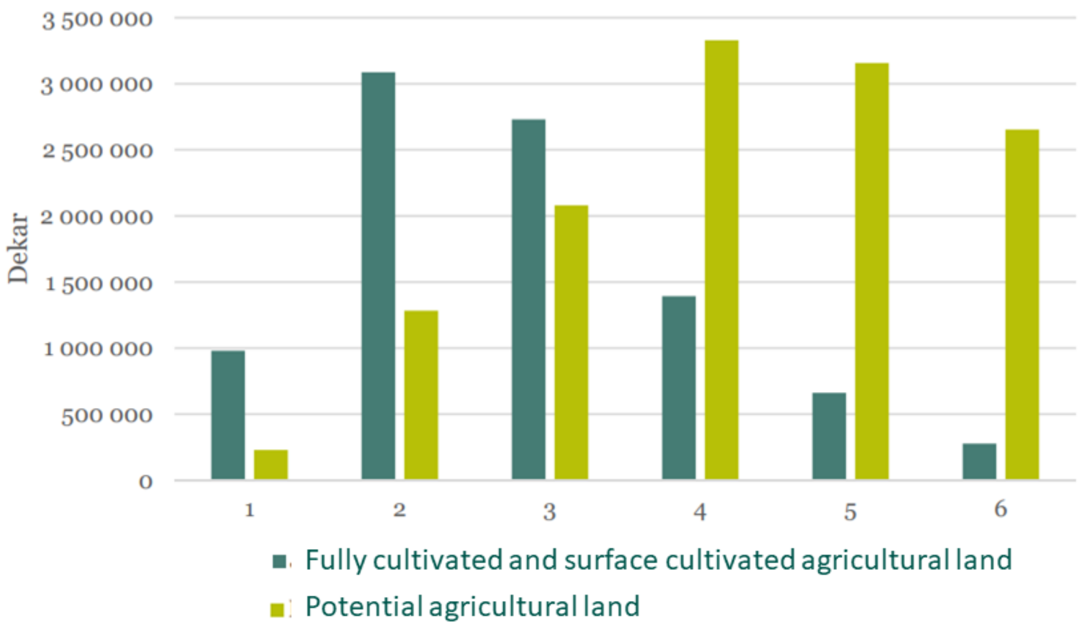

Figure 3. Agricultural area and potential new agricultural land (dyrkbar jord) within climatic zones. Climatic zone 1 shows areas with the best growth conditions within Norway. Climatic zone 6 shows areas where it is common with only one harvest of grass during the summer. Figure from Bardalen et al. (2021).

2.2 Agricultural land use across Norway

Agricultural land can be used in several ways, either for wood production (forest), feed production for livestock, food production as vegetables and grain for direct human consumption, and recreation (for example golf courses). A major part of the agricultural land in Norway is used for feed production for ruminants, in the form of pastures and grass stored as ensilage (see Figure 4). In an average year within the last 10 years, around 40 % of the wheat did not have sufficient quality to be used as food (Totalkalkylen, 2020), but the crop was used for animal feed production. Most of the barley and oats are also used in concentrates for different types of animals, such as pig, poultry, horses, and ruminants.

2.2.1 Grass contra grain

Due to climatic conditions and Norwegian agricultural policy, there are defined regions for grain and grass production in Norway. The subsidy scheme favors grass production in regions where it is difficult to grow grain and favor grain in the regions that are most suitable for grain production. In Figure 4, the land use in 2021 is divided in four groups:

i) pasture,
ii) cultivated land used for grass and other crops used directly as feed crops,
iii) grain and oil seed crops,
iv) other (vegetable, potatoes, fruit and berry and other).

The figure illustrates that grain and oil seed crops are rare along the west coast. However, grain is common in parts of Trøndelag. Table 3 shows the amount of area in the different counties, where the last column shows grain and other crops combined. Tables and figures are based on the application for producer support in 2021 from the Norwegian Agriculture Agency (Landbruksdirektoratet).

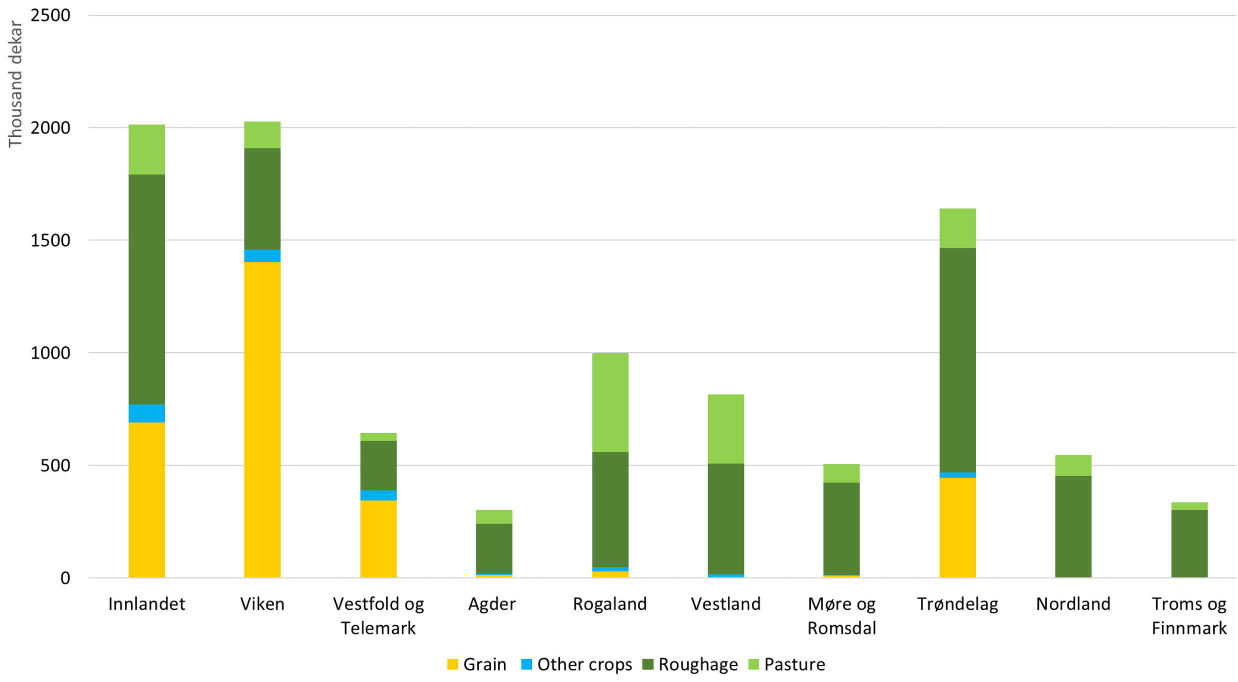

Figure 4. Land use for grain, grass pasture and other crops in 2021. Grain includes oilseeds, field beans, peas and seed production from grass. (Source: Application for producer support from the Norwegian Agriculture Agency).

Table 3. Agricultural land in decares divided into different types of use (Source: Norwegian Agriculture Agency).

	Pasture	Fully cultivated and surface cultivated land used for grazing and winterfeed, mainly grass	Grain and other crops
Innlandet	221 721	1 020 968	852 282
Viken	118 696	449 585	1 517 025
Vestfold og Telemark	34 521	218 143	434 720
Agder	60 411	222 629	25 729
Rogaland	439 215	510 958	65 329
Vestland	306 238	493 212	31 463
Møre og Romsdal	81 201	410 960	17 906
Trøndelag	174 817	997 823	493 157
Nordland	93 913	448 133	6 857
Troms og Finnmark	34 637	299 331	6 324
Norway	1 565 370	5 071 742	3 450 792

Table 3 and Figure 4 show that a large share of the agricultural land is used for production of roughage.

2.2.2 Grain, beans, and oil seed

Farmers' crop choice depends on climate and soil conditions. The different crops and varieties of crops have different requirements with respect to the length of the growing season. Figure 3 shows the time in months between seed date and expected harvesting date for crop varieties used in Norway.

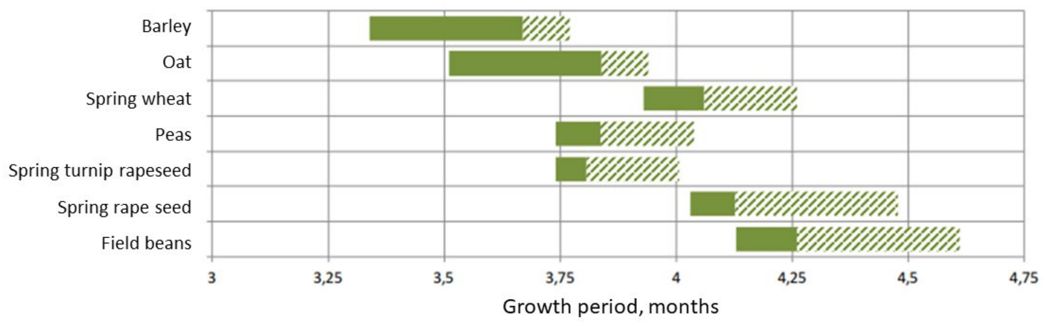

Figure 5. Time between seed date and expected harvesting date for different crops. The shaded area illustrates that some crops can require much more time under unfavorable conditions. (From Abrahamsen at.al, 2016).

The most common grain crop in Norway is barley, which made up 50% of the grain area in 2021 (Table 4). 98% of the area with grain crops was found in the counties Viken, Innlandet, Trøndelag and Vestfold og Telemark. Grain production in Rogaland, Møre og Romsdal and further north was primarily barley in 2021. Winter wheat was grown in the south-east, with 65 % grown in Viken.

Table 4. Area (in decare) used for different types of grain crops within counties in Norway in 2021 and the share og crop at the national level.

Region:	Winter wheat	Spring wheat	Barley	Oates	Ray and ray-wheat	Other grain and seeds	Grain used for crossing
Innlandet	23 988	69 594	430 245	152 018	8 282	750	441
Viken + Oslo	119 500	269 867	497 560	417 251	45 588	1 693	459
Vestfold og Telemark	33 632	105 491	70 486	62 987	28 608	549	19
Agder	55	173	3 342	7 332	0	195	0
Rogaland	421	420	26 760	2 954	100	0	20
Vestland	0	80	276	278	190	16	6
Møre og Romsdal	0	30	9 574	534	20	0	142
Trøndelag	4 958	6 860	388 378	40 553	283	156	1 946
Nordland	0	90	1 392	551	0	1	137
Troms og Finnmark	0	0	34	0	0	0	0
Norway	182 554	452 605	1 428 047	684 458	83 071	3 360	3 170
Share of grain area	6 %	16 %	50 %	24 %	3 %	0,1 %	0,1 %

Table 5. Area (measured in decare) with oilseeds, peas, beans, and other crops in 2021.

	Oil-seeds	Matured peas and bean etc.	Seed production of gras and other plants	Peas and bean for (human consumption) (not matured)
Innlandet	1 736	1 569	2 248	195
Viken	16 213	22 966	7 427	4 365
Vestfold and Telemark	5 759	7 115	24 645	6 751
Agder	0	0	1 754	0
Rogaland	30	100	0	0
Vesland	4	7	0	0
Møre and Romsdal	0	0	0	0
Trøndelag	470	428	541	150
Nordland	0	0	0	0
Troms and Finnmark	0	0	0	0
Norway	24 212	32 185	36 615	11 461

2.2.3 Grain and roughage production

Table 6. Kilo per decare in 2021 and total production in 1 000 tonnes of each type of crop

	Wheat	Barley	Oates	Ray and raywheat
Innlandet	473	449	392	543
Viken + Oslo	416	436	401	414
Vestfold og Telemark	383	406	361	538
Agder	0	293	419	0
Rogaland	423	570	614	0
Møre og Romsdal	0	402	448	0
Trøndelag	381	394	340	231
Nordland	0	238	0	0
Average yield/decare for Norway	417	429	393	469
Total production in 1 000 ton in 2021	264.9	611.8	269	39

Grain with 15 % water content. Source: StatBank Norway table 04510 and 07479.

Table 7 shows the amount of each feed type measured in feed units. One feed unit is equivalent to the energy from one kg barley.

Meadows are either used to produce winter feed or they are grazed or cut and transported for direct feeding during the growing season. Winter feed is usually stored as ensilage or, less commonly, as hay.

Roughage can also consist of straw from grain production, although it makes up a very small share of the roughage used in Norway (Table 7).

Table 7. Estimated use of roughage as feed in Norway between 2016 and 2020, annual share of feed production from the different sources (Based on data from Totalkalkylen in 2022).

	Use of roughage in 1000 feed units (1 feed unit is equal to the energy from 1 kg barley).					
Year	Straw from grain production	Harvested grass	Grazed meadows and pastures	Other roughage crops	Outfield pasture	Sum feed production
2016	4 544	1 811 592	587 014	20 669	325 000	2 748 819
2017	6 492	1 679 482	527 322	21 155	295 000	2 529 451
2018	41 221	1 320 073	368 003	13 702	258 000	2 000 999
2019	14 256	2 094 933	576 613	20 404	330 000	3 036 206
2020	10 031	1 980 364	547 465	18 919	322 000	2 878 779
	Straw from grain production	Harvested grass	Grazed meadows and pastures	Other roughage crops	Outfield pasture	Sum
2016	0.2 %	65.9 %	21.4 %	0.8 %	11.8 %	100.0 %
2017	0.3 %	66.4 %	20.8 %	0.8 %	11.7 %	100.0 %
2018	2.1 %	66.0 %	18.4 %	0.7 %	12.9 %	100.0 %
2019	0.5 %	69.0 %	19.0 %	0.7 %	10.9 %	100.0 %
2020	0.3 %	68.8 %	19.0 %	0.7 %	11.2 %	100.0 %

2.3 Forage crops

Grain, beans, and grasses can all be feed crops. The potential use of a crop and the nutritional value of a crop for ruminants depend on the type of crop and the growth stage of the crop when harvested. Some crops perform better under wet conditions, while other crops can handle drought. Also, some crops require high pH while others can handle low pH.

Feed crops are typically divided into seed-crops and roughage-crops. For seed-crops, the main product is the mature seed (grain and beans). These are typically harvested with the use of a combiner[1] . For roughage-crops (timoty, raigrasses, clover) the whole crop is harvested by cutting the straws or through grazing. Grain and some other typical seed-crops may also be harvested as whole-crop grain and stored as silage.

