Proceedings of the ASME 2017 36th International Conference on Ocean, Offshore and Arctic Engineering
OMAE2017
June 25-30, 2017, Trondheim, Norway

OMAE2017-61659

CLASSIFICATION OF AQUACULTURE LOCATIONS IN NORWAY WITH RESPECT TO WIND WAVE EXPOSURE

Pål Lader
EXPOSED Aquaculture Operations Centre, SINTEF Ocean
Trondheim, Norway

David Kristiansen
EXPOSED Aquaculture Operations Centre, SINTEF Ocean
Trondheim, Norway

Morten Alver
SINTEF Ocean
Trondheim, Norway

Hans V. Bjelland
EXPOSED Aquaculture Operations Centre, SINTEF Ocean
Trondheim, Norway

Dag Myrhaug
Department of Marine Technology
Norwegian University of Science and Technology, Trondheim, Norway

ABSTRACT

In Norway there are a total of 1070 registered sites for salmon farming all along the coast. Trends in the aquaculture industry in the recent decade are that salmon farming sites tend to gradually relocate to more wave and current exposed locations. This trend is mainly motivated by the good water quality found in more exposed areas, as well as a lack of available sheltered locations. On the other hand, the increased exposure puts higher loads on the structures and this needs to be addressed by the development of more robust technology. The first step in order to address an increased exposure is to quantify the level of exposure of waves and current, and in this paper a method to easily estimate the level of wind wave exposure on a large number of sites are presented, and subsequently used to analyse all Norwegian sites.

The method can be called *fetch analysis*, and use long term wind data connected with the fetch length in order to estimate wind wave conditions. The method is divided into four steps: 1) Fetch analysis, 2) Wind data, 3) Estimating wave parameters H_s and T_p and 4) Wave statistics. Significant wave height H_s with return period 1 year and 50 years are estimated for each site. $H_{s\ 50\ year}$ is often used for design, and the analysis shows that for 38% of the sites $H_{s\ 50\ year}$ exceeds 1 meter, for 17% of the sites $H_{s\ 50\ year}$ exceeds 1.5 meter, while 1.4% of the sites have $H_{s\ 50\ year}$ larger than 2.5 meter. The most exposed site has a $H_{s\ 50\ year}$ of 2.9 meter. Thus there are large differences in $H_{s\ 50\ year}$ in the various coastal regions of Norway.

INTRODUCTION

Producing enough healthy food for a growing world population is a global challenge. Fish farming will play a major part in meeting future food needs. By 2030, the World bank projects that 62% of all seafood consumed will be farm raised [1]. Norway's salmon farming industry is a key success story in global aquaculture production, and in the recent years the industry has increased its attention towards using more exposed coastal areas. This is driven by a need for more space and better production environments. Exposed farming locations could be ideal for production and simultaneously reduce key environmental effects. Exposed areas provide more stable culture conditions and greater dispersal of wastes due to constant water flow, both of which improve the production environment [2].

Farming in exposed locations poses unique challenges to operations, structures and equipment due to severe and irregular wind, wave and current conditions, and sheer remoteness. Solving these challenges in Norway is expected to significantly benefit both existing operations in more sheltered areas in Norway, as well as the global aquaculture industry in general.

But what does "exposed locations" actually mean? This is hard to answer objectively since there is no clear overall definition to this term. The term is, however, frequently used when the aquaculture industry is discussed, and it usually refers to a site where the most common sea state (and current) is more energetic than what is experienced on an average site. What sea states are most common on average have also never been objectively quantified, so when it is commonly accepted that the Norwegian aquaculture industry has gradually moved towards more exposed sites in recent years this is based on subjective assessment of the sites.

Each aquaculture site in Norway is subjected to a site survey before it is licenced for production. The scope of this site survey is described in Norwegian Standard NS 9415 [3], and includes assessment of waves, wind and current. This data is, however, not commonly available, and it is practically difficult to use this data to make a quantitative assessments of the wave and current exposure on Norwegian sites as a whole.

There are several wave models available (e.g. SWAN etc.) that can be used to simulate/model both swell and wind wave on a given site. The amount of time and resources involved in setting up a simulation is, however, extensive, and it would be impractical to use these models to establish wave statistics for many sites over a larger geographic area (e.g. all sites in Norway, other countries or larger regions). In order to describe the wave exposure in such situations simplified methods are convenient to be used. In this paper a simplified method to find wind wave statistics for all sites in Norway is described. The method is a simplified version of the one used by Kjeldsen et al. in a study on dangerous wave conditions with respect to capsize of fishing vessels [4]. The method (called *fetch analysis* in the following) uses the fetch situation on each site coupled with available wind statistics in order to produce a frequency distribution of significant wave height (H_s) and peak period (T_p), and from that calculate H_s and T_p for relevant return period which can be used as quantitative measure for wind wave exposure.

It must be noted that this method is crude with respect to the assessment of each individual site. Swell waves are not included, and the model does not include bathymetry - deep water conditions are assumed all over. The main motivation is, however, not to accurately describe each individual site, but to get a statistical description of all sites in Norway, and to objectively identify sites that are significantly more exposed than the average. This will in turn be used to propose objective descriptions of how exposure should be quantified.

Norwegian aquaculture sites

All aquaculture sites in Norway are registered at the Directories of Fisheries, and the register with geographical coordinates is publicly available at their website. This register includes all aquaculture sites in Norway, but in this study only sea based salmon sites are considered relevant. There are a total of 1070 salmon sites in Norway (according to the register per October 27, 2015). In Figure 1 all these sites are shown in the map together with the distribution of sites in the different administrative counties. Norway have a total of 19 administrative counties, and 11 of these counties have salmon aquaculture sites. All these sites are used in the following analysis.

