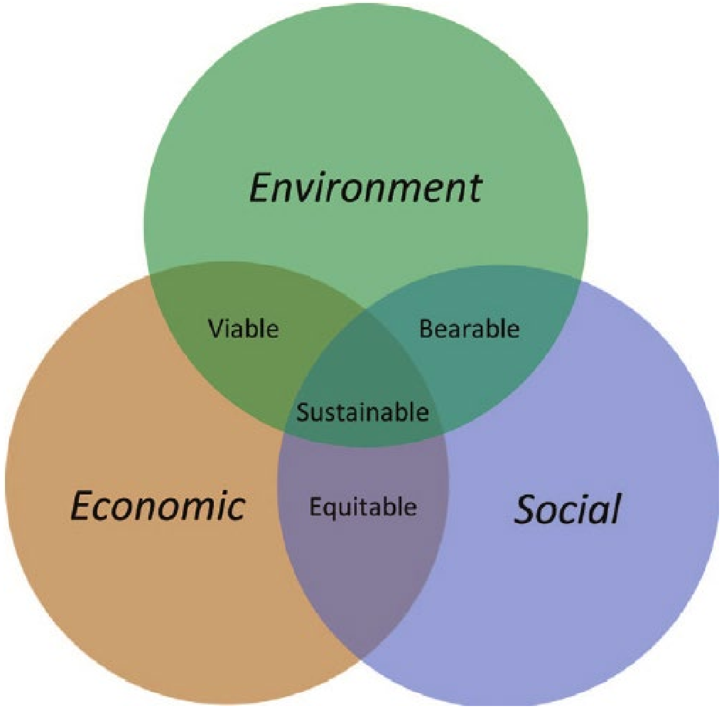
# Carrying capacity (CC) eller hållbar bärförmåga

- Fysisk CC - beskriver det område som är geografiskt tillgängligt och fysiskt/kemiskt lämpligt för en viss typ av vattenbruk. Beror av hydrodynamiska förhållanden (strömmar, vågor, vind), batymetri, vattenkvalitet och tillgängligt utrymme.
- Produktion CC - ur ett biomassaperspektiv som maximal nivå för vattenbruksproduktionen. I praktiken ofta ’trial-and-error’. För musslor är beståndsuppskattningar oumbärliga, både naturliga och odlade
- Ekologisk CC - vattenbruksproduktionen som kan stödjas utan att det leder till oacceptabla förändringar i ekologiska processer, arter, populationer eller samhällen i miljön. Hänger ihop med SCC. Behöver ekosystem kopplingar, både negativa och positiva, samt bestämda gränsvärden satta av myndigheter
- Social CC – mängden vattenbruk som kan utvecklas från vad samhället som helhet är villiga att acceptera




”En ekosystemansats för vattenbruk (EAA) är en strategi för integrering av verksamheten inom det bredare ekosystemet så att den främjar hållbar utveckling, rättvisa och motståndskraft hos sammanlänkade socio-ekologiska system.”
(Ecosystem approach to aquaculture management. Handbook 2010, 2020 http://fff.fao.org/3/ca7972en/ca7972en.pdf)

## Musselodling

| Fysisk CC | Produktion CC | Ekologisk CC | Social CC |
|---|---|---|---|
| Vind | Temperatur | Kritiska livsmiljöer | Sjörättigheter |
| Vågor | Salthalt | Biologisk mångfald | Tillgång till kapital |
| Strömmar | Klorofyll och | Syrebrist indikatorer | Arbetskraft |
| Klorofyll och | produktivitet | Visuellt intryck | Förmånstagare |
| Produktivitet | Investeringar | Allmänna MKB-data | Etc. |
| Djup | Kostnader | Etc. | |
| Temperatur | Marknader | | |
| Salthalt | Etc. | | |
| Etc. | | | |

## Algodling

| Fysisk CC | Produktion CC | Ekologisk CC | Social CC |
|---|---|---|---|
| Vind | Temperatur | Kritiska livsmiljöer | Sjörättigheter |
| Vågor | Salthalt | Biologisk mångfald | Tillgång till kapital |
| Strömmar | Närsalts- | Visuellt intryck | Arbetskraft |
| Närsalts- | tillgång | Allmänna MKB-data | Förmånstagare |
| koncentrationer | Investeringar | Etc. | Etc. |
| Djup | Kostnader | | |
| Temperatur | Marknader | | |
| Salthalt | Etc. | | |
| Etc. | | | |

FAO/Institute of Aquaculture, University of Stirling, Expert Workshop 6–8 December 2010

## Musselodling

| Fysisk CC | Produktion CC | Ekologisk CC | Social CC |
|---|---|---|---|
| Vind | Temperatur | Kritiska livsmiljöer | Sjörättigheter |
| Vågor | Salthalt | Biologisk mångfald | Tillgång till kapital |
| Strömmar | Klorofyll och | Syrebrist indikatorer | Arbetskraft |
| Klorofyll och | produktivitet | Visuellt intryck | Förmånstagare |
| Produktivitet | Investeringar | Allmänna MKB-data | Etc. |
| Djup | Kostnader | Etc. | |
| Temperatur | Marknader | | |
| Salthalt | Etc. | | |
| Etc. | | | |

## Algodling

| Fysisk CC | Produktion CC | Ekologisk CC | Social CC |
|---|---|---|---|
| Vind | Temperatur | Kritiska livsmiljöer | Sjörättigheter |
| Vågor | Salthalt | Biologisk mångfald | Tillgång till kapital |
| Strömmar | Närsalts- | Visuellt intryck | Arbetskraft |
| Närsalts- | tillgång | Allmänna MKB-data | Förmånstagare |
| koncentrationer | Investeringar | Etc. | Etc. |
| Djup | Kostnader | | |
| Temperatur | Marknader | | |
| Salthalt | Etc. | | |
| Etc. | | | |