2.3.1 Seed crops

2.3.1.1 Grain

Barley (*Hordeum vulgare*, bygg)

Barley is a cereal plant of the grass family Poaceae. Barley is the fourth largest grain crop globally, after wheat, rice, and corn. It is also the most common grain crop in Norway, and 50 % of the grain area was used for growing barley in 2021. Barley is easily recognized by its long awns. It comes in two varieties, six-row and two-row barely. The two types are distinguished by the number of rows of flowers on its flower spike. Six-row barley is more suited for animal feed due to its higher protein content, while two-row barley has a higher sugar content and may therefore be used for malt production (Graminor). Barley comes in many varieties which are adapted to different local growing conditions. Some varieties have a short growing season and can therefore be grown outside the typical grain-regions. Barley can also be cultivated on poorer soils and at lower temperatures than wheat. The varieties developed and grown in Norway are mainly spring sown (Graminor).

[1] A combiner is a harvesting machine that heads, threshes, and cleans grain while moving over a field.

Wheat (*Triticum aestivum*, hvete)

Norwegian wheat production is both winter wheat and spring wheat. Wheat requires a warmer climate to mature and are thus grown mainly in the south-eastern parts of Norway, including Vestfold and Telemark, Viken and the southern parts of Innlandet. Winter wheat needs good winter conditions to survive (Graminor).

Spring wheat in Norway is also used for human consumption, while winter wheat, which is expected to have higher yields, is used for feed production. The amount of wheat that is suitable for baking varies between years and thus, also the share, which is used as feed ingredient.

Oat (*Avena sativa*, havre)

Oat is mainly grown as a feed ingredient, but the use of oats for human consumption is increasing (Graminor). In 2021, oat is grown on 24 % of the areas used for grain production. Oat is seeded in the spring, grows well in cool climate and does not require the best soil types. However, oat is also a good crop to include in a rotation with other cereals since it has few diseases in common with other cereals. The growth season to produce seeds is longer than for barley, but oat plants can also be harvested at earlier stages and used as feed.

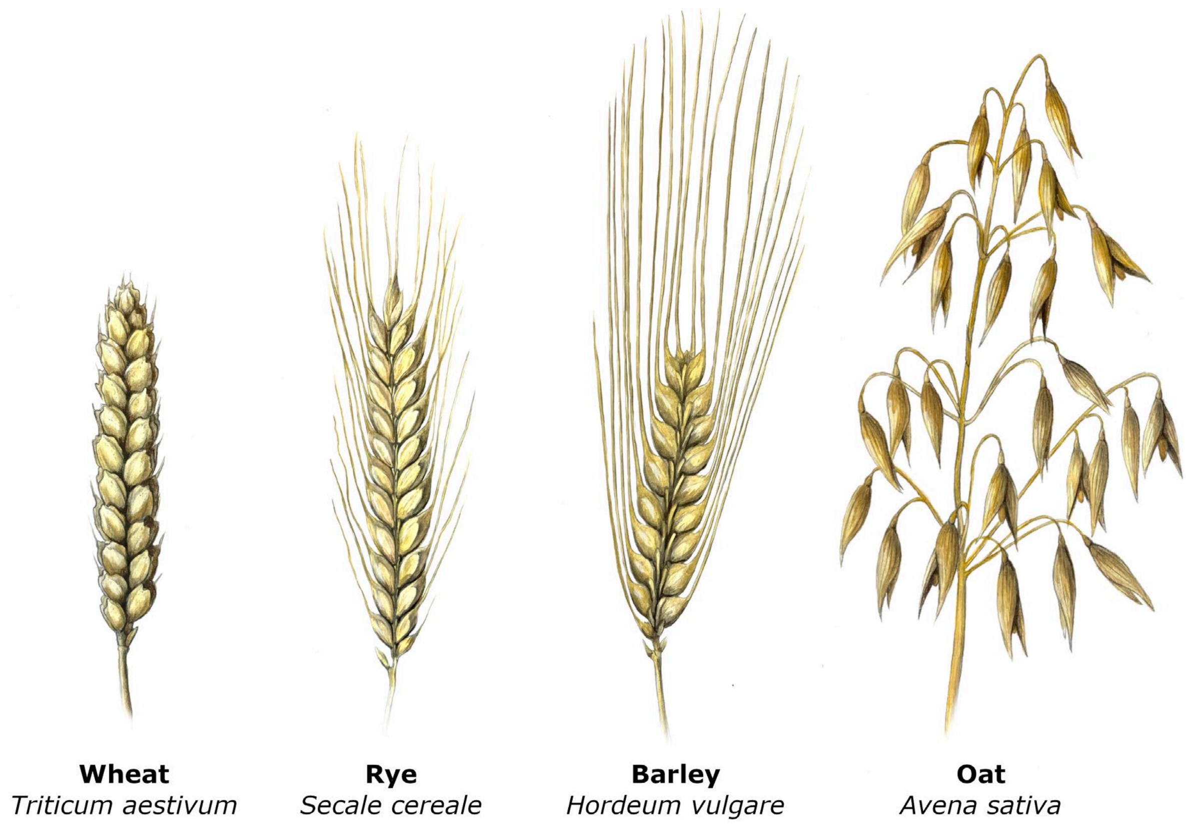

Figure 6. Common grain crops in Norway. Illustration by Ulrike Bayr/NIBIO

Rye and rye-wheat (secale and triticale, rug og rughvete)

Rye-wheat (triticale) is a grain crop based on a combination of wheat and rye. Rye (secale) and rye-wheat was produced on only 3 % of the grain area in 2021. Today, 2/3 of the Norwegian production of rye is used for food, while the rest is used in feed production (Graminor).

Rye-wheat has higher yield potential than rye but requires also better soil than rye. Rye-wheat is solely used for feed production in Norway (Graminor). Ruy and ray-wheat have both deep roots and thus, are more drought-resistant than other grain crops grown in Norway. They are therefore often cultivated on “light soils”.

2.3.1.2 Oilseed

Oilseeds grown in Norway are brassica species. Rotation with other crop types is necessary to avoid diseases. For example, clubroot disease can survive for a long time. Thus, it is suggested to wait 6-7 year between growing brassica species in the same field (Øverland, 2021).

Rape seed and turnip rapeseed (*Brassica napus* subsp. *oleifera* (raps) and *Brassica rapa* subsp. *oleifera*, rybs)

There are both spring sown and winter (autumn) varieties of both crops. Spring-varieties can be grown on all types of soil. Drought prone soil is not suitable, but Brassica napus (raps) is more drought-resistant than brassica rapa (rybs). The soils should be in god status (relatively high) with respect to lime content. It will reduce the need for N-fertilizing with 10 kg N per hectare the following year (Øverland 2022). Oilseeds are good crops to alternate with grain crops.

Jarrestad Agro (downloaded 2022) compared the two crops and found that turnip rapeseed (rybs) grew faster than brassica napus (raps). It is also a more robust crop than napus (raps). Rapeseed (raps) has higher yields under good conditions, while turnip rapeseed (rybs) will often perform better under more harsh conditions and a shorter growing season.

False flax (*Camelina sativia*, oljedodre)

False flax is also a cruciferous oil crop with a high content of omega-3 and antioxidants. According to Øverland (2021), only spring crops are grown in Norway and the crop can be grown on all soil types. It is relatively drought resistant and is less dependent on high lime content and high pH than rape seed. However, the soil needs to be in good conditions with respect to drainage and soil structure. The plants' need for nitrogen is relatively low, and it is important to avoid high N-fertilization to reduce the risk of lodging.

2.3.1.3 Field beans and peas (åkerbønner og erter)

Peas (*Pisum sativum*) and field beans (*Vicia faba*) are species in the pea family. Both are good break-crops. Field beans and peas are also leguminous plants with the ability to fixate nitrogen, eliminating the need for applied N in the year of production. However, on more marginal areas, N applications may still be necessary. The beans leave residual N for the following crop in the rotations.

Field beans are less drought-resistant than peas (Frøseth 2021). Thus, irrigation on crops with field beans may be necessary in the dry season and on light soils.

Both crops require good soil structure, good trenching, and a relatively high pH (6) to perform well. The same field should not be used for beans or peas more often than each 6-7 year due to disease control (Øverland, 2021 and Mellemstad, 2021). Field beans are high in protein with around 30 % of dry matter while peas have slightly lower protein content with around 24 % protein of dry matter (Frøseth, 2021). Field beans can be grown in the grain areas within Eastern Norway, while peas also can be grown within the grain areas of Trøndelag (Frøsteth, 2021).

2.3.2 Crops used for roughage

Usually, a combination of different grasses, often with clover, is used in a seed mix for ensilage, hay and pasture. The seed mix depends on the climatic conditions and the planned use of the crop. Thus, seed mixes for different types of use are sold as well as seed of single grass and clover types.

Different type of grasses matures at different times. Cutting frequency, soil condition and weather conditions may influence which plant type will dominate over the lifetime of the grass field seeded by a seed mix.

2.3.2.1 Grasses

Ray grass (*Lolium perenne*, raigras)

Ray grass are annual or perennial crops. Perennial ray grass is often used in seed mixes. The palatability of the grass is good at early stages and has a slightly higher level of protein content than many other grasses at the same stage. This is due to the large share of leaves in relation to stems. The benefit of using perennial ray grasses is that they give high yields from the first year and tolerate several harvests per year. Ray grasses are used for ensilage, direct feeding, and grazing, while they are less suitable for hay making (Bjørno, 2015).

Timothy (*Phleum pratense*, timotei)

Timothy is the most widely grown forage grass in the northern part of the Nordic countries of Europe (Larsen and Marum, 2006). Timothy has good palatability and is often used in seed mixes. Timothy is suitable for making hay and ensilage but does not survive over time with frequent harvesting. However, timothy has good winter hardiness.

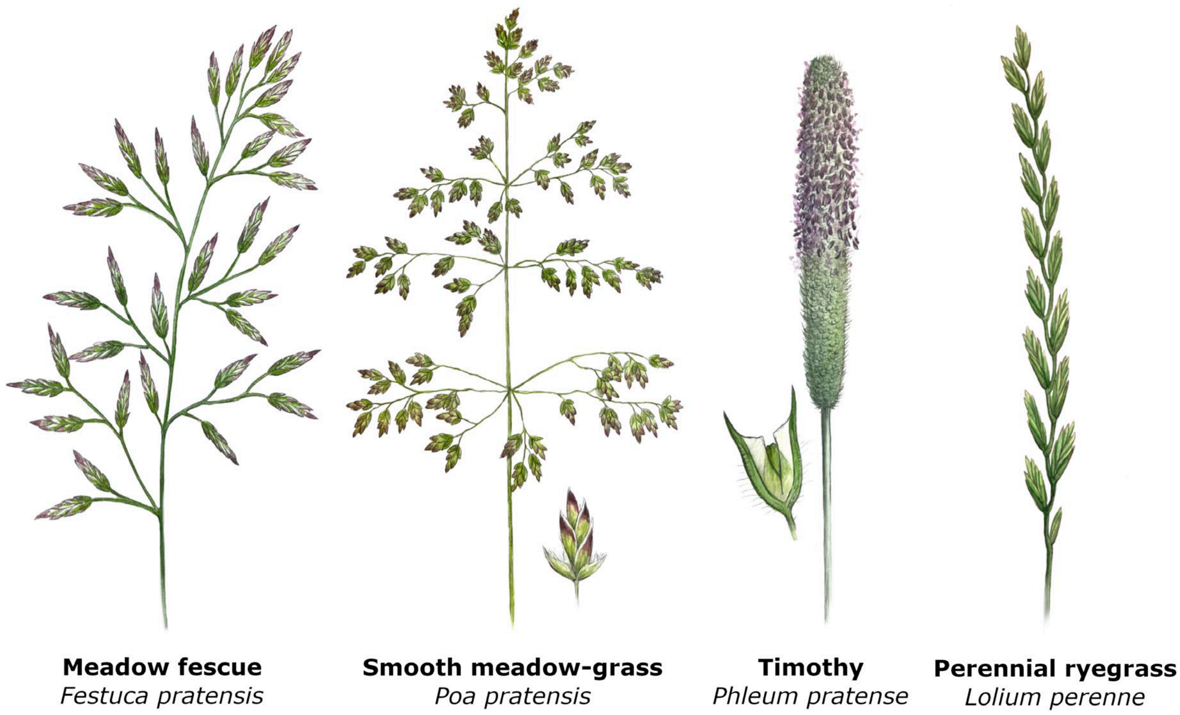

Figure 7. Common grass species used in seed mixes. Illustration by Ulrike Bayr/NIBIO

Meadow fescue (*Festuca pratensis*, engsvingel)

Meadow fescue is often used in seed mixes together with timothy which it may replace over time. It is better suited for intensive harvesting than timothy and higher levels of fertilization (Norsk Landbruksrådgivning, 2022). Meadow fescue matures slightly earlier than timothy, thus, needs to be harvested earlier to have the same nutritional value.

It is one of the larger fescues and is a valuable grazing grass, even though it has less palatability than timothy. Meadow fescue can also be made into hay and will grow on nearly all soils.

Smooth meadow-grass (*Poa pratensis*, engrapp)

Smooth meadow-grass prefers good growing conditions and dislikes waterlogged soil or dry sandy soil. It is primarily used in seed mixes for long lasting pastures but may also be used in mixes for a combination of ensilage and grazing. It is hardy, drought resistant and expected to last for a long time (Bjørnå, 2015).

Cocksfoot (*Dactylis glomerata*, hundegras)

Cocksfoot is palatable when young but loses palatability and digestibility more quickly than other grasses when maturing. It is not as winter hardy as timothy. It will not persist in wet soils but is relatively drought-resistant (Brørno, 2015). It may be used for silage with frequent cuts or early-cut haylage. Cocksfoot has deep roots and therefore thrives on light, free-draining soil.

Smooth bromegrass (*Bromus inermis*, bladfaks)

Smoot bromegrass requires a high pH between 6-7 and is very drought-resistant when it is established. The gras has less palatability than timothy and meadow fescue when used for pasture. It is suitable for silage with two cuts. It must be harvested earlier than timothy to maintain nutritional value. In Norway, the species is suggested for long lasting meadows on drought-prone areas. (Bjørnå, 2015)

Red fescue (*Festuca rubra*, rødsvingel)

Red fescue is winter hard and has good resistance against drought. It is used in seed mixes for long lasting pastures since it has good wear tolerance. It competes well under dry conditions and on less nutritious soils but is less attractive for grazing animals than other typical pasture grasses (Norsk landbruksrådgivning, 2022).

Tall fescue (*Festuca arunddinancea*, strandsvingel)

Tall festuca may be a high plant, particularly on damp or wet soils. On light soils it is drought resistant, but it is less palatable than meadow fescue and so is less attractive for forage production. Quality reduces fast when the plant grows (”skyter”), thus it has poor nutritional value when harvested late. The species can be used for long-lived meadows in areas with the risk of drought or flooding (Molteberg, 2017)

2.3.2.2 Legumes

Clover and lucerne are legumes. In general, legumes produce higher quantities of protein than grasses. Legumes have the capacity to use atmospheric nitrogen. Legumes also supply nitrogen to the grass it grows with.