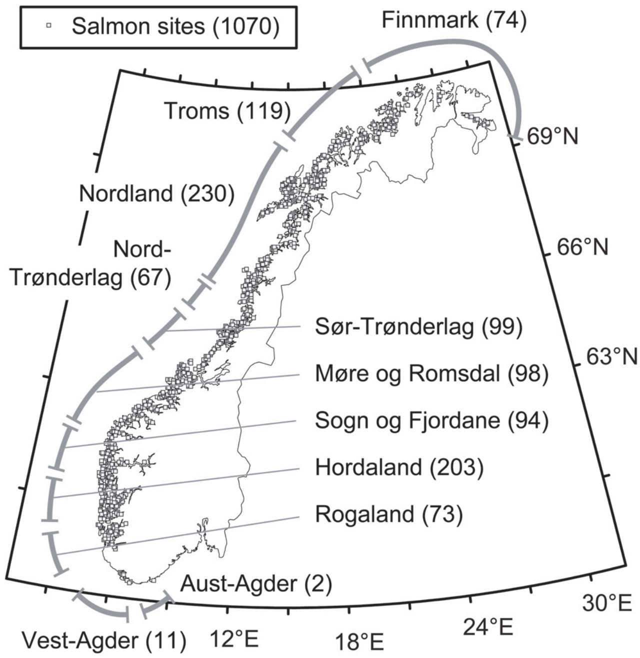

Figure 1. Sea based salmon aquaculture sites in Norway (as of October 2015).

The sites in Norway are owned and operated by a variety of companies, 143 in total. Most of these companies are small, with less than five sites each (83), but the seven largest companies owns 43% of the sites. An overall outline of the ownership structure is shown in Table 1. Each of the sites can have multiple permits connected to them, and the total capacity of each site is varying (Figure 2). The most common capacity of a site is about 3000 tons, but there are sites with up to 9000 tons capacity. The total capacity of all Norwegian sites is more than 3 Mtons.

Table 1. Site ownership structure.

Number of sites pr. company	Companies	Total number of sites	
> 50	3	317	(30%)
49 - 25	4	137	(13%)
24 - 10	13	191	(18%)
9 - 5	40	251	(23%)
5 >	83	174	(16%)
	143	1070	

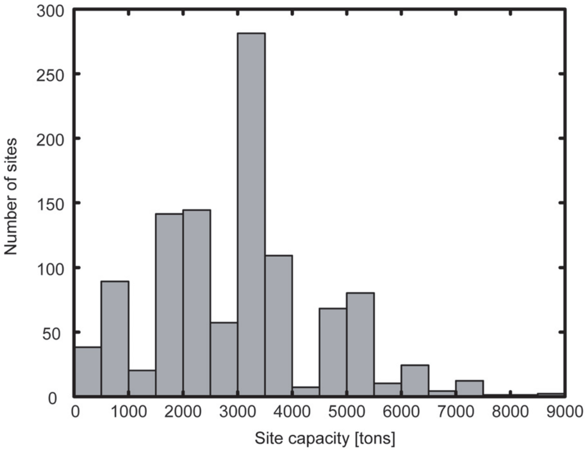

Figure 2. Distribution of site capacity.

METHOD

Ocean waves can generally be divided into two groups; wind waves and swell waves. Wind waves are waves that are generated locally by wind, while swell waves are waves generated in wind events far off at sea and then travel a distance and reach the area in question at a later time. Only the most energetic waves (lower frequency waves) are able to travel a long distance without being dissipated, and swell waves have therefore usually lower, and more narrow banded frequency than the wider frequency band of the locally generated wind waves. For aquaculture sites both wave types are important, but in this work, only wind waves are addressed. This simplification is done to limit the scope of this paper since the approach to model swell waves and wind waves are highly different.

One way to estimate wind wave conditions is to use known wind data connected with the fetch length. Fetch is defined as *the length of water over which a given wind has blown* (en.wikipedia.org), and can be used to estimate the wave condition if it is coupled with wind speed and duration. The proposed method uses this approach and is divided into four steps: 1) Fetch analysis, 2) Wind data, 3) Estimating wave parameters H_s and T_p, and 4) Wave statistics. Each of the steps will be described in the following.

Fetch is calculated using map data of the coastal region around the site positions. The Matlab package M_Map is used for the mapping work (http://www.eos.ubc.ca/~rich/map.html), and the map data is taken from the Global Self-consistent Hierarchical High-resolution Geography (GSHHG) database (http://www.ngdc.noaa.gov/mgg/shorelines/gshhs.html) [5]. Example of map data are shown in Figure 3. With origin in the site, consecutive circles with increasing radius (100m increments) are drawn. The points on the circle have 1 deg sector increments, and for each circle the points that lies within a land area are removed for the circle itself and for all subsequent circles. This process is repeated until the circle eventually have no points, or reach a radius of 40 km. The collected points now represents the fetch area in 1 deg sectors around the site, and the fetch length in each sector is equal to the distance to the farthest point in the sector. Examples of calculated fetch areas are shown in Figure 4. This is done with all 1070 sites.

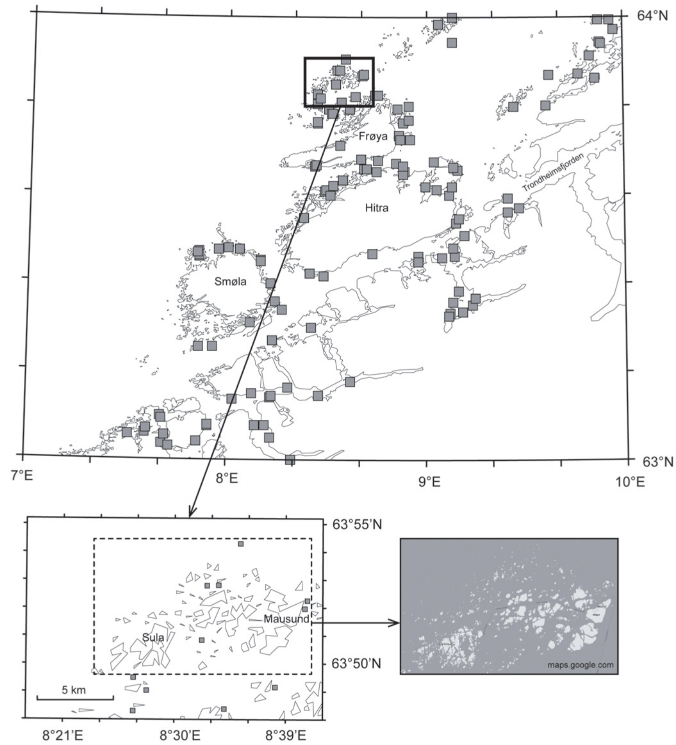

Figure 3. Example of the map data used in the fetch analysis. Salmon aquaculture sites (squares) in Nordmøre/Trønderlag area are shown (top) with an enlarged section of Sula and Mausund (bottom) compared with higher-resolution map (maps.google.com) to illustrate the resolution of the map data.

Step 1. Fetch analysis

With the fetch for all sites established it is possible to have a first view of how exposed the sites are. As stated earlier, both swell and wind waves are important, but the present fetch analysis only gives statistical parameters for the wind waves. It is, however, possible to get an indication on the exposure of swell waves on the sites based on the fetch analysis. It can be assumed that the likelihood of swell exposure increases with the size of the open sectors. Swell comes from storm events far off at sea, and needs a path to travel to the site. The size of the open sector will thus say something about how possible it is for the swell waves to reach the site. This is of course a significant simplification, since it assumes that the waves are not refracted as they reach the coastline, which they are. Because of refraction it might well be that a site <u>without</u> open sectors are more exposed to swell, than a site <u>with</u> open sectors. However, for a large ensemble of sites it is a fair assumption that the overall likelihood of swell exposure increases with increasing open sectors on the sites. In Figure 5 the distribution of the sites with largest open sectors on each site is shown. Most of the sites (679 of 1070) have no open sectors, and 90% of the sites have a largest open sector of less than 15 deg. Even though it is difficult to make any quantitative conclusion of the level of swell from these numbers it can be assumed that the majority of the sites are most exposed to wind waves, but that swell may constitute an important contribution to the wave exposure on a significant number of sites. It is thus important to use a swell model in addition to the present method to get a full understanding of the wave exposure on the most exposed sites.

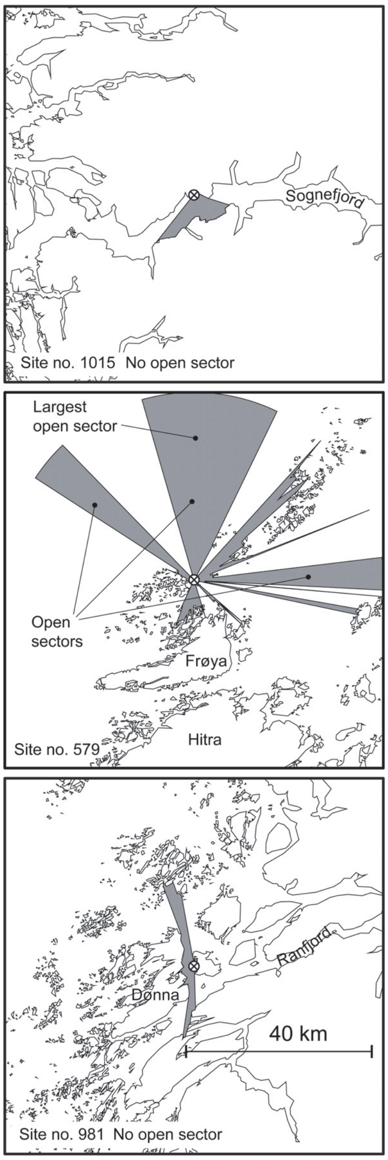

Figure 4. Example of fetch sectors of three different sites. The grey area indicate the fetch length at one-degree sectors all around the site position. When the fetch reaches 40 km further search for land is terminated, and the sector is assumed to be open (open sectors are shown in the middle figure).

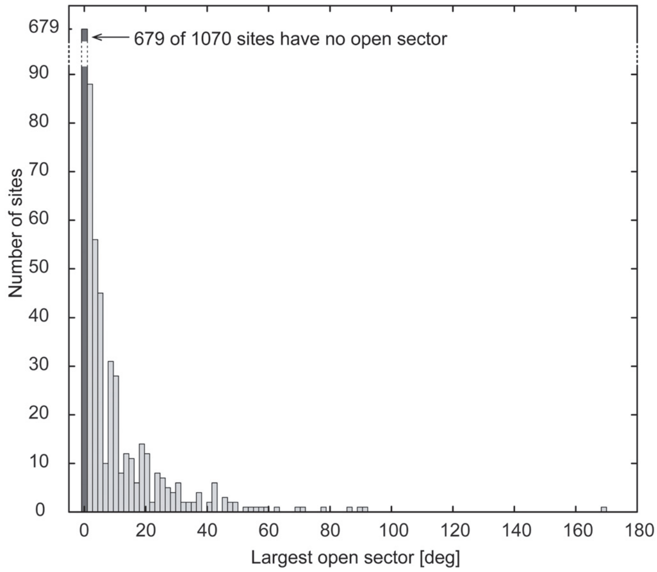

Figure 5. The distribution of the largest open sector on all sites.

Step 2. Wind data

The wind data is obtained from the ERA-interim reanalysis [6] available from the European Centre for Medium-Range Weather Forecasts. Generally speaking, a meteorological reanalysis is a data assimilation product where historically observed data is used as corrections to an atmospheric model. The reanalysis uses a consistent assimilation scheme throughout its whole time span, as opposed to an operational data analysis, which may have inconsistencies due to gradual improvements to the assimilation scheme over time. ERA-interim covers the period from 1979 up to the present, and its core components are the ECMWF Integrated Forecast Model and a 4D-var data assimilation scheme.

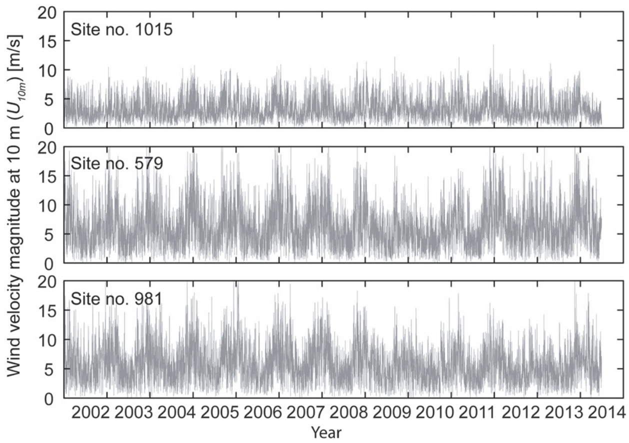

Figure 6. Time series of wind velocity magnitude at 10 meter ($U_{10m}= \sqrt{(Ux_{10m}^2+Uy_{10m}^2)}$ for the example sites. Time resolution is 6 hours.