White clover (*Trifolium repens*, Hvitkløver)

White clover is used in seed mixes for pasture or used as pasture and ensilage combined. It is tolerant for frequent grazing and has good palatability. It is a short-lived perennial which reseeds itself.

Red clover (*Trifolium pratense*, Rødkløver)

Red clover is a short-lived perennial with good yields in the second year. It is best used in silage since it is difficult to dry the plant without losing the leaves of the plant. Red clover is often included in seed mixes.

Alsike clover (*Trifolium hybridum*, Alsikekløver)

Alsike clover can be grown on soils that are acid and poorly drained. It can, however, cause photosensitivity and liver damage in horses.

Lucerne (alfalfa) (*Medicaga sativia*, luserne)

Lucerne is widely used in warmer climate and can only be grown in the best areas of Norway. Lucerne (or alfalfa) is a perennial crop with deep roots. It requires pH 6,5-7,5 and has deep roots making it resistant to drought. Yields and protein content are high. Also, the species has a high palatability and may have high nutritional value (high digestibility). However, the winter hardiness of the crop is poor. (Source: Landsverk, 2023).

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3 Outfield grazing

There are many unused resources for outfield grazing in Norway. The use of these resources during the summer requires that the grazing animals (cattle, goats and sheep) also are fed during the rest of the year. Thus, the use of the outfields is closely tied to the production of winterfeed (typically ensilage from grasses) on cultivated land, and grazing on pastures or cultivated land in the spring and in the fall.

3.1 Use of outfield pasture and available grazing areas

In Norway, it is primarily sheep that graze in the outfields. The amount of pasture is measured in sheep units (Table 8). One sheep unit is equivalent to one feed unit shown in Table 7 (page 15) or one kg barely (grain). Table 9 shows the available area for outfield grazing and a classification into three quality categories of the land for cattle and sheep. The table shows that Troms is an area with a large share of outfields areas with very good quality. Grazing quality of outfields are dependent on the type of bedrock in the area and topography (Strand et.al 2021).

Table 8. Use of pasture and unused pasture capacity in the outfields in Norway. Use of pasture is measured in s.u. which is equivalent to a feed unit or the same feed value as 1 kg barely.

	Capacity	Sheep, cattle, goats and horses		Cervid (reindeer, and wild cervid)		Total pasture pressure		Unused capacity	
	s.u.	s.u.	%	s.u.	%	s.u.	%	s.u.	%
Akershus, Oslo, Østfold & Vestfold	373 299	62 209	17	32 378	9	94 587	25	278 712	75
Hedmark	728 050	183 631	25	85 569	12	269 200	37	458 849	63
Oppland	724 850	426 258	59	60 402	8	486 660	67	238 190	33
Buskerud	504 880	141 912	28	46 418	9	188 331	37	316 550	63
Telemark	463 545	74 916	16	39 363	8	114 279	25	349 266	75
Agder	418 448	175 854	42	33 953	8	209 807	50	208 641	50
Rogaland	229 457	219 803	96	24 699	11	244 502	107	-15 045	-7
Hordaland	446 776	267 550	60	90 373	20	357 923	80	88 854	20
Sogn og Fjordane	539 663	267 614	50	113 037	21	380 650	71	159 012	29
Møre og Romsdal	426 547	187 270	44	111 202	26	298 472	70	128 075	30
Sør-Trøndelag	587 114	220 050	37	80 537	14	300 587	51	286 527	49
Nord-Trøndelag	805 603	162 026	20	88 398	11	250 424	31	555 179	69
Nordland	1 240 569	282 333	23	166 164	13	448 498	36	792 071	64
Troms	1 035 907	145 422	14	192 118	19	337 539	33	698 368	67
Finnmark	981 677	28 277	3	236 223	24	264 499	27	717 178	73
NORWAY	9 506 385	2 845 124	30	1 400 835	15	4 245 958	45	5 260 427	55

Source: Strand et.al (2021).

Table 9. Amount of available outfield grazing areas, share of area of different grazing qualities for cattle and sheep. Total area of good and very good quality, which are valuable grazing areas. (Table from Strand et.al, 2021)

	Available area (km^2)	Share (%) Less good	Good	Very good	Area of good and very good quality Km²	%
Akershus, Oslo, Vestfold & Østfold	8 405	40	47	13	5 038	60
Hedmark	24 469	55	39	6	10 907	45
Oppland	19 059	43	43	14	10 878	57
Buskerud	12 657	43	41	15	7 173	57
Telemark	13 076	51	38	12	6 452	49
Agder	14 160	55	42	3	6 358	45
Rogaland	6 752	46	46	8	3 664	54
Hordaland	11 556	40	46	14	6 897	60
Sogn og Fjordane	14 053	41	48	11	8 244	59
Møre og Romsdal	10 979	42	46	12	6 409	58
Sør-Trøndelag	16 790	51	41	7	8 202	49
Nord-Trøndelag	19 576	42	49	9	11 431	58
Nordland	28 492	43	40	17	16 350	57
Troms	21 363	39	36	26	13 037	61
Finnmark	40 648	61	34	4	15 710	39
Norway	262 035	48	41	11	136 750	52

Source: Strand et.al (2021).

3.2 References

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4 Bioresources from forest

4.1 Norwegian wood species – frequency and distribution

Svensson et al. (2021) and Strand et al. (2021) both provide detailed insight regarding forest resources and utilization potentials. A brief summary of some of the results from these two reports is given below.

Svensson et al. (2021) provided an overview of raw material volumes by wood species for different regions in Norway (Table 10). For more details we refer to Svensson et al. (2021).

Table 10. Forestry land, volume excluding bark by tree species (1 000 m^3) for different regions in Norway. Data modified from Svensson et al. (2021).

	Viken, Oslo	Innlandet	Vestfold, Telemark	Agder	Vestlandet	Trøndelag	Nordland	Troms og Finnmark	All
Pinus sylvestris **Norway spruce** (Gran)	86 225	122 155	42 320	24 555	33 069	64 662	15 237	2 197	390 420
Abies and *Picea* **Introduced spruce** (Introdusert gran)	0	142	6	1 097	4 851	283	2 877	173	9 429
Pinus sylvestris **Scots pine** (Furu)	52 494	74 555	26 035	37 434	37 553	17 387	2 904	4 680	253 042
Pinus **Introduced pine** (Introdusert furu)	-	238	30	15	1 164	585	106	0	2 138
Betula sp. **Birch** (Bjørk)	17 134	25 262	9 980	9 221	26 024	14 203	15 832	20 627	138 283
Populus tremula **Aspen** (Osp)	2 556	1 403	3 601	3 006	2 470	849	1024	444	15 354
Alnus incana **Grey alder** (Gråor)	3 168	1940	617	7	4 410	3 838	1 002	1 471	16 452
Quercus robur and *Q. petraea* **Oak** (Eik)	158	-	1 233	5 159	953	-	-	-	7 503
Other noble hardwoods (Andre edelløvtrær)	1 423	349	3 585	920	3201	91	0	-	9 568
Other hardwoods (Andre løvtrær)	1 836	1 905	2 245	1 032	6 038	2 988	2 599	1 602	20 246
Total	164 995	227 948	89 652	82 446	119 733	104 886	41 580	31 194	862 435

Strand et al. (2021) provided a report about status and opportunities for value creation in outfields from forestry, unmanaged pasture, reindeer husbandry, hunting and fishing. In Table 11, a summary of productive forest areas, volumes of trees, percent increment and percent harvest for different regions of Norway. For more details we refer to Strand et al. (2021).

Table 11. Productive forest: area in 1 000 ha, volume in 1 000 m^3, increment and harvest in percent of annual harvest. Area, volume and increment modified from Strand et al. (2021). Harvest data from Landbruksdirektoratat 2014, modified from Alfredsen et al. (2018).

	Østfold, Akershus, Oslo, Hedmark		Oppland, Buskerud, Vestfold		Telemark, Agder		Rogaland, Hordaland, Sogn og Fjordane		Trøndelag, Møre og Romsdal		Nordland, Troms, Finnmark		All	
	Area	Volum	Area	Volum	Area	Volum	Area	Volum	Area	Volum	Area	Volum	Area	Volum
Forestry	1 936	236 791	1 501	173 702	1 191	155 854	727	88 423	1 402	141 080	1 488	74 025	8 246	869 875
Protected	71	8 248	62	7 813	39	5 381	19	1 575	55	5 457	83	4 721	328	33 196
Other	22	651	27	1 526	16	1 001	11	571	15	92	14	94	104	3 934
Total	2 029	245 691	1 590	183 042	1 246	162 236	756	90 568	1 472	146 630	1 585	78 839	8 678	907 005
Increment %	28.9		20.3		16.3		8.9		17.4		8.2			
Harvest %	46.3		24.2		11.8		4.9		11.5		1.5			

4.2 Forest products

Statistics Norway (SSB) collects information about import, export and production volumes for forest products. The results are reported by SSB to the Food and Agriculture Organisation of the United Nations (FAOSTAT). FAOSTAT is used as input data (activity data) for the Norwegian greenhouse gas reporting for harvested wood products (HWP) to the UNFCCC. In this chapter, data from FAOSTAT was used to illustrate the material flow and production volumes of the different forest products. The terminology and definitions (Table 12) are based on the Joint Forest Sector Questionnaire (JFSQ) including FAOSTAT, European Commission DG Eurostat (Eurostat), International Tropical Timber Organization (ITTO) and United Nations Economic Commission for Europe (UNECE). Figure 8 gives a visual overview of the forest products material flow from harvest (roundwood) to semi-finished categories. For obvious reasons it is not possible to illustrate all the finished products that are produced from timber.

Table 12 provides volumes for import, export and production of different forest product categories. In addition, domestic consumption is calculated (i.e. production volume – export). Domestic consumption is included due to the annual HWP reporting to UNFCCC, using the production approach (IPCC 2006). It is important to note that only domestic consumption and export is reported as including import would result in double counting. More details on the historic trends for the forest product categories listed in Table 11 are given in Alfredsen et al. (2022) for the years 1961-2019. The resource availability is decided by the annual harvest volumes and market demand. Hence, the forest product flow can change quickly and quite drastically.

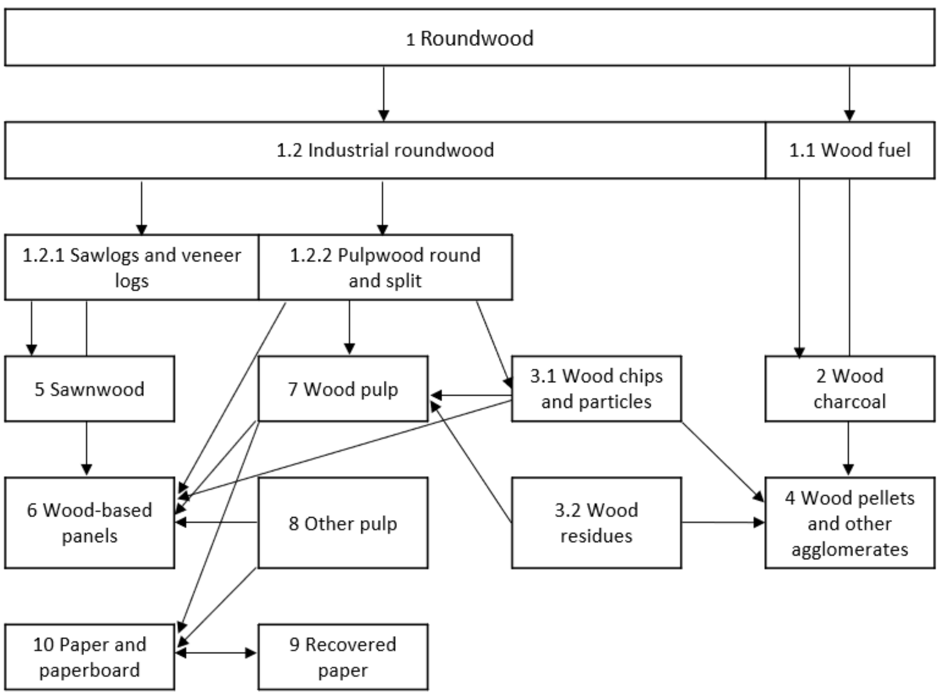

Figure 8. Forest product categories according to Joint Forest Sector Questionnaire/FAOSAT and material flow between the categories. Adapted from Alfredsen et al. (2022).

Table 12. Forest product categories (Norwegian name in brackets), and the volumes from import, production, domestic consumption (production – export) and export. All data are from FAOSTAT for the year 2020. In addition, the Joint Forest Sector Questionary (JFSQ) code and the FAOSTAT code is provided. Please note that the volumes are given as cubic meters (m³) or metric tonnes (t). More details about the reported categories are provided in Table 12. – means no data is provided by FAOSTAT, NA occurs for domestic consumption when production or export data are unavailable.

Forest product category	Import	Production	Domestic consumption	Export	JFSQ code	FAOSTAT code
Roundwood (Rundvirke)	458 925 m³	11 771 417 m³	8 189 692 m³	3 581 725 m³	1	1861
Wood fuel (Trebrensel)	122 292 m³	1 529 731 m³	1 507 658 m³	22 073 m³	1.1	1864
Industrial roundwood (Industrielt rundvirke)	336 633 m³	10 241 686 m³	6 682 034 m³	3 559 652 m³	1.2	1865
Sawlogs and veneer logs (Sag- og finértømmer)	-	5 457 864 m³	NA	-	1.2.1	1868
Pulpwood round and split (Massevirke)	-	4 703 112 m³	NA	-	1.2.2	2038
Wood charcoal (Trekull)	44 917 t	0 t	0 t	4 229 t	2	1630
Wood chips, particles and residues (Treflis, trepartikler og restprodukt)	732 694 m³	2 183 146 m³	1 427 552 m³	755 594 m³	3	1695
Wood chips and particles (Treflis og trepartikler)	268 486 m³	1 419 045 m³	1 055 630 m³	363 415 m³	3.1	1619
Wood residues including wood for agglomerates (Restprodukt fra trevirke)	464208 m³	764 101 m³	371 922 m³	392179 m³.	3.2	1620
Wood pellets (Trepellets)	73 507 t	95 768 t	3 954 t	91 814 t	4	1696
Sawnwood (Trelast)	1 043 240 m³	2 683 000 m³	1 822 615 m³	860 385 m³	5	1872
Wood-based panels (Trebaserte plater)	472 525 m³	45 8000 m³	229 765 m³	228 235 m³	6	1873
Wood pulp (Papirmasse fra tre)	68 348 t	983 000 t	629 836 t	353 164 t	7	1875
Other pulp (Annen papirmasse)	1 898 t	0 t	NA	1 000 t	8*	1668+ 1609
Recovered paper (Gjenvunnet papir)	20 260 t	533 000 t	215 000 t	318 000 t	9	1669
Paper and paperboard (Papir- og kartongprodukter)	161 904 t	136 000 t	25 681 t	110 319 t	10	1876

*The sum of the FAOSTAT categories '8.1 Pulp from fibres other than wood' and '8.2 Recovered fibre pulp'

Table 13 lists the forest product definitions and provides an evaluation of how usable the different categories are as potential substrate for fungal depolymerization, which in turn is used for insect feed. Please note that the list includes raw materials that are further processed into semi-finished products ref. Figure 8. For example, a sawlog cannot be used directly because of the size, but the side stream of wood residues from the sawmill could be used as substrate. An alternative way to convert wood to feed ingredients are bioconversion by yeast fungi, e.g., yeast flour as feed for pigs and salmon. For more details we refer to Foods of Norway at NMBU (https://www.foodsofnorway.net/). However, the raw material for bioconversion will principally be the same as for fungal depolymerization but the size and quality needs to be right for the process.