The output variables used are the 2D fields "10 meter Ux wind component" and "10 meter Uy wind component", with a sampling interval of 6 hours and a horizontal resolution of 0.75x0.75 degrees. For each aquaculture site, the geographical position is looked up in the grid of the ERA-interim data, and linearly interpolated for each wind component between the closest grid cells. Example of wind data time series for the example sites is shown in Figure 6, and the distribution of the wind speeds are shown in Figure 7.

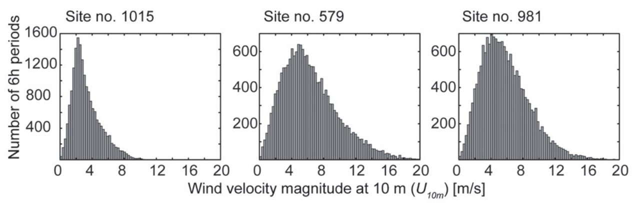

Figure 7. The distribution of wind velocity magnitude at 10 meter (U_{10m}) from the time series shown in Figure 6.

Step 3. Estimation of wave parameters H_s and T_p

Significant wave height (H_s) and peak period (T_p) can now be calculated, using established formulas, from the wind data and the fetch area around each site. The formulas can be found in [7], and are the same as the Norwegian Standard [3] suggest to use in site analysis:

$$H_s = 5.112\ 10^{-4} U_A F^{\frac{1}{2}}$$

$$T_p = 6.238\ 10^{-2} (U_A F)^{\frac{1}{3}}$$

where F is the fetch length in meter and U_A is the wind-stress factor that can be calculated from:

$$U_A = 0.71\ U_{10m}^{\ 1.23}$$

where U_{10m} is the wind velocity magnitude at 10m height in m/s. This relationship assumes no temperature difference between the sea and the air. These equations assumes that the sea states are fetch limited, and that the wind is constant over the fetch area and over the duration of the sea state. The sampling interval in the wind data is 6 hours, and the duration of the sea states is thus assumed equal to this. This relative long duration would imply that the assumption of a fetch limited sea state is valid, while the assumption of a constant wind condition over the fetch area may be more inaccurate. It is difficult to assess and quantify the errors connected to these assumptions in more detail, but the validity of the entire method will be investigated later by comparison with selected wave buoy data.

In Figure 8 the distribution of the wind direction is shown together with the corresponding fetch area. For each 6 hour period the direction of the wind is used to find the correct fetch length. The fetch length and the wind speed are then put into the equations, and H_s and T_p are calculated. This results in the time series shown in Figure 9 and Figure 11, and the distributions of H_s and T_p are shown in Figure 10 and Figure 12 respectively.

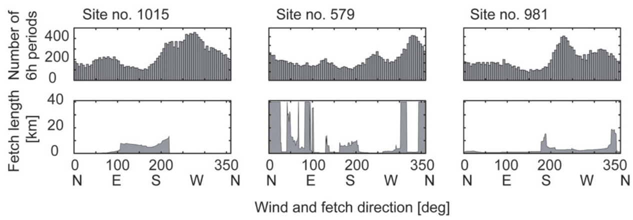

Figure 8. The direction distribution of the wind (top) shown together with the corresponding fetch length (bottom) for the example sites.

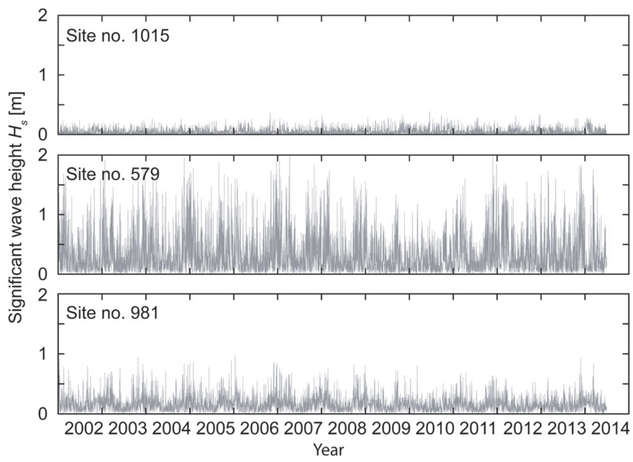

Figure 9. Time series of significant wave height H_s for the example sites.

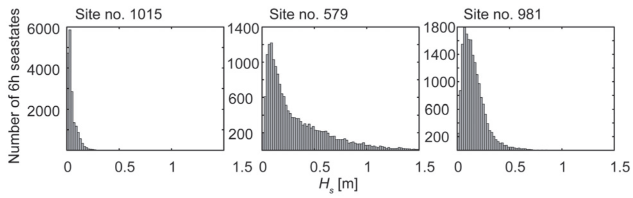

Figure 10. Distribution of significant wave height H_s from the time series shown in Figure 9.

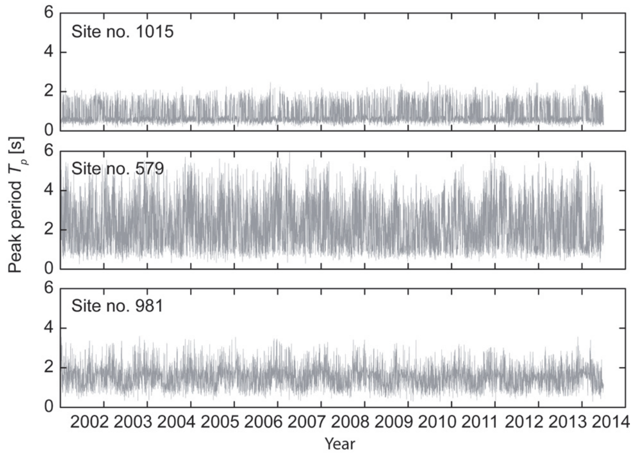

Figure 11. Peak period for the three example sites.