Please note in Table 13: The suitability of the substrate is based on the direct use of the given category. As seen in Figure 8, category 1 and its subcategories are raw material categories feeding into the other categories.

Table 13. Definitions of forest product categories from Joint Forest Sector Questionary (JFSQ 2016) (https://www.fao.org/forestry/34572-0902b3c041384fd87f2451da2bb9237.pdf)

Forest product category	Definition from JFSQ	Usability as substrate for feed production
1 **Roundwood** (Rundvirke)	"All roundwood felled or otherwise harvested and removed. It comprises all wood obtained from removals, i.e. the quantities removed from forests and from trees outside the forest, including wood recovered from natural, felling and logging losses during the period, calendar year or forest year. **It includes** all wood removed with or without bark, including wood removed in its round form, or split, roughly squared or in other form (e.g. branches, roots, stumps and burls (where these are harvested) and wood that is roughly shaped or pointed. It is an aggregate comprising wood fuel, including wood for charcoal and industrial roundwood (wood in the rough). **It is reported in** cubic metres solid volume underbark (i.e. excluding bark)."	Not suitable Raw material
1.1 **Wood fuel** (Trebrensel)	"Roundwood that will be used as fuel for purposes such as cooking, heating or power production. **It includes** wood harvested from main stems, branches and other parts of trees (where these are harvested for fuel) and wood that will be used for the production of charcoal (e.g. in pit kilns and portable ovens), wood pellets and other agglomerates. The volume of roundwood used in charcoal production is estimated by using a factor of 6.0 to convert from the weight (mt) of charcoal produced to the solid volume (m^3) of roundwood used in production. It also includes wood chips to be used for fuel that are made directly (i.e. in the forest) from roundwood. **It excludes** wood charcoal, pellets and other agglomerates. **It is reported in** cubic metres solid volume underbark (i.e. excluding bark)."	Not suitable Raw material
1.2 **Industrial roundwood** (Industrielt rundvirke)	"All roundwood except wood fuel. **In production statistics, it is an aggregate comprising** sawlogs and veneer logs; pulpwood, round and split; and other industrial roundwood. **It is reported in** cubic metres solid volume underbark (i.e. excluding bark). The customs classification systems used by most countries do not allow the division of Industrial Roundwood trade statistics into the different end-use categories that have long been recognized in production statistics (i.e. sawlogs and veneer logs, pulpwood and other industrial roundwood). Thus, these components do not appear in trade."	Not suitable Raw material
1.2.1 **Sawlogs and veneer logs** (Sag- og finértømmer)	"Roundwood that will be sawn (or chipped) lengthways for the manufacture of sawnwood or railway sleepers (ties) or used for the production of veneer (mainly by peeling or slicing). **It includes** roundwood (whether or not it is roughly squared) that will be used for these purposes; shingle bolts and stave bolts; match billets and other special types of roundwood (e.g. burls and roots, etc.) used for veneer production. **It is reported in** cubic metres solid volume underbark (i.e. excluding bark)."	Not suitable Raw material

1.2.2 **Pulpwood round and split** (Massevirke)	"Roundwood that will be used for the production of pulp, particleboard or fibreboard. **It includes:** roundwood (with or without bark) that will be used for these purposes in its round form or as splitwood or wood chips made directly (i.e. in the forest) from roundwood. **It is reported in** cubic metres solid volume underbark (i.e. excluding bark)"	Not suitable Raw material
2 **Wood charcoal** (Trekull)	"Wood carbonised by partial combustion or the application of heat from external sources. **It includes** charcoal used as a fuel or for other uses, e.g. as a reduction agent in metallurgy or as an absorption or filtration medium. **It is reported in** metric tonnes."	Not suitable Pyrolyzed, no nutrition value left
3 **Wood chips, particles and residues** (Treflis, trepartikler og restprodukt)	**"This product category is an aggregate comprising** wood chips, particles and wood residues. It is the volume of roundwood that is left over after the production of forest products in the wood processing industry (i.e. wood processing co-products) and has not been agglomerated. **It is reported in** cubic metres solid volume excluding bark."	Suitable
3.1 **Wood chips and particles** (Treflis og trepartikler)	"Wood that has been reduced to small pieces and is suitable for pulping, for particle board and/or fibreboard production, for use as a fuel, or for other purposes. **It excludes** wood chips made directly in the forest from roundwood (i.e. already counted as pulpwood or wood fuel). **It is reported in** cubic metres solid volume excluding bark."	Suitable
3.2 **Wood residues including wood for agglomerates** (Restprodukt fra trevirke)	"Other wood processing co-products. **It includes** wood waste and scrap not useable as timber such as sawmill rejects, slabs, edgings and trimmings, veneer log cores, veneer rejects, sawdust, residues from carpentry and joinery production, and wood residues that will be used for production of pellets and other agglomerated products. **It excludes** wood chips, made either directly in the forest from roundwood or made in the wood processing industry (i.e. already counted as pulpwood or wood chips and particles), and agglomerated products such as logs, briquettes, pellets or similar forms as well as post-consumer wood. **It is reported in** cubic metres solid volume excluding bark."	Suitable
4 **Wood pellets and other agglomerates** (Trepellets)	"Agglomerates produced either directly by compression or by the addition of a binder in a proportion not exceeding 3% by weight. Such pellets are cylindrical, with a diameter not exceeding 25 mm and a length not exceeding 100 mm. **It is reported in** metric tonnes."	Not suitable The densification process is not needed, or beneficial, for use as fungal substrate
5 **Sawnwood** (Trelast)	"Wood that has been produced from both domestic and imported roundwood, either by sawing lengthways or by a profile-chipping process and that exceeds 6 mm in thickness. **It includes** planks, beams, joists, boards, rafters, scantlings, laths, boxboards and "lumber", etc., in the following forms: unplaned, planed, end-jointed (for example finger-jointed), etc. **It excludes** sleepers, wooden flooring, mouldings (sawnwood continuously shaped along any of its edges or faces, like tongued, grooved, rebated, V-jointed, beaded, moulded, rounded or the like) and sawnwood produced by resawing previously sawn pieces. **It is reported in** cubic metres solid volume."	Not suitable High value commercial products
6 **Wood-based panels** (Trebaserte plater)	"**This product category is an aggregate comprising** veneer sheets, plywood, particle board, and fibreboard. **It is reported in** cubic metres solid volume."	Not suitable Mixed product, often containing glue

7 **Wood pulp** (Papirmasse fra tre)	"Fibrous material prepared from pulpwood, wood chips, particles or residues by mechanical and/or chemical process for further manufacture into paper, paperboard, fiberboard or other cellulose products. **It is an aggregate comprising** mechanical wood pulp; semi-chemical wood pulp; chemical wood pulp; and dissolving wood pulp. **It is reported in** metric tonnes air-dry weight (i.e. with 10% moisture content)."	Not suitable Chemically and/or thermal processes will reduce the utilization potential as substrate
8 **Other pulp** (Annen papirmasse)	"Pulp manufactured from wastepaper or from fibrous vegetable materials other than wood and used for the manufacture of paper, paperboard and fiberboard. **It is an aggregate comprising** pulp from fibrer other than wood and recovered fiber pulp. **It is reported in** metric tonnes air-dry weight (i.e. with 10% moisture content)."	Not suitable Very small volumes and nutrition value regarded as low
9 **Recovered paper** (Gjenvunnet papir)	"Waste and scraps of paper or paperboard that have been collected for re-use or trade. **It includes** paper and paperboard that has been used for its original purpose and residues from paper and paperboard production. **It is reported in** metric tonnes."	Not suitable Some qualities of recovered paper could theoretically potentially be used, but the sorting process is very complicated
10 **Paper and paperboard** (Papir- og kartongprodukter)	"The paper and paperboard category is an aggregate category. **In the production and trade statistics, it represents the sum of** graphic papers; sanitary and household papers; packaging materials and other paper and paperboard. **It excludes** manufactured paper products such as boxes, cartons, books and magazines, etc. **It is reported in** metric tonnes."	Not suitable A commercial product. Some qualities of recovered paper could theoretically potentially be used, but the sorting process is very complicated

4.3 Secondary raw material from forest operations, sawmills and waste wood

Increasing demand for bioenergy, biofuel and other biobased products have resulted in an increasing interest for the utilization of secondary raw materials (by-products) from the forest-based value chain.

Figure 9 roughly illustrates how volumes of a harvested conifer is allocated, i.e., the amount of stem wood and the different quality allocations of stem wood. At the sawmill, the yield is 52-55 % (based on timber volume under bark), and with some variations with regard to dimensions, wood species, quality etc. The remaining volume fractions is referred to as "secondary raw materials" and includes chip fractions, offcuts and bark.

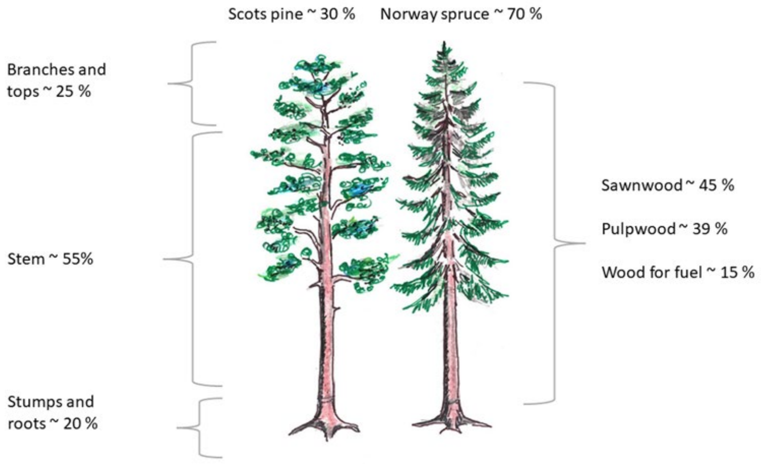

Figure 9. Biomass allocation for parts of the tree and allocation of biomass to main use areas

The materials that can be used as substrate for fungal depolymerization of wood and as a food source for insects are expected to be relatively homogeneous fractions of wood chips or shavings. These materials are partly covered by the forest product categories '3 Wood chips, particles and residues volumes of wood residues' and it's sub-categories '3.1 Wood chips and particles' and '3.2 Wood residues including wood for agglomerates'.

Statistics for secondary raw materials from forest operations and sawmills are scattered. Further, reclaimed wood is not one of the forest product categories listed in chapter 4.2. Theoretically, clean reclaimed wood can be utilized as substrate, but the sorting and processing steps would be complicated.

An overview of types, volumes and use areas for secondary raw material from forest operations, sawmills and recovered wood is provided in Table 13, and for wood waste in Table 14. A summary of volumes and their usability as substrate for fungal depolymerization is provided in Table 15.

According to key numbers from Treindustrien (www.treindustrien.no), the allocation between different product categories from the sawmill industry is:

Sawnwood	51 %	¾ construction timber, 1/3 semi-finished products
Wood chips for pulp	26 %	Special product for the paper industry
Wood chips and particles	14 %	For wood-based panel production
Dry by-products	4 %	For other industry and energy recovery
Loss due to drying etc.	5 %	

In addition, around 500 000 m^3 bark used for energy recovery (80 %) and soil amendment- garden- and other special products (20 %). This implies that it is only the ash from energy recovery that is deposited. All other products and secondary raw materials are currently utilized nationally or exported.

Table 14. Definitions, volumes, quality and use areas for secondary raw materials from forest operations and sawmills. Modified from Alfredsen et al. (2018).

Raw materials from forest operations	
Logging residues (GROT, stubber og røtter)	
Definition	Forest residues left in the forest after harvest and includes tops, branches, stumps and roots.
Volumes	- Approximately 6 mill m^3 biomass is left in the forest each year. - Accounts for 3.7 mill m^3, the rest is stumps and roots. - Branches and tops have to some degree been utilised, while roots and stumps are not utilised in Norway. For all practical purposes the collection of branches and tops has been 0 since 2013 (subsidies disappeared). In 2015 and 2016 the collected volumes were 900 m^3 and 1 180 m^3.
Quality	- The amount of branches and tops vary depending on the type of forest. In Norway spruce stands approximately 30 % of the volume, while for Scots pine approximately 20 % of the volume. Utilisation of branches and tops has a potential, but also several challenges (for more details see Alfredsen et al. 2018).
Use areas	Bioenergy
Chips from the entire tree (heltreflis)	
Definition	Chips from the entire tree, i.e., including branches. Stumps are not included. Can be both softwood and hardwood.
Volumes	Currently, the production is minimal. In 2013, 800 000 m^3 whole trees was harvested for chips production whereby 57 % of this volume came from agricultural land, 23% from forests and 14% from clearing of roadsides. In addition, 6% came from first time thinning.
Quality	Nordhagen and Gjølsjø (2013) analyzed the quality of whole tree chips. The trees dry better during storage than branches and tops due to better ventilation. All bioenergy facilities can use 100 % whole tree chips.
Use areas	Bioenergy
Sumps and roots (stubber og røtter)	
Definition	Stumps and roots left after harvest. Accounts for approximately 20% of the tree volume and has a considerable energy potential.
Volumes	- There is no utilization of stumps or roots in Norway. - In Sweden stumps accounts for 0.1 TWh, approximately 2 % of forest fuel utilization in Sweden. In Finland stumps are commercially harvested and the annual volume is approximately 1.3 mill m^3 (both Norway spruce and Scots pine).
Quality	Due to high ash content stumps must be burned in larger facilities.
Use areas	Bioenergy in larger heating plants
Raw material from sawmills	
Bark (bark)	
Definition	Bark
Volumes	Approximately 470 000 m^3 annually
Quality	Bark is produced throughout the year and is separated from the wood with different methods. The cost of the process and the value of the bark, given by season variations, decides the profitability of the process.
Use areas	Bioenergy (ca. 80 %), soil amendment/garden/special products (ca. 20 %) plus a small amount for oil absorption
Wood chips and particles (sagflis)	
Definition	Produced at the sawmill when cutting timber into dimensions. The volumes produced depend on the used saw technology.
Volumes	Approximately 400 000 m^3 per year
Quality	The mean moisture content can be above 100 % (8-10 % of the timber volume)

Use areas	Used for wood-based panels, animal bedding, pellets production, bioenergy mix.
Wood chips for pulp (celluloseflis/sagbruksflis)	
Definition	Wood residues produced when the timber is profiled directly under the cutting process in the saw machines.
Volumes	Approximately 1.5 mill m^3 per year
Quality	The quality varies depending on the tools, speed, timber quality and dimension distribution and resulting in different geometries and size distributions.
Use areas	Mainly paper industry. Since the paper industry is declining nationally, the export has increased.
By-products from the planning process (kutterflis)	
Definition	When shaving the surface of wooden boards.
Volumes	Data is lacking
Quality	Moisture content of 15-18 %.
Use areas	Wood-based panels, animal bedding, biofuel. Recent years increased export.
Offcut (avkapp, rått og tørt)	
Definition	Offcut
Volumes	Raw ca. 28 000 m^3 per year, dry ca. 70 000 m^3 per year
Quality	Often mixed with wood chips for pulp
Use areas	Used for wood-based panels and for bioenergy. The raw fractions are cut to cellulose chips and used in the paper industry
Ash (aske)	
Definition	Ash after energy recovery of bark and wood residues
Volumes	Approximately 4 000 kg per year
Quality	Depends on the raw materials
Use areas	Used as forest fertilizer in Sweden and Finland. In Norway the ash is mainly deposited

Table 15. Definitions, volumes, quality and use areas for secondary raw materials wood waste. Modified from Alfredsen et al. (2018).