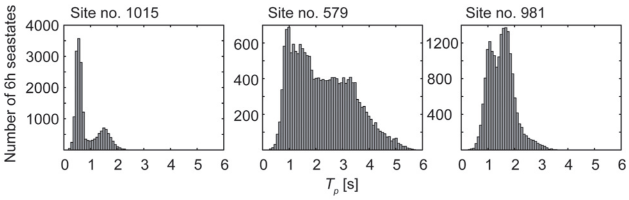

Figure 12. Distribution of significant peak period T_p from the time series shown in Figure 11.

Step 4. Wave statistics

For each site, a 12 year time series of H_s is now established that consists of more than 18 000 data points (6 h sea states). In order to compare and assess the wave exposure on all 1070 sites it is necessary to find a more compact way to represent the H_s condition on each site. One way to do this is, based on the datasets, to calculate the most probable H_s with different return periods. Calculation of conditions with different return periods are commonly used in design of structures, referred to as *extreme value analysis*. The return period of critical conditions then usually needs to be at least longer than the life span of the structure. For aquaculture structures, 50 years is a commonly used return period in design, and $H_{s\ 50\ year}$ will be used as a parameter here. In addition to the 50 years value it can be useful to have a parameter that is more observable in the short run. For a farmer working on a site it is hard to relate to conditions that are likely to occur once every fifty years. For the people on the site it is easier to relate to conditions that likely occur once a year. It is thus chosen to use $H_{s\ 1\ year}$ in addition to $H_{s\ 50\ year}$ in order to have a parameter that can easier be understood by those who observe the site on a daily basis.

Return period conditions are calculated by assuming that a given probability function can be fitted to the dataset. The conditions for any return period can then be calculated from the fitted function, and this makes it possible to calculate values that are extrapolated from the observed data, like the 50 year return period condition that lies well outside our 12 years of data. There are several different probability functions that can be used for this purpose, depending on the nature of the dataset. One of the most common functions are the Weibull distribution function, which will be used here. This type of analysis can be done using the Matlab Toolbox WAFO ([8], [9]), and a general description of extreme value statistics can be found in [10].

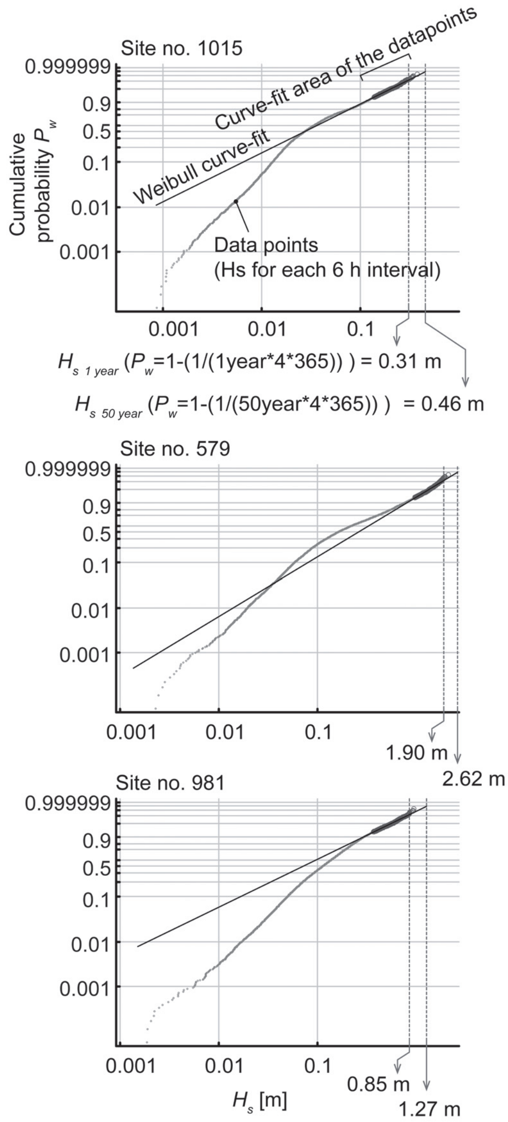

Figure 13. Weibull plot for the H_s at the example sites with 1 and 50 years return periods indicated.

In Figure 13 the Weibull plots for the example sites are shown. The straight lines are the fitted Weibull distributions. If the data follow a Weibull distribution perfectly, the data points will follow a straight line in the Weibull plot. As can be seen from all three example sites the data deviates somewhat from a straight line. Since the Weibull fit will be used to calculate 1 year and 50 years return period value (corresponding to a cumulative probability 0.9993 and 0.999986 calculated using: $P(H_s<H_{s\ n\ year})=1-1/(n*365*6/24)$) the Weibull functions are fitted to a smaller interval in the high value part of the data (as indicated in the figure). From the Weibull fit the return value of H_s can now be found by using the cumulative probabilities, and calculate the corresponding H_s, where $H_{s\ 1\ year}$ and $H_{s\ 50\ year}$ are shown in the figure for the example sites.