Wood waste	
Definition	Wood waste is collected from private consumers, construction sector, service sector and industry and includes wood and wood-based materials, wood-based panels, furniture, wood chips and painted/unpainted cladding.
Volumes	792 000 t in 2016
Quality	Huge variation in quality. Sorting is a big challenge.
Use areas	Currently mainly energy recovery (90 % in 2015) while 8 % was reused in new products. But form 2020, the EU Directive 2008 demands that 70 % (in weight) of wood waste from the construction sector and 50 % (in weight) from private consumers shall be reused.

Table 16. Summary table of volumes of secondary raw materials from forest operations, sawmills, and wood waste. Modified from Alfredsen et al. (2018).

Product	Annual production	Year	Source	Usability as substrate for feed production
Forest operations				
Branches and tops (greiner og topper)	1 180 m³	2016	Landbruksdirektoratet 2017	Not suitable
Whole tree chips (heltreflis)	Data not available			Suitable
Stumps and roots (stubber og røtter)	Data not available			Not suitable
Sawmills				
Bark (bark)	468 000 m³	2016	Tellnes et al. (2011) volume adjusted to 2016 (Alfredsen et al. 2018)	Not suitable
Wood chips and particles **(sagflis)**	398 000 m³	2016	Tellnes et al. (2011) volume adjusted to 2016 (Alfredsen et al. 2018)	Suitable
Raw offcut (råkapp)	28 000 m³	2016	Tellnes et al. (2011) volume adjusted to 2016 (Alfredsen et al. 2018)	Suitable if processed to smaller fractions
Dry offcut (tørrkapp)	70 000 m³	2016	Tellnes et al. (2011) volume adjusted to 2016 (Alfredsen et al. 2018)	Suitable if processed to smaller fractions
Pulpwood chips (celluloseflis /råflis)	1 522 000 m³	2016	Tellnes et al. (2011) volume adjusted to 2016 (Alfredsen et al. 2018)	Suitable
By-products from the planing process **(kutterflis)**	Data not available			Suitable
Sawmill ash (sagbruksaske)	4 000 kg	2016	Tellnes et al. (2011) volume adjusted to 2016 (Alfredsen et al. 2018)	Not suitable
Wood waste				
Wood waste (total)	792 000 t	2016	SSB – waste statistics	Not suitable. Sorting challenges
- Private consumption	284 000 t	2016	SSB - waste statistics	
- Construction sector (total)	259 613 t	2016	SSB - waste statistics	
- new constructions	113 011 t	2016	SSB - waste statistics	
- rehabilitation	103 134 t	2016	SSB - waste statistics	
- demolition	43 468 t	2016	SSB - waste statistics	
- Service sector	150 000 t	2016	SSB - waste statistics	
- Industry	92 000 t	2016	SSB - waste statistics	

How well secondary raw materials are suited for future utilization within different areas depends on: 1) price and demand for the respective material, 2) raw material properties and the cost and environmental impact processing includes, 3) existing utilization of the material, i.e. competition, 4) the price and demand of the new end product.

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5 Marine based resources

5.1 Aim and Scope

This chapter provides an overview of the potential marine feed resources in Norway and estimates of the existing or potential volumes of these resources. The chapter covers fish, zooplankton, macroalgae, microalgae, low-trophic organisms and hetero- and chemoautotrophic organisms. Where possible, the biochemical contents of lipids, proteins, and omega-3 fatty acids (EPA and DHA) have been included. The report is based on relevant literature and public statistics.

Abbreviations:

DW = Dry weigh

RRM = Residual raw materials

WW = Wet weight

5.2 Background

Norwegian feed systems today are heavily dependent on imports of both marine and vegetable ingredients, both for livestock and aquaculture production. Norway imports 95 % of the feed ingredients for aquaculture production and almost all the proteins in concentrates feed (Benjamin Hernes Vogl, 2022). There is a high need for proteins produced in Norway both for feed to aquaculture and livestock production in Norway. Feed for livestock consisted of 39 % imported ingredients in 2020 (Landbruksdirektoratet, 2021).

For aquaculture production, there is a need for novel feed resources to sustain required level of omega-3 fatty acids and proteins for a growing production of salmon in Norway. Salmon feed today consist of mostly plant-based ingredients, since the amount of marine fish resources are limited due to over-exploitation of the world's fish stocks. There are, however, several other marine resources including algae, mesopelagic fish, species at low-trophic levels and other that have not yet been fully utilized. Table 17 summarizes the total production of marine resources in Norway and globally, as well as the harvested number of resources. These potential resources can increase the amount of feed produced Norway for aquaculture and livestock production.

Table 17: Potential marine feed resources in Norway and globally.

Marine resource		Stock and/or estimated annual wild production	Aquaculture in Norway	Wild-caught in Norway	Globally (harvested and/or cultivated)
Fish	Whitefish	-	-	697 274 tonnes (2021)[2]	179 million[1] (2018)
	Pelagic fish	-	-	1 329 217 tonnes (2021)[2]	~7 million tonnes (Coast of South America)[3]
	Mesopelagic fish	1000-10 000 million tonnes (expected to be in the North-Atlantic)[4,5]	-	-	Iceland: 46 000 tonnes (2009) and 18 000 tonnes (2010) [5]
Zooplankton	*Calanus finmarchicus*	30 million tonnes – 200-300 million tonnes annual production	-	~1000 tonnes annually[3]	-
	Northern Krill	300 million tonnes annual production	-	Not harvested in Norway	-
Residual raw materials	Whitefish	-	-	292 000 tons[7]	-
	Pelagic	-	-	236 000 tons[7]	-
	Aquaculture	-	-	478 000 tons[7]	-
	Shellfish	-	-	13 000 tons[7]	-
Macroalgae	Macroalgae	80 million WW = 12 million dry weight[3]	336 000 tonnes WW[8]	150-170 000 tonnes (2018-2021)[2]	30 million tonnes WW[9]
	L. hyperborea (Stortare)	59 million tonnes annually[3]	-	130-180 000 tonnes annually[3,6]	-
	A. nodosum (Grisetang)	900 000 tonnes annually[3]	-	20 000 tonnes annually[3]	-
Microalgae	Microalgae	-	-	-	30 – 40 000 tonnes DW[10,11]
Low-trophic organisms	*Annelids*	-	-	-	120 000 tons[12]
	Gammaridea	-	-	-	-
	Tunicates	-	-	-	-
	Mussels	-	2000 tons[13]	-	1.5-2 million tons[14]

Sources: 1: FAO (2020), 2: Fiskeridirektoratet (2021a), 3:Fiskeridirektoratet (2021a), 4: Gjøsæter & Kawaguchi (1980), 5: Standal and Grimaldo (2020), 6: Vea and Ask (2011), 7: Myhre et al. (2021), 8: Fiskeridirektoratet (2021b), 9: Ferdouse et al. (2018), 10: FAO (2018), 11: Benemann (2013), 12: Watson et al. (2017), 13: Havforskningsinstituttet (2019), 14: Naik and Hayes (2019)

5.3 Fish

In 2018, the world total fish production was 179 million tonnes (FAO, 2020). 54 % comes from fisheries, while aquaculture accounts for 46 % of the total fish production. 22 million tonnes of this went to the production of fishmeal and fish oil, and 87 % to human consumption. In 2017, only 6.2 % of the fish harvested were from stocks not fully or exploited. The total amount of harvested fish, crustaceans and macroalgae production have been around 2.2-2.6 million tonnes the last 10 years (Fiskeridirektoratet, 2021a). In 2021, 2.1 million tonnes of fish were caught by Norwegian fishing vessels. This catch constitutes pelagic fish, whitefish, flatfish and cartilaginous fish. The catch is dominated by pelagic (approximately 1.3 million tons) and whitefish (approximately 700 000 tons). According to Almås et al. (2020) mesopelagic fish could also become an important ingredient in the future. However, there are great uncertainties related to the stock volumes and efficient fisheries would require development and upscaling(Grimaldo et al., 2020; Standal and Grimaldo, 2021). The challenges lie within management, detection, harvest methods, catch method and processing. Pelagic fish is easier to catch, manage and process than the mesopelagic fish, but stocks here already fully exploited.

5.3.1 Whitefish

The catch of whitefish, including cod, pollock and haddock, was 697 274 tonnes in 2021 (Fiskeridirektoratet, 2021a). The catch volumes have been between 650 000- 750 000 tonnes the last ten years. Whitefish is mostly consumed by humans, and not used primarily as a feed ingredient. However, rest raw materials from whitefish can be used as input in fish feed production. Use of rest raw materials from fisheries and aquaculture is covered in section 5.9.

5.3.2 Pelagic fish

The catch of pelagic fish was just under 1.3 million tonnes in 2021 (Fiskeridirektoratet, 2021a). The annual catch volumes of pelagic fish have been quite stable around 1.3-1.4 million tonnes the last ten years. Species include herring, mackerel, capelin, and blue whiting. Traditionally pelagic fish has been a valuable resource of protein, EPA, and DHA (Omega-3 fatty acids) but the use of fishmeal and fish oil in the feed of aquaculture has increased. The number of feeding yield from pelagic fish is also not expected to increase according to Almås et al. (2020).

Globally, the annual catch volume varies, but around 7 million tonnes of anchoveta (*Engraulis ringens*) can be harvested outside of the coast of South America (FAO, 2020). Many pelagic species go directly to human consumption. The smaller species are often used to produce fishmeal and oil. From 1985, the total catch of pelagic fish on Norwegian vessels varied between 1-2 million tons (Almås et al., 2020). A lot of the pelagic fish was used for reduction, to produce fish meal and fish oil for fish feed production. However, the price of pelagic fish has increased, and a significant amount is now going directly to human consumption. Therefore, it is not expected that the volume of pelagic fish used for feed production will increase in the upcoming years, even though the residual raw material can be used in the production of both fishmeal and oil.

In 2016, marine proteins from fishmeal and oil production accounted for 14.5 %, equivalent to 190 000 tons. Around 115 000 tonnes of this were produced from catches in the North-Atlantic. Marine oil (10.4 %), accounted for about 126 000 tons, and about half of it came from fish that was caught in the North Atlantic. With the assumption that pelagic fish species has a fat content on 8-14 % and a protein content on 16-22 % (Brækkan, 1976), around 50-65 % of the pelagic fish that are being caught from Norwegian vessels goes to salmon feed.

Figure 10: Blue whiting. Photo by Susan Smith, https://www.flickr.com/photos/cellphonesusie/3951143853/ (CC BY-NC-ND 2.0)

Figure 11: Herring. Photo by Robert Aguilar, https://www.marylandbiodiversity.com/view/5150 (CC BY-NC).

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Figure 12: Atlantic mackerel. Photo by Titus Tscharntke https://commons.wikimedia.org/wiki/File:Atlantic_mackerel_fish.jpg (CC BY-SA)

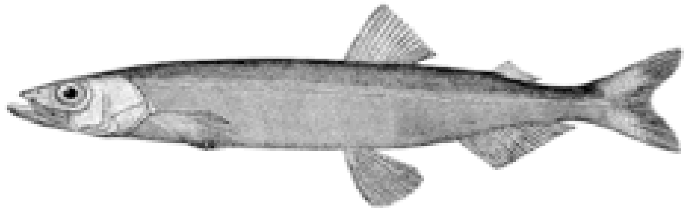

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Figure 13: Capelin. https://commons.wikimedia.org/wiki/File:Mallotus_villosus.gif, public domain. Original in Evermann, B.W. and E.L. Goldsborough, 1907. The fishes of Alaska.

5.3.3 Mesopelagic fish

A fish is considered mesopelagic if it lives in depth between 200 and 1000 meters. There has not been registered a lot of commercial exploitation, but catches have been registered in South-Africa, West-Africa, South-Eastern Australia, in the Gulf outside of Oman and South for Iceland. In Iceland it was caught around 40 000 and 18 000 tonnes of mesopelagic fish (*Marulicus muelleri*) in 2009 and 2010 (Standal and Grimaldo, 2020). There is a lot of uncertainty around the actual volumes of mesopelagic fisheries, as there are great variations of the estimations between 1000 to 10 000 million tonnes (Gjøsæter and Kawaguchi, 1980; Irigoien et al., 2014; Proud et al., 2019). A large portion of the stock is expected to be in the North-Atlantic, within the Norwegian economic zone. However, there is a lack of both biological and economical knowledge about this resource.

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Figure 14: Fully grown Maurolicus muelleri. https://namu.moe/w/%EC%95%A8%ED%89%81%EC%9D%B4 (CC BY-SA-NC)

An increase of the supply of omega-3 fatty acids and proteins is needed to increase aquaculture production. There is currently a focus in Norway to establish a value chain for harvesting, landing, and processing of mesopelagic fish, to meet this demand, such as the research project SFI Harvest ("SFI Harvest," n.d.). The aim is to make products for fish feed, consumption, or marine ingredients of higher value. Mesopelagic fish, especially Silvery lightfish (*M. muellery)* and northern lanternfish (*Benthosema glacie*) are resources that can be harvested and used for fish feed. Salmon herring has a biochemical composition that makes it coveted for this purpose (Brækkan, 1976).

The results after the trial fishing of salmon herring in 2018 was 17 tons, and 2000 tonnes in 2019. However, there are some challenges with establishing commercial harvesting and the use of mesopelagic fish in Norway, which is linked to management, detection, harvesting methods, and processing of catch. Fishing companies can now apply for licenses with a ten years duration for trial fishing of mesopelagic fish (Leif Grimsmo, 2022). Some species also contains high levels of wax ester, such as *Myctophidae* which contains 70-80 % wax ester. This can be especially challenging if the fish is used as a starting feed for salmon larvae.

Table 18 shows the biochemical content of *M. muellery*. An estimated annual catch on 1 million ton of *M. muellery* (wet weight) can give 150 thousand tonnes proteins and around 20 thousand tonnes EPA + DHA. This is equivalent to 7-8 % of protein and about 15 % of EPA and DHA that is needed in 2050. An annual catch on 1 million tonnes of salmon herring is a significant volume, equivalent to near half of today's Norwegian catch volume (Fiskeridirektoratet, 2021a).

Table 18: Biochemical composition of meal from *Maurolicus muellery* (Brækkan, 1976).

Component	*Maurolicus muellery*
Water	68.2-76 %
Lipids (extracted) of WW	4.3 – 15.8 %
Protein	13.5-16.5 %
N-3 fatty acids avg. of total lipids	24.5 %
EPA + DHA avg. of total lipids	22 %

5.4 Zooplankton

Zooplankton can also be a source of proteins and omega-3 acids in salmon feed. The annual production of zooplankton in Norwegian oceans are about 1 billion tons, and *Calanus finmarchicus* (a species of copepods and a zooplankton) and northern krill are the most important species (Almås et al., 2020).

It is estimated that the annual production *Calanus finmarchicus* in the North Atlantic is 200-300 million tonnes or more (Aksnes and Blindheim, 1996). The annual production of northern krill is estimated to 300 million tonnes (Havforskninsinstituttet, 2019b). Based on measurement in the Barents Sea from 1988-2017, the biomass (dry weight) of zooplankton bigger than 2mm, is five times as large as zooplankton smaller than 2mm (Norwegian Polar Institute, 2020). This leads to the estimation of a total production of zooplankton in Norwegian oceans to be around 2-4 billion tonnes per year (Almås et al., 2020). However, the harvest of zooplankton is challenging, because there is little knowledge of where the zooplankton exists in the deepest concentrations, and the best way to catch them in a way that is financially profitable.

5.4.1 Calanus finmarchicus

Calanus finmarchicus is considered the biggest, harvestable species in the Norwegian Ocean and is a potential source to omega-3 acids in feed to salmon (Almås et al., 2020). The estimations of standing biomass and biological production vary, depending on the area. But standing biomass is around 30 million tonnes or higher, while annual production is estimated at 2-300 million tonnes or more (Aksnes and Blindheim, 1996).

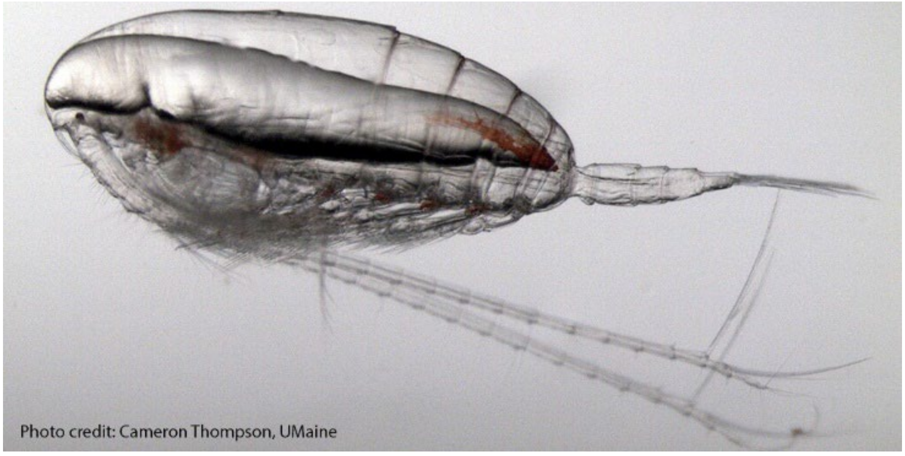

Figure 15: Calanus finmarchicus. Photo by: Cameron Thompson, UMaine. (CC BY-SA)

Fish oil consists of a high level of triglycerides, and krill oil is known for a high content of phospholipids. Calanus oil consists of a significant amount of wax ester. Studies shows that Calanus oil can be added to fish feed (Pedersen et al., 2014). One study found that Calanus oil could replace 30 % of the lipids in the salmon feed without any negative effect, while a higher amount than 30 % lead to reduced growth in the salmon, probably due to the high wax ester content in Calanus oil (Bogevik et al., 2011). The biochemical composition is presented in Table 19.

Table 19: Biochemical composition of C. finmarchicus.

Component	*C. finmarchicus*
Water	72.5 % of WW
Protein	16.9 % of WW
Lipids	3.9 % of WW
Ash	2.0 % of WW
Omega-3 fatty acids	13-33 % of total lipids
EPA+DHA	8.5-13.6 % of total lipids

Source: Pedersen et al.(2014)

In March 2019, a management plan opened for catches of *C. finmarchicus* up to 254 000 tonnes (Nærings- og fiskeridepartementet, 2019). Of this total quota, 246 000 tonnes must be caught outside the 1000 meters depth code. Up to 3000 tonnes can be fished within this depth quota. To get one of the 3000 tonnes quota, you need a separate, limited permit, and there are only ten of those where eight have already been assigned (Fiskeridirektoratet, 2020). There are no limits in number of permits for fishing outside the 1000 meters quota, where five is already allotted. The ban against catching krill and other zooplankton in the Atlantic ocean is still maintained (Fiskeridirektoratet, 2019). There is a need for further development within the technology to increase harvest outside 1000 meters depth quota.

Catch volume in 2022 only amounted to 1336 tonnes (Fiskeridirektoratet, 2021a) and most went to high-value products (Almås et al., 2020). Calanus oil is used for high-value omega-3 products for human consumption, while the protein fraction (meal/hydrolyzate) goes to high-value feed ingredients (mainly attractive in starter feed / shrimp farming). The raw material is frozen on board, and further processing into oil and protein fractions takes place on land.

Potential for *C. finmarchicus* as a source to protein and EPA and DHA in fish feed. An estimated annually catch on 1 million tonnes *C. finmarchicus* (wet weight) can give around 170 thousand tonnes proteins and about 4 thousand tonnes EPA + DHA, equivalent to 8-9 % of the protein requirement and about 3 % of the requirement for EPA and DHA to fish farming in 2050 (Almås et al., 2020). A million tonnes are a significant catch volume and is about half of the size of Norwegian catch of fish today.

5.4.2 Northern krill

Northern krill is a potential source to protein and omega-3 acids in salmon feed. However, it is currently illegal with commercial catch of northern krill in the Norwegian oceans. Annual production of krill in the Norwegian Ocean and the Barents Sea is estimated to be around 287 million tonnes (Havforskninsinstituttet, 2019b). However, this number is uncertain as the fishing gears used for the calculation are not optimal to measure the number of krill (Almås et al., 2020).

Figure 16: Northern krill. Photo by Uwe Kils licensed under CC BY-SA. https://en.wikipedia.org/wiki/Northern_krill#/media/File:Meganyctiphanes_norvegica.jpg.

The nutritional composition of krill varies throughout the year (Sæther, 1986). If, on assumption, the average dry matter concentration in krill is 22 %, and 40 % of the dry matter is proteins, 880 000 tonnes krill (wet weight) would have to be harvested to obtain 100 000 tonnes protein. This is equivalent to 5 % of the estimated need for fish farming in 2050. This catch-volume corresponds to 0.3 % if the estimated annual production of northern krill (287 million tons), or around 3 % of the total stock (Almås et al, 2020). At the same time, the harvested amount of EPA + DHA would be 15-20 000 tons, which is about 10-15 % of the estimated required amount for these kinds of fat acids in 2050. The commercial capture and processing of krill is more imminent than *C. finmarchicus*, but it cannot be done since it from 2006 became illegal to fish for zooplankton. Table 20 shows the biochemical content in two species of Northern krill.

Table 20: Biochemical composition of Northern krill (Sæther, 1986).

Component	*Thysanoessa spp.*	*M. norvegica*
Protein	32-50 % of DW	32-50 % of DW
Amino acids	5-10 % of DW	5-10 % of DW
Lipids	12-50 % of DW	12-50 % of DW
EPA	5-38 % of total lipids	3-17 % of total lipids
DHA	1-32 % of total lipids	4-29 % of total lipids

5.5 Macroalgae

The harvested volume of macroalge in Norway in 2021 was 159 804 tonnes (Fiskeridirektoratet, 2021b). The volume has varied between 140 000 - 170 000 tonnes the last ten years. Seaweeds, such as *Ascophyllum nodosum* (in Norwegian Grisetang) has been used for feed for a long time as it has been available in the tidal zone on the shore (Almås et al., 2020). Kelp represents a much larger biomass than seaweeds along the Norwegian coast. However, the large kelp forests are important for the coastal ecosystem, where they function as breeding grounds, shelters, and food vessels for the many different pelagic (free-living) and benthic (sedentary) organisms that live there (Frangoudes, 2011). The annual production of kelp, seaweeds and eelgrass along the Norwegian coast is more than 80 million tonnes (wet weight), corresponding to 12 million tonnes dry weight (Almås et al., 2020).

Macroalgae as an ingredient in salmon feed is a potential source for protein but have a lower EPA and DHA content. The share of proteins from macroalgae varies a lot from less than 1 % till 48 %, the usual amount is between 10-30 % as presented in Table 21. Macroalgae is still valued as a high-quality source of protein and works as an added small proportion of the feed. The biochemical composition of the most common macroalgae species in Norway are presented in Table 21.

Table 21: Biochemical composition of most common macroalgae species in Norway.

Composition	*S. latissima* (g/100 g DW)	*L. digitata* (g/100 g DW)	*l. hyperborean* (g/100 g DW)	*A. esculenta* (g/100 g DW)	*A. nodosum* (g/100 g DW)
Protein	5-101	5-81	4-81	9-19-121	3-155
Lipids	0.7-3.33	0.94	0.3-0.82/1.14	1.54	3.66
N-3 fatty acids	0.14-0.283	0.34	0.01-0.062/0.24	0.34	-
DHA + EPA	0.07-0.143	0.14	0.001-0.0062/0.064	0.074	7.2 %6 (of total fatty acids)

Sources: 1: Schiener et al. (2015), 2: Foseid et al. (2017), 3: Marinho et al. (2015), 4: Mæhre et al. (2014), 5: Fleurence (1999), 6: Lorenzo et al. (2017).

5.5.1 L. hyperborea

Annually, 130-180 000 tonnes *of L. hyperborea* (stortare) are harvested on the stretch between Rogaland and Trøndelag using trawlers (Vea and Ask, 2011). The harvest is regulated through management plans from each county and the same area can only be harvested every fifth year to ensure regrowth (Norderhaug et al., 2020). This rotation system is important for stability in the kelp forest, and the trawlers take no more than 10-15 % of the available biomass in each field, even though they are allowed to harvest all the biomass in that year's harvesting areas.

The population and trawling activity of *L. hyperborea* are evaluated and controlled by the Institute of Marine Research to investigate the effects on the ecosystem in and around the kelp forests. Environmental protection organizations believe that kelp trawling has a negative effect on the *L. hyperborea* forest ecosystem and especially on seabirds that feed on the fish there. The Institute of Marine Research has evaluated the fish stock and found that the species composition was the same before and after trawling. Despite this, some harvesting fields have been declared marine protected areas and restrictions have been placed on trawling activity (Frangoudes, 2011). *L. hyperborea* is used in the production of alginate (Almås et al., 2020). The Norwegian production accounts for 25 % of the world's alginate production.

5.5.2 A. nodosum

Twenty thousand tonnes of *A. nodosum* (grisetang) are harvested annually (Almås et al., 2020). This results in about 6000 tonnes dry weight and 180-900 tonnes protein. This is a small portion compared to an estimated need of 2 million tonnes of protein in 2050. Similarly, 20 000 tonnes of *A. nodosum* may provide about 15 tonnes of EPA, which is small compared to the need of 135 tonnes of EPA/DHA in 2050.

A. nodosum is also cut with 10 centimeters left to regrow when harvested. *A. nodosum* is reduced to seaweed meal that is mixed in feed for hogs, cattle, poultry, sheep, fish, horses and domestic animals (Almås et al., 2020). *A. nodosum* is also used as fertilizer and soil improver.

Figure 17. A. nodusum(grisetang). Foto by Richard Droker https://www.flickr.com/photos/29750062@N06/43480491274 (CC BY-NC-ND 2.0)

5.5.3 Wild-growing seaweeds and kelp used for fish feed

Almås et al. (2020) estimates that a yield of 5-10 thousand tonnes of protein per million tonnes of kelp (wet weight) may be possible. This means that to produce 100 000 tonnes of protein (5 % of the estimated protein requirement in 2050), there must be harvested 10-20 million tonnes of kelp (wet weight). This corresponds to 12-25 % of today's wild-growing production and would involve a dramatically increased harvest compared to the current situation. Currently, only 0.3 % of the annual production of kelp is harvested under strict regulations and monitoring, and it is not desirable to increase the harvest of wild kelp for other uses than the existing industry, which limits its potential as a feed ingredient.

Almås et al. (2020) proposes three alternatives to increase the use of kelp and seaweed in fish feed production:

- Utilize the harvested kelp better by using is as a source of protein as well as alginate. However, the current process is unsuitable for harvesting protein as a by-product, and in any case the amount of protein is limited, 500-700 tons.
- Feeding insect larvae on the kelp residues is another alternative, but experiments have shown that kelp, due to the high salt content, can only be added in limited quantities in the feed to insect larvae.
- Special feed based on components in kelp and/or seaweed that provide better digestion and thus feed utilization or have other desired properties beyond the protein content. The inclusion level in feed will then be significantly lower than when tang and tare are used as a protein source, only 0.1-1 %. But even an addition of only 0.1 % dry weight of kelp/seaweed in 1 million tonnes of feed requires the harvesting of 50-100 thousand tonnes of wet weight of kelp/seaweeds. This is a significant increase compared to today's harvest of 150-200 thousand tons. The conclusion is therefore that large-scale utilization of seaweed and kelp for fish feed requires cultivation.