VERIFICATION AND VALIDATION

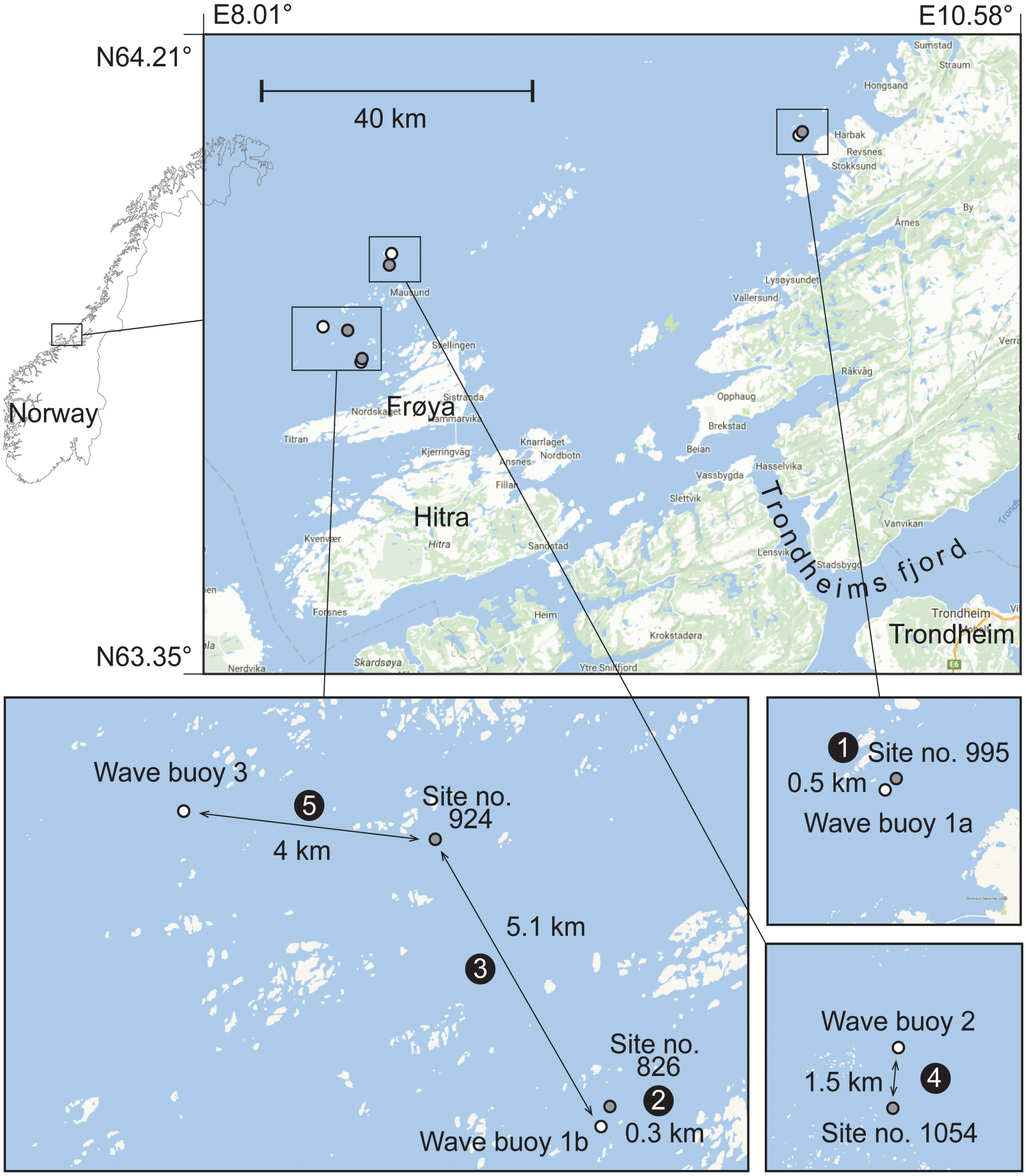

Figure 14. The position of the wave buoys used in the validation. The wave buoy positions are marked with white circles, while the position of the adjacent aquaculture sites are marked with grey circles. The distance between the wave buoy and site are given in km. The numbers in black circles indicate buoy and site comparison pairs.

In order to validate and assess the method, estimates found from the fetch calculations are compared with wave buoy data. Unfortunately, very limited amount of wave measurements from the Norwegian coastal zone were available to the authors, and only four series of wave buoy data from the Trøndelag coast were possible to be used in the validation and verification of the method. The position of the buoys are shown in Figure 14. Each of these buoys were adjacent to a site (from 0.3 to 5.1 km away), and these sites are also shown in the figure. In Table 2 the positions of the buoys and sites are given together with the distance between the sites and the buoys and the measurements period for the wave buoy data. The wave buoys were all of the type *Fugro OCEANOR SEAWATCH Midi 185 Buoy*.

Table 2. The four wave buoy positions and adjacent aquaculture sites.

Wave buoy		Measurement period		Adjacent aquaculture site		Distance between site and buoy
1a	N64.0822 E9.87781	06.11.2014 - 30.06.2015	(8 months)	Site No. 995	N64.0852 E9.8847	0.5 km
1b	N63.7782 E8.5148	02.07.2015 - 08.11.2016	(1.4 years)	Site No. 826	N63.7809 E8.5174	0.3 km
				Site No. 924	N63.8173 E8.4625	5.1 km
2	N63.91959 E8.59268	10.03.2016 - 08.11.2016	(8 months)	Site No. 1054	N63.9049 E8.5891	1.6 km
3	N63.82144 E8.38239	25.01.2016 - 08.11.2016	(10 months)	Site No. 924	N63.8173 E8.4625	4.0 km

Table 3. Comparison between wave buoy data and fetch analysis at the sites. Significant wave height $H_{s\ 1\ year}$ and $H_{s\ 50\ year}$ are given in meter. For the fetch analysis, which are based on twelve years of wind data, the calculated values based on each individual year are also given in increasing order. The five numbered pairs of buoys and sites can also be found in Figure 14. The thick vertical line in the list of individual years shows where the buoy data would lie.

	1		2		3		4		5	
[m]	H_s 1y	H_s 50y	H_s 1y	H_s 50y	H_s 1y	H_s 50y	H_s 1y	H_s 50y	H_s 1y	H_s 50y
Wave buoy recording	Wave buoy 1a		Wave buoy 1b		Wave buoy 1b		Wave buoy 2		Wave buoy 3	
	2.79	3.56	1.05	1.39	1.05	1.39	1.69	2.07	3.59	4.73
Fetch analysis (2002-2013)	Site no. 995		Site no. 826		Site no. 924		Site no. 1054		Site no. 924	
	1.34	1.77	1.05	1.41	1.15	1.57	2.12	2.63	1.15	1.57
Individual years sorted in increasing order	1.02	1.26	0.87	1.18	0.90	1.17	1.60	2.05	0.90	1.17
	1.22	1.50	0.92	1.25	0.93	1.17	1.93	2.41	0.93	1.17
	1.22	1.60	0.96	1.30	0.94	1.17	2.01	2.42	0.94	1.17
	1.23	1.61	1.00	1.31	0.98	1.29	2.02	2.49	0.98	1.29
	1.26	1.61	1.01	1.32	1.08	1.42	2.03	2.49	1.08	1.42
	1.26	1.61	1.04	1.35	1.09	1.46	2.08	2.50	1.09	1.46
	1.28	1.66	1.07	1.40	1.17	1.63	2.08	2.58	1.17	1.63
	1.29	1.70	1.07	1.41	1.20	1.68	2.15	2.70	1.20	1.68
	1.29	1.70	1.07	1.45	1.26	1.73	2.18	2.72	1.26	1.73
	1.31	1.76	1.09	1.47	1.27	1.85	2.22	2.79	1.27	1.85
	1.31	1.76	1.15	1.58	1.30	1.88	2.25	2.82	1.30	1.88
	1.35	1.80	1.15	1.59	1.32	1.94	2.26	2.88	1.32	1.94

Since wave buoy 1b is adjacent to two different sites (0.3 km from site 826, and 5.1 km from site 924) a total of five comparisons between sites and buoys can be made. In Table 3, these five comparisons are shown numbered one to five. These numbers can also be found in Figure 14. As can be seen from the table, comparison 2, 3 and 4 show that the H_s (with 1 and 50 years return period) found from the wave buoy measurements lies within the range of individual year estimates from the fetch analysis. This must be characterized as satisfactory agreement. However, for comparison 1 and 5, the wave buoy measurements are significantly higher than the fetch analysis. A possible explanation for this large discrepancy is the influence of swell at wave buoys 1a and 3, since these two sites have the most direct exposure to the open ocean. Measurements error in the wave buoy is also a possibility. Due to different practicalities, the raw data from the wave buoys where not available to the authors at the time of writing, and it was thus not possible to see if swell was present.

RESULTS AND DISCUSSION

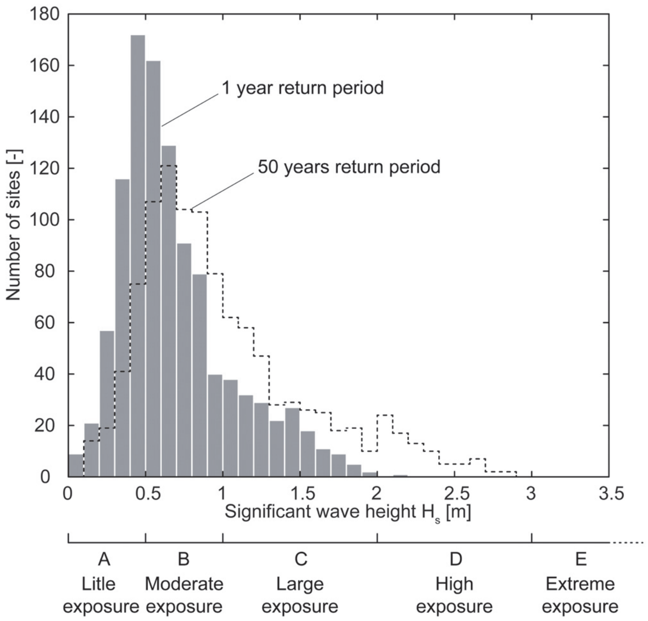

Figure 15. Distribution of $H_{s\ 1\ year}$ and $H_{s\ 50\ year}$ (significant wave height with 1 and 50 years return period) for all 1070 sites. The H_s classification (bottom of the figure) is taken from Norwegian Standard NS 9415 [3].

In Figure 15 the distribution of significant wave height with return period 1 and 50 years for all 1070 sites are shown. Using the H_s classification from NS 9415 it can be seen that a significant number of sites (194 of 1070 sites) have a $H_{s\ 1\ year}$ that is characterized as *C - Large exposure*, and a $H_{s\ 50\ year}$ characterized as *D - High exposure* (85 of 1070 sites). Thus about 18% of Norwegian aquaculture sites experience wave conditions characterized as large and high exposure statistically at least once a year. It is worth to notice that no sites have $H_{s\ 1\ year}$ or $H_{s\ 50\ year}$ characterized as *E – Extreme exposure*, but keep in mind that the fetch analysis does not include swell. As indicated by the wave buoy data swell exposure can greatly increase the $H_{s\ 1\ year}$ and $H_{s\ 50\ year}$ for a site. For the same reason it is important to use the results from the fetch analysis carefully, and take into account the possibility for swell exposure before making any final conclusions/analysis.

In Figure 16 it is shown how the wind wave exposure varies for sites in different parts of the Norwegian coast. The map shows clearly that the most exposed sites are in the outer regions of the coast. Interestingly it can also be seen that the most exposed sites are not evenly distributed along the coast. The county of *Sør-Trøndelag* have by far the most wind wave exposure, about half the sites (46 of 99 sites) in this county have $H_{s\ 1\ year}$ characterized as *C - Large exposure*. Information like this can thus be used to further study the structures of the aquaculture industry; is this a result of the nature of the coastline in this county, or is it due to trends in the companies that operates in the region? Or both? Or something else? It would also be interesting to correlate this information with accident statistics from the industry to see if wave loads have a possible impact on health and safety.

CONCLUDING REMARKS

The fetch analysis method makes it possible to easily obtain long term wind wave statistics for a large amount of sites, and this can give valuable information on how the industry operates in larger regions and countries. Such information can be used to study how the industry operates, but more importantly, it can be used to give objective quantitative measures for what "exposed locations" actually means in the terms of significant wave height and peak period. This understanding can then be used to map out the road ahead when it comes to technology development in aquaculture structures, and the environmental loads the future brings for these installations.

ACKNOWLEDGEMENT

This research has been funded by the Research Council Norway, *EXPOSED Aquaculture Research Centre*, grant number 237790.