5.5.4 Macroalgae cultivation in Norway

Cultivation of macroalgae has a long tradition in several countries in Asia. The global production of macroalgae is 30 million tonnes wet weight macroalgae (FAO, 2018). This equals to approximately 27 % of all marine aquaculture (Ferdouse et al., 2018). Cultivation of macroalgae is still at developing stage in Norway, even though the number of producers has increased the last years. There are currently 520 licenses for cultivating macroalgae in Norway (Fiskeridirektoratet, 2021b). The first licenses were given in 2014. In 2020, 27 companies 336 000 tonnes to a value on 8.6 million NOK.

The growth depends on good light conditions, nutrients, high salinity, and low temperatures. In Norway, the most suitable areas for cultivating macroalgae are outside the coast, where the Atlantic currents can transport nutrients (Almås et al., 2020). Cultivating macroalgae in proximity of a salmon aquaculture farm in a IMTA system, can also increase the growth, since the nutrients in the waste streams of the salmon functions as fertilizers for the macroalgae (Broch et al., 2013; Førde et al., 2016; Handå et al., 2013). The Norwegian Seaweed Technology Center at SINTEF Ocean aims to develop macroalgae to a new, large industry ("Norwegian Seaweed Technology Center," n.d.).

Ulva lactuca is a promising species of macroalgae and can be grown in RAS systems in the wastewater of fish or other species (Almås et al., 2020). *U. lactuca* can sustain higher variations in salinity, temperature, and light. Cultivating the macroalgae in RAS systems have several benefits as the macroalgae can also function as a biofilter in the system. Experiments have shown that cultivating *U. lactuca* on waste water from fish contains 2-4 more protein than *U. lactuca* grown in normal sea-water (Wang et al., 2014).

5.6 Microalgae

Microalgae is a potential source of omega-3 fatty acids and protein in feed production. Microalgae is phototropic organism. They use pigments (chlorophylls, carotenoid and phycobilin) to harvest light energy and transform it into chemical energy through photosynthesis where carbon and water is transformed to oxygen and sugar (Enzing et al., 2014). They also require macronutrients, such as NH_4/NO_3 and PO_4.

The main challenge of producing microalgae is suboptimal light conditions (Martínez et al., 2018; Ooms et al., 2016). Microalgae is an important source of feed for aquatic animals, and it is mandatory to have microalgae as feed for living feed (copepods) and fish larvae that cannot eat feed directly. The content of protein and N-3 fatty acids varies from the different species of microalgae. For *Nannochloropsis spp.* the EPA content can be 25-28 % of total lipids, whereas in *Cryptophyceae* the amount of EPA and DHA is around 12-21 % of total lipids (Nymark et al., 2016; Patel et al., 2020; Peltomaa et al., 2017). The protein content can be as high as 50 % of the dry weight in most species of microalgae.

There is a growing interest in the production of microalgae for human consumption and animal feed, both in aquaculture and feed for terrestrial animals (Caporgno and Mathys, 2018). The nutritional value depends on the amino acid profile of the proteins. An advantage of marine microalgae is an amino acid profile that is beneficial to aquatic organisms. There is a need for more knowledge about the properties and nutritional value of biomass for animals, digestibility, and possible anti-nutrients.

Sustainable production of microalgae using seawater, process water or wastewater, and on areas that are not suitable for agriculture, has renewed interest in microalgae production (Almås et al., 2020). In recent years, interest has increased in connecting microalgae production to recycling aquaculture facilities (RAS) in fish farming or aquaponics, both as a water treatment measure (removal of N before the water is released) and in producing microalgae as feed for e.g., shrimp in farming. There can also be a lot to gain from combining light-guided production (autotrophy) with partially heterotrophic production (mixotrophy), e.g., build up biomass with light energy to a point where it no longer increases due to dense culture, and then add organic carbon to increase the growth/storage of desired compounds.

This is possible because microalgae belong to different evolutionary branches and have different properties, some are strictly autotrophic while others can switch between different modes. The project AlgScaleUp aims to achieve sustainable production of microalgae for salmon feed by utilizing surplus heat and CO_2 emissions from the ferrosilium plant Finnfjord ("AlgScaleUp," 2022).

According to the FAO, the global production of cultured microalgae, including cyanobacteria, in 2018 was at least 87 thousand tonnes (probably wet weight), but the reporting of cultivation of microalgae was incomplete and figures were missing for key countries such as Israel, India, Japan, Australia and the United States (FAO, 2018). More than 99 % of the reported volume was produced in China. Another sources states that the global industrial production of phototrophic microalgae, including cyanobacteria, in the early 2010s was about 15 thousand tonnes dry weight per year (Benemann, 2013). This amount did probably not include Chinese production. Combining these sources, an estimation of at least 30-40 thousand tonnes dry weight per year is possible globally (Almås et al., 2020).

Production of microalgae for feed or as a source of EPA/DHA will require a production scale far above the current level. Production of 100 thousand tonnes of microalgae protein, which corresponds to 5 % of the estimated protein requirement in 2050, will require about 200 thousand tonnes of dry weight microalgae per year, or 0.6-0.8 million tonnes of wet weight microalgae (Almås et al., 2020). In the production of 7 thousand tonnes of EPA/DHA, corresponding to the estimated requirements for 2050, using 60-120 thousand tonnes (dry weight) phototrophic microalgae result in you 20-60 thousand tonnes of protein.

Production of new ingredients based on microalgae can also be limited by legal regulations (Almås et al., 2020). The list of approved microalgae is not long. The microalgae *Chlorella*, *Dunaliella* and *Haemato* are on the list together with the cyanobacterium *Arthrospira*. In recent years, a few more species have been added to the list, such as *Isochrysis*, *Nannochloropsis* and *Phaeodactylum*. This places restrictions on the possibilities of utilizing the great diversity of microalgae to produce new foods, but the extent to which this will also apply to products is more unclear.

5.7 Hetero- and chemoautotrophic microorganisms – single-cell protein and single-cell oil

Hetero- and chemoautotrophic (non-phototrophic) microorganisms (bacteria, yeast, fungi, etc.) can be a source of protein in feed. Most microbial oils are like vegetable oils in terms of fatty acid composition. Thraustochytrids, known as a heterotrophic microalga, is also a source of the omega-3 fatty acids DHA and EPA. Thraustochytrids belong to a completely different phylum then autotrophic microalgae, and are only distantly related to algae (Marchan et al., 2018). Thraustochytrids are eukaryotic, obligate marine and heterotrophic, and can accumulate more than 50 % oil by dry weight, with more than 30 % DHA (Aasen et al., 2016). Some strains also produce smaller amounts of EPA.

The cultivation of bacteria, yeast, fungi and thraustochytrids to produce single-cell protein and/or single-cell oil normally takes place in closed stirring tanks called bioreactors (Almås et al., 2020). The current technological level to produce hetero- and chemoautotrophic microorganisms depends on the product and the processing. The production of bacteria, fungi and other micro-organisms heterotrophically with sugar as a carbon and energy source is a well-established technology. Heterotrophic production based on several other substrates such as methanol and methane still have technological challenges, even though the production takes place on an industrial scale. Autotrophic production of bacteria with CO_2 as a carbon source and energy sources such as hydrogen (H_2) or hydrogen sulfide (H_2S) still requires considerable research and development to be realized on an industrial scale. The production of single-cell protein is an established technology, while the production of EPA/DHA-rich oils varies from established industrial processes based on thraustochytrids to laboratory processes based on several other microorganisms.

Microorganisms normally contain about 50 % protein dry weight. Depending on the type of microorganism, single-cell protein can replace from 20-55 % of the protein in feed for fish and shrimp (Jones et al., 2020).

5.7.1 Sugar as energy and carbon source

Traditionally, the source of sugar in most fermentation processes come from glucose produced by hydrolysis of starch, most often from corn, and sucrose from sugar cane and sugar beet (Almås et al., 2020). The use of these raw materials is potentially limited for feed production, as they can be used directly for human consumption and their cultivation area can also be used for food production. The fermentation processes with sucrose and glucose as a carbon source are established technology. More than 5 million tonnes of amino acids are currently produced annually by fermentation, for use in food and feed. The limiting factor of protein and omega-3 yield from fermentation processes is the supply of sugar as substrate. The problem here is that the price of protein produced by microbial fermentation is too high compared to protein from other sources. Microbial oil rich in omega-3 fatty acids is also currently too expensive in competition with fish oil.

Sugars from lignocellulose from wood and straw consists of cellulose, hemicellulose and lignin. In order to utilize sugar from cellulose as a carbon source for fermentation, lignin must be removed and the cellulose fibers made available for enzymatic hydrolysis to glucose. This requires mechanical, thermal and/or chemical pre-treatment. Efficient processes for converting lignocellulose into fermentable sugars have been an important field of research for the past 10-15 years, but primarily with the aim of producing biofuel. Several different pre-treatment technologies have been developed, with and without the inclusion of the hemicellulose. In general, wood is more resistant and requires stronger treatment than straw, and softwood is more demanding than hardwood, i.e., the dominant Norwegian wood species, spruce and pine, are the most challenging.

5.7.2 Single cell protein

Single-cell protein for feed based on the fermentation of sugar is mainly produced with yeast. Bacteria can also be used, but due to a higher content of nucleic acids in bacteria, yeast is preferred on a substrate where yeast grows well. Fermentation of sugar with yeast is already an established technology. The first processes were developed in the 1960s. Around 580 000 tonnes of cell mass (dry weight) is produced globally, and approximately 215 000 tonnes is produced in Europe (Skogli et al., 2019). The protein content is between 50-55 % protein, which corresponds to 300 000 and 110 000 tonnes of protein respectively.

The most important yeast species produced specifically for applications in feed are *Kluyveromyces marxianus* and *Candida utilis* ("Torula"), in addition to *Saccharomyces cerevisae*, which is produced as a by-product in the brewing industry. Yeast protein has a high content of all essential amino acids (Øverland and Skrede, 2016). The SFI "Foods of Norway" includes a focus on the production of single-cell protein and characterization of properties as a feed ingredient ("Foods of Norway," 2017). The R&D challenge in the area is primarily to achieve more efficient production processes so that the price of the protein can be reduced. The most important thing, however, will be a lower sugar price.

5.7.3 Thraustochytrids

Commercial production of Thraustochytrids for human consumption (dietary supplements) has been going on for more than 20 years (Almås et al., 2020). Production of DHA by fermentation of thraustochytrids is a well-established technology. In industrial production, strains of the genera *Schizochytrium* and *Aurantiochytrium* are used. The production costs are still too high for the products to be used to a significant extent in feed, but several Norwegian feed producers mix in smaller quantities. DHA makes up a minimum of 30 % of the fatty acids in the production organisms, while the content of

EPA is normally less than 5 %. However, VeraMaris (DSM/Martek) has a strain that produces 12-15 % EPA, out of a total of 50 % EPA + DHA ("VeraMaris," n.d.).

The oil in fat-accumulating thraustochytrids is triglyceride. This can be relatively easily extracted and can be added to the feed in the same way as fish oil by vacuum coating the pellet after extrusion. An alternative is to use the entire cell mass, which will provide protein in addition to the oil. Whole cells typically contain 50-60 % fat and 20-25 % protein of total dry matter. Depending on the quantities used in the feed, this may require changes to the processing at the feed manufacturers.

Production of DHA/EPA-rich oils by fermentation has greater potential for productivity improvement than production of yeast protein. Both production speed, DHA proportion of the oil and yield on a sugar basis can probably be increased by process optimization, and possibly further by genetic modification. By genetic modification, it may also be possible to achieve EPA/DHA production in yeast and bacteria.

5.7.4 Natural gas (methane) as carbon source

Production of bacteria (single-cell protein) with methane (CH4) as a carbon source is an established technology, although it can certainly be improved. The access to resources is almost infinite in a feed context. In 2018, Norway exported 114 billion Sm^3 (standard m^3) of natural gas, which in theory, could have been used to produce 91-114 million tonnes of bacteria corresponding to 46-57 million tonnes of protein (Almås et al., 2020). The challenge in the production of single-cell protein based on methane is to achieve an economically profitable process that can compete with fishmeal on price.

A disadvantage of natural gas as a substrate to produce single-cell protein is that ultimately the carbon will be released into the atmosphere and contribute to the fossil-based emissions of the greenhouse gas CO2. Methane is also a powerful greenhouse gas, and it is hardly possible to run a fermentation process based on methane without small amounts of methane escaping into the atmosphere. An alternative is to use methane from biogas as substrate, but then the volume of available substrate will be several orders of magnitude lower.

5.7.5 CO_2 as a carbon source

CO_2 is an inexhaustible source of carbon to produce both lipids and protein with the help of plants and microorganisms. CO_2 can and is harvested directly from the air but can also be concentrated from the air using "direct air capture" (DAC) technology, or obtained from the exhaust gas in combustion processes, from other CO_2 -rich industrial exhaust gas streams or from biogas plants (Almås et al., 2020). Autotrophic bacterial processes could theoretically (at 100 % utilization of CO_2.) produce 0.57 tonnes of biomass with 0.28 tonnes of protein per tonne CO_2. The challenge here is not access to a carbon source, but access to energy for micro -the organisms, such as hydrogen.

To build up organic molecules from CO_2, energy is required which can come from sunlight, from the oxidation of reduced inorganic compounds, or hydrogen. The processes and energy sources described in the sections below are all technically possible but challenging to achieve economically profitable.

5.7.5.1 Chemolitotrophic bacteria – H_2S as energy source and CO_2 as C source

Chemolitotrophic bacteria can use inorganic reduced compounds as an energy source and CO_2 as a carbon source. The only inorganic reduced compound available in such quantities that it can provide a basis for the industrial production of single-cell protein is hydrogen sulphide (H_2S)(Almås et al., 2020). This is a very toxic gas that can occur in relatively large quantities in some oil and gas wells, and which must be taken care of at the production site. The U.S. produces approx. 10 million tonnes of elemental sulfur per year (James L Gaddy and Ching-Whan Ko, 2009).

Microbial oxidation of H_2S can, depending on the type of bacteria and process conditions, either stop at elemental sulphur, or go all the way to sulphate. Elemental sulfur has advantages in terms of disposal, but the energy yield for the bacteria in case of complete oxidation to sulfate is twice as high per molecule of H_2S oxidized.