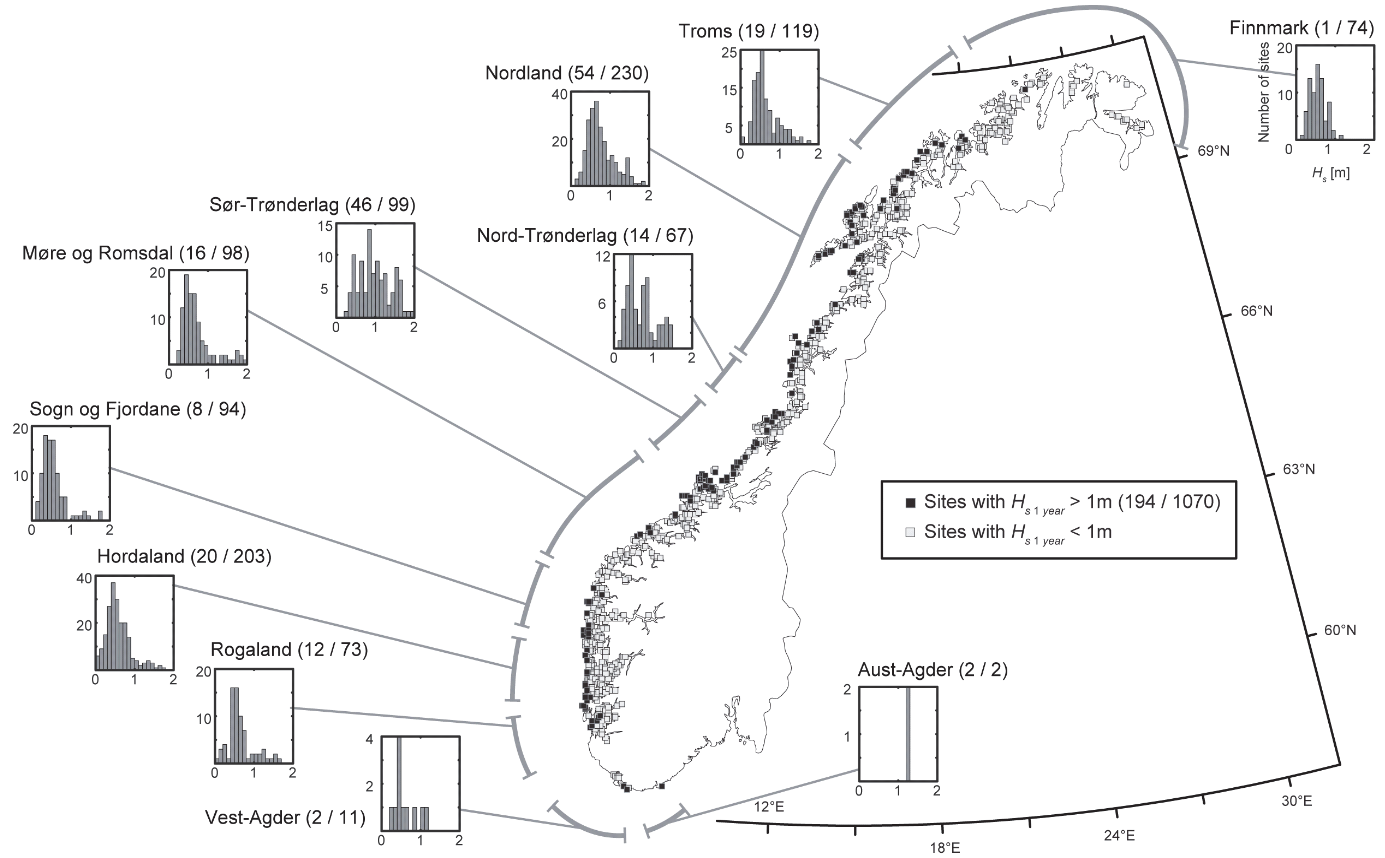

Figure 16. The distribution of $H_{s\ 1\ year}$ in each of the Norwegian counties. The numbers in the parenthesis show the number of sites with $H_{s\ 1\ year}$ larger than 1m together with the total number of sites in the area. In the map, sites with $H_{s\ 1\ year}$ > 1m are shown as black filled squares, while the less exposed sites are shown as white squares.

REFERENCES

[1] Anon, 2013, "Prospects for fisheries and aquaculture," No. 83177, World Bank report.

[2] Holmer, M., 2010, "Environmental issues of fish farming in offshore waters: perspectives, concerns and research needs," Aquacult. Environ. Interact., 1(1), pp. 57-70.

[3] Standard Norge, 2009, "NS 9415:2009 Marine fish farms. Requirements for desing, dimensioning, production, installation and operation.," Norsk Standard No. NS 9415, Norges Standardiseringsforbund (NSF), Oslo.

[4] Kjeldsen, S. P., Lystad, M., and Myrhaug, D., 1981, "Forecast of breaking waves on the Norwegian continental shelf," SINTEF Report, Trondheim.

[5] Wessel, P., and Smith, W. H., 1996, "A global, self - consistent, hierarchical, high - resolution shoreline database," Journal of Geophysical Research: Solid Earth (1978–2012), 101(B4), pp. 8741-8743.

[6] Dee, D., Uppala, S., Simmons, A., Berrisford, P., Poli, P., Kobayashi, S., Andrae, U., Balmaseda, M., Balsamo, G., and Bauer, P., 2011, "The ERA - Interim reanalysis: Configuration and performance of the data assimilation system," Quarterly Journal of the Royal Meteorological Society, 137(656), pp. 553-597.

[7] Coastal Engineering Research Center United States, 1984, Shore protection manual / [prepared for Department of the Army, US Army Corps of Engineers], Dept. of the Army, Waterways Experiment Station, Corps of Engineers, Coastal Engineering Research Center ;, Vicksburg, Miss. :.

[8] Brodtkorb, P. A., Johannesson, P., Lindgren, G., Rychlik, I., Rydén, J., and Sjö, E., "WAFO-a Matlab toolbox for analysis of random waves and loads," Proc. The Tenth International Offshore and Polar Engineering Conference, International Society of Offshore and Polar Engineers.

[9] WAFO-group, 2011, "WAFO - A Matlab Toolbox for Analysis of Random Waves and Loads - Tutorial for WAFO version 2.5," Mathematical Statistics, Center for Mathematical Sciences, Lund University, Lund, Sweden.

[10] Coles, S., Bawa, J., Trenner, L., and Dorazio, P., 2001, An introduction to statistical modeling of extreme values, Springer.