5.7.5.2 Flammable gas bacteria – H_2 as energy source and CO_2 as C source

These are aerobic bacteria (known as Knallgas bacteria) use hydrogen (H_2) as an energy source and CO_2 as a carbon source and must be grown in the presence of both H_2 and O_2 (Almås et al., 2020). The production therefore requires significant safety measures to minimize the risk of explosion. A bacterium that has been extensively studied due to its good growth characteristics under these conditions, is *Cupriavidus necator* (formerly known as *Ralstonia eutropha*). The bacterium was already seen in the 1960s as a possible candidate to produce single-cell protein based on CO_2 and H_2 produced by electrolysis of water (Foster and Litchfield, 1964), and in the 1970s *C. necator* was developed as a source of single-cell protein both for human use and in feed. The maximum yield of hydrogen is 3.3-3.6 g dry weight bacteria/g H_2, but in fermenter studies the yield was significantly lower due to large losses of H2 in the exhaust gas (Reed et al., 2017). *C. necator* can also grow on syngas ($CO + CO_2 + H_2$). *C. necator* can accumulate large amounts of intracellular poly-β-hydroksy-butyrat (PHB) and other polyhydroxyalkanoates (PHA). These are indigestible in mammals and pass almost untouched through the digestive system (Ong et al., 2018).

A possible process to produce single-cell protein based on *C. necator* requires either fermentation conditions that minimize the formation of PHA or mutants that have lost the ability to produce PHA. Studies in recent years have focused on the production of single-cell oil for conversion to biodiesel. Here, genetically modified strains that accumulate lipid rather than PHA have been a target (Reed et al., 2017). The production of single-cell protein based on *C. necator* and H_2 produced by hydrolysis of water is currently not a profitable process.

5.7.5.3 Synthesis gas as raw material

Synthesis gas (syngas: $CO + CO_2 + H_2$) can be produced from biomass such as wood (lignocellulose) by gasification of the biomass. The goal of the syngas process is primarily chemical transformation of the gases into various products, but the energy-rich gas can also be used in microbial gas fermentations based on chemoautotrophic, anaerobic bacteria that use H_2 and CO as an energy source, and CO and CO_2 as a carbon source, and form products such as acetic acid (acetate) or ethanol (Phillips et al., 2017). In anaerobic fermentation processes, the yield of biomass per gram of energy source is limited and in practice will only become a by-product. However, if the processes become larger in terms of volume, e.g., ethanol as biofuel, the surplus of cellular mass could be significant.

Microbial fermentation of syngas has particularly focused on the production of ethanol as a biofuel. Here, gasification + fermentation of the gases is an alternative to hydrolysis of lignocellulose + fermentation of the sugars. An advantage of processing into syngas is that the carbon in lignin also becomes available as a substrate (Phillips et al., 2017).

5.8 Cultivation of low-trophic organisms

Low-trophic organisms can be a source of both protein and omega-3 fatty acids (Almås et al., 2020). Low-trophic organisms includes annelids, Gammaridea, tunicates, and mussels. These organisms are cultivated or can be cultivated for use as feed components or as food for human consumption. It is more energy efficient to harvest species at a lower trophic level, as only 10-20 % of the energy is conserved for each trophic level. Cultivation of low-trophic organisms can also be done in IMTA (Integrated Multi-Trophic Aquaculture), where the aim is that species of a lower trophic level will feed on the waste of a species on a higher trophic level and recycle nutrients such as phosphorus and nitrogen.

5.8.1 Annelids and bristle worms

Annelids (Annelida) is a group of animals, ringed worms, or segmented worms, that includes of the classes of bristle worms Polychaete, Oligochaeta and Hirudinea. There are around 20 000 species in 85 families (Fadhullah and Syakir, 2016; Nygren and Pleijel, 2015) of which 15 000 species are marine. Their size varies from a few millimeters to several meters. 700 species of ragworms have been identified in Norwegian waters (Nygren and Pleijel, 2015).

To cultivate bristle worms, it is important to have enough knowledge about their biology (Almås et al., 2020). Feed assimilation, environmental criteria, size, fertility, and growth rates are all important factors to consider for cultivation of annelids. Bristle worms often have different requirements for both feed and environment before and after metamorphosis. There have been several studies on using annelids in integrated systems, where the annelids feed on the waste products of another species. It is estimated that 62-70 % of carbon, 57-62 % of the nitrogen and 70-76 % of the phosphorus in the salmon feed is emitted to the environment (Wang et al., 2013, 2012). Bristle worms could be used to recycle these limited resources such as proteins and lipids and the waste products (Wang et al., 2019a, 2019a). It is currently illegal in the EU (Transmissible Spongiform Encephalipathies (TSEs) regulations (European Commission, 2001) to feed bristle worms with waste products from unknown sources, if they are intended as a feed ingredient to animals such as salmon or livestock for human consumption. However, it is legal to produce phototrophic organisms in the wastewater and feed these to the annelids.

Bristle worms have a high protein content and contain the essential amino acids for marine fish and are rich on lipids. The chemical composition of the annelid *Hediste Diversicolor* is summarized in Table 22. Globally, it is harvested around 121 000 tonnes of annelids, which are primarily used as bait (Watson et al., 2017).

Table 22: Biochemical composition of cultivated and wild caught bristle worm, *Hediste diversicolor*.

Component	Cultivated *Hediste diversicolor*	Harvested *Hediste diversicolor*
Water (% of WW)	79-80	80-81
Protein (% of DW)	54-58	60
Lipids (% of DW)	12-16	11-13-15
Carbohydrates (% of DW)	25-28	37
Ash (% of DW)	10-19	4-9
DHA (% of total lipids)	4.6-7.8	1.4 ± 0.1
EPA (% of total lipids)	19-22.6	22.8 ± 0.6

Sources: Wang et al. (2019); (2019b).

5.8.2 Gammaridae

Gammaridae (tanglopper) can be a source of protein, omega-3 fatty acids and astaxanthin, that is a colorant used to create red colour of the salmon (Almås et al., 2020). There are about 6000 species of *Gammaridae* worldwide. There are about 400 marine species in Norway as well as five freshwater species. The species *Gammarus locusta* and *Gammarus oceanicus* are common in the littoral zone and feed on detritus, which means that they have a great potential of feeding on residuals from the agricultural sector, the paper industry, and the aquaculture industry. Production of *Gammaridae* for feed is also under the TSE regulation, and it is not allowed to use waste products of another animal as a feed input. However, the Gammaridaes has shown to grow on legal substrates such as residuals from agriculture (Standal, 2022). Production of Gammaridae is still at an experimental level, where the technology has been validated in relevant environment. There is an ongoing SINTEF project, Biocycles, that investigates the possibility of cultivating *Gammaridae* on co-streams such as sludge from the smolt production, or from the paper industry or with residuals from agriculture (Standal, 2022). The benefits of using Gammaridae is that they are a local resource, which are nutrient rich and that they can upgrade co-streams and be grown and intensive facilities. They do require substrates and an automized cultivation as well as marked interest for it to become a success. The biochemical composition of *Gammarus locusta* and *Gammarus oceanicus* is presented in Table 23.

Figure 18: Gammaridae. Dikerogammarus villosus. Photo by S. Giesen (1998) licensed under CC BY-SA https://en.wikipedia.org/wiki/Dikerogammarus_villosus#/media/File:Dikerogammarus_villosus_(8740859563).jpg

Table 23: Biochemical composition of *Gammarus locusta* and *Gammarus oceanicus*.

Component	*Gammarus locusta*	*Gammarus oceanicus*
Water (% of WW)	90	90
Protein (% of DW)	47-53	48-51
Lipid (% of DW)*	7-14	6-12
DHA (Of total FA)*	5-10	7-10
EPA (of total FA)*	8-12	9-12
Astaxanthin (mg g^{-1} of DW)	0.36	0.40

*Lipid composition will vary with what substrate the Gammaridaes are fed
Sources: J.O. Evjemo (2007); J. O. Evjemo (2011).

5.8.3 Tunicates

Tunicates (sekkedyr) are filter feeders and a potential feed source. *Ciona intestinalis* and *Clavelina lapaiformis* are two species that can be found in Norwegian waters, growing on ropes and other installations in the sea (Almås et al., 2020). Tunicates usually grow in colonies. *C. intestinalis* can be cultivated in concentrations of 2 500-10 000 individuals per m^2 surface (Troedsson, 2018). This roughly equals 200-450 kg per m^2. The biochemical composition of the tunicate *C. intestinalis* is presented in Table 24. Given this information, 250 kg of *C. intestinalis* would equal 3-4 kg proteins. This means that production of tunicates could cover 5 % of the required protein level for salmon production in 2050 by cultivating tunicates on 25-33 km^2. However, in the processing of tunicates, both proteins and lipids are lost, and the actual protein content is reduced by 40 % (Troedsson et al., 2013).

Figure 19: Tunicates. Photo credited Marianne Per og Martin G. Gulbrandsen. https://www.librebox.no/dykkealbum/ (CC BY).

Table 24: Chemical composition of the tunicate *C. intestinalis*.

Component	*C. intestinalis*
Water (% of WW)	Ca. 951
Ash (% of DW)	40-602,3
Proteins (% of AFDW)	502
Carbohydrates (% of AFDW)	162
Lipid (% of AFDW)	6-142,3
EPA (% of FA)	24-252,3
DHA (% of FA)	3-112,3

Sources : 1: Laupsa (2015), 2: Troedsson (2018), Troedsson (2013).

5.8.4 Mussels

Mussels, such as blue mussels (*Mytilus edulis*) are filter feeders and get their food from particles in the water. Production of mussels is mostly for human consumption. In Norway the annual production of blue mussels are 2000 tonnes (Havforskninsinstituttet, 2019a). The annual global production is around 1.5-2 million tonnes blue mussels (Naik and Hayes, 2019). Table 25 shows the biochemical composition of blue mussels.

Table 25. Biochemical composition of blue mussels (*Mytilus edulis*)

Component	*Mytilus edulis*
Proteins (% of DW)	651
Lipids (% of DW)	82
EPA (% of total lipids)	12-212
DHA (% of total lipids)	16-222

Sources: 1: Naik and Hayes (2019), 2:Hamre (2020).

Figure 20: Blue mussels. Photo by Mark A. Wilson (Department of Geology, The College of Wooster) licensed under CC BY-SA. https://en.wikipedia.org/wiki/File:CornishMussels.JPG

5.9 Residual raw material from the seafood industry

Residual raw materials (RRM) from seafood are a good source of marine oils and proteins and can be used for many purposes, including the production of new and value-adding products for the feed, food, pharmaceutical, and ingredient industries (Almås et al., 2020). Better utilization and processing of residual raw materials from fish are important factors for the sustainable and economic development of the seafood industry (Aspevik et al., 2017).

Table 26 shows the available utilized RRM in 2020. The aquaculture industry produced 478 000 tonnes of available RRM, while whitefish, pelagic fish and shellfish harvest produced 540 000 tonnes (Myhre et al., 2021). The proportion of utilized RRM is 58 % for whitefish, 62 % for shellfish, 93 % for the aquaculture industry, and 100 % for pelagic fish. All residual raw material from pelagic fish is utilized for fishmeal and fish oil.

Table 26: Available and utilized rest-raw materials from fisheries and aquaculture in Norway in 2020. The table is based on Myhre et al. (2021).

	Whitefish	Pelagic fish*	Aquaculture	Shellfish	Total
Raw materials (tons)	671 000	1 472 000	1 585 000	44 000	3 772 000
Available rest raw materials	292 000	236 000	478 000	13 000	1 018 000
% Available rest raw materials	44 %	16 %	30 %	30 %	27 %
Utilized rest raw materials	169 000	236 000	447 000	8 000	861 000
% Utilized rest raw materials	58 %	100 %	93 %	62 %	85 %

*Includes herring, mackerel, capelin, and blue whiting.

There is a potential to increase the degree of utilization of RRM, especially the whitefish sector. In 2020, 69 % of the utilized marine residual raw materials went to feed production for fish and livestock (Myhre et al., 2021). In recent years, the need for marine ingredients has increased and especially the need for marine oils, because the fish feed market demands these components more than ever. Proteins, both in the form of fish protein hydrolysates, and fish protein concentrate from silage, have clearly increasing interest from the feed industry (Richardsen et al., 2019). Dead fish from farming cannot be used for food for human consumption or feed and go to biogas instead. In 2018, this amounted to a total of approx. 95 thousand tonnes (Richardsen et al., 2019).

5.9.1 Residual raw materials from aquaculture

Residual rest material accounts for about 40 % of the farmed fish. In 2020, the volume of utilized residual raw material, subtracted dead fish, was approximately 447 000 tons. With an estimated protein content of 15 % and a lipid content of 20 %, this biomass contained approximately 43 000 tonnes of proteins and 57 000 tonnes of marine lipids (Almås et al., 2020) (Almås et al., 2020). With further growth in the aquaculture industry, the volume of residual raw material will increase. Given a production of 5 million tonnes of salmon in 2050, the amount of utilized residual raw material minus dead fish can amount to approximately 972 000 tons, of which about 194 000 tonnes lipids. With an EPA + DHA content of about 10 % in "raw" salmon oil (Ma et al., 2014), salmon oil could theoretically return to salmon about 14 % of the estimated need of 135 000 tonnes of EPA + DHA in 2050 (Almås et al, 2020).

Currently, blood is the only substance of RRM from aquaculture not utilized. Blood makes up 3.5-4.0 % of the live weight of a salmon and make up a significant volume of around 51 000-59 000 tonnes from the production of 1.47 million tonnes of salmon and trout in 2018, of this amount it is estimated that about 37 000 tonnes could have been collected during slaughter (Richardsen et al., 2019). The blood contains 12.5 % protein and 0.8 % lipid with a high content (55 %) of EPA + DHA, which in a scenario of 5 million tonnes of salmon in 2050, this could produce 135 000 tonnes of collected blood with 17 000 tonnes of proteins and 600 tonnes of EPA + DHA (Storrø, 2005).

5.9.2 Residual raw material from wild-caught fish and shellfish

In 2020, there were 128 000 tonnes of non-utilized rest-raw materials from wild caught fish and fisheries (Myhre et al., 2021). Most of this is from the whitefish sector, where only 58 % of the rest raw materials was utilized. About 100 % of the residual raw material from pelagic fish was utilized.

Significant amounts of residual raw material are produced in the whitefish, pelagic, and shellfish industries, which also contain valuable lipids, proteins, and other components. Most of the RRM from fisheries are already being utilized and the amount of RRM is not expected to increase in the future, other than the use of RRM tossed overboard from the fishing fleet (Almås et al., 2020). An estimate made by Almås et al. (2020) based on the analyses of Myhre et al. (2021) shows that residual raw material (including the fish tossed overboard) in 2050 could equal 465 000 tonnes. With a protein content of 15 %, this equals about 70 000 tonnes of protein which corresponds to 3.5 % of the estimated need for protein for salmon feed in 2050.

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