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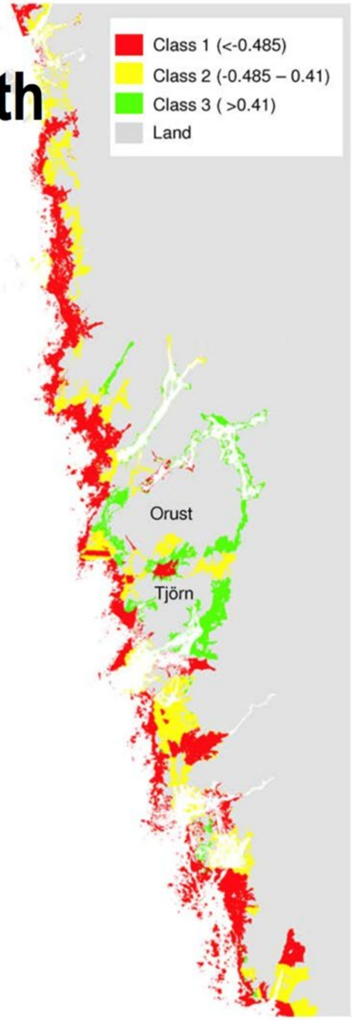
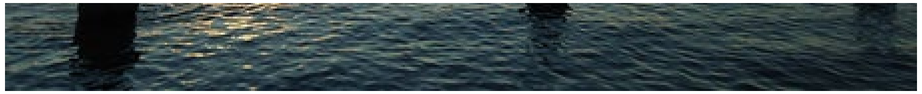
## Resulting layer of spatial predictions for mussel growth

- Off-shore areas generally have lower growth rates
- Inner fjord areas, which have the most severe eutrophication problems have higher growth rates.
- 15% of the area is characterised as high growth areas.
- Largely coincides with farming permits.
- Useful in MSP and regional planning



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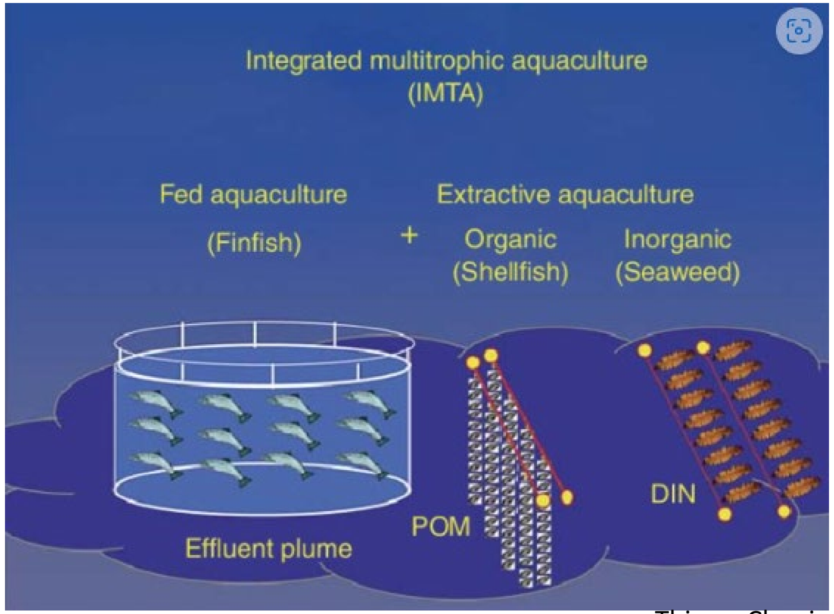
# Fiskodling i havet

| Fysisk CC | Produktion CC | Ekologisk CC | Social CC |
|---|---|---|---|
| Vind<br>Vågor<br>strömmar<br>Djup<br>Temperatur<br>Salthalt<br>infrastruktur<br>Etc. | Temperatur<br>Foder typ<br>Utfodringsutr.<br>Infrastruktur<br>Investerings<br>kostnader<br>Etc. | Kritiska livsmiljöer<br>Biologisk mångfald<br>Eutrofierings status<br>Visuellt intryck<br>Allmänna MKB-data<br>Etc. | Hav o kust rättigheter<br>Tillgång till kapital<br>Arbetskraft<br>Förmånstagare<br>Etc. |

# Kombinerad odling




Thierry Chopin

The SeaOr Marine Enterprises Ltd. IMTA farm in Mikhmoret, Israel. The abalones ( Haliotis discus hannai ) are grown in the white building in the background, the green-covered fishponds ( Sparus aurata ) are in the middle, and the elongated seaweed ponds ( Ulva sp. and Gracilaria sp.) are in front. Photo by M. Shpigel and B. Scharfstein.

# Carrying capacity kan beräknas med Modeller eller uppskattas grovt med enkla index

Ex på använda index (Dame and Prins, 1998)

Vattnets uppehållstid (RT) – tiden det tar att förnya vattenvolymen

Primärproduktions tid (PT) – tiden det tar att förnya fytoplankton beståndet i ett område

Klarningstid (CT) – tiden det tar för musslorna att filtrera vattenvolymen

CT/RT klarningskvot

CT/PT beteskvot

CT/RT > 1 vattnet förnyas snabbare än det filtreras

CT/RT < 1 musslorna kontrollerar potentiellt pelagiska processer

CT/PT > 1 fytoplankton förnyas snabbare än de filtreras

CT/PT < 1 födan tar slut och systemet ’stannar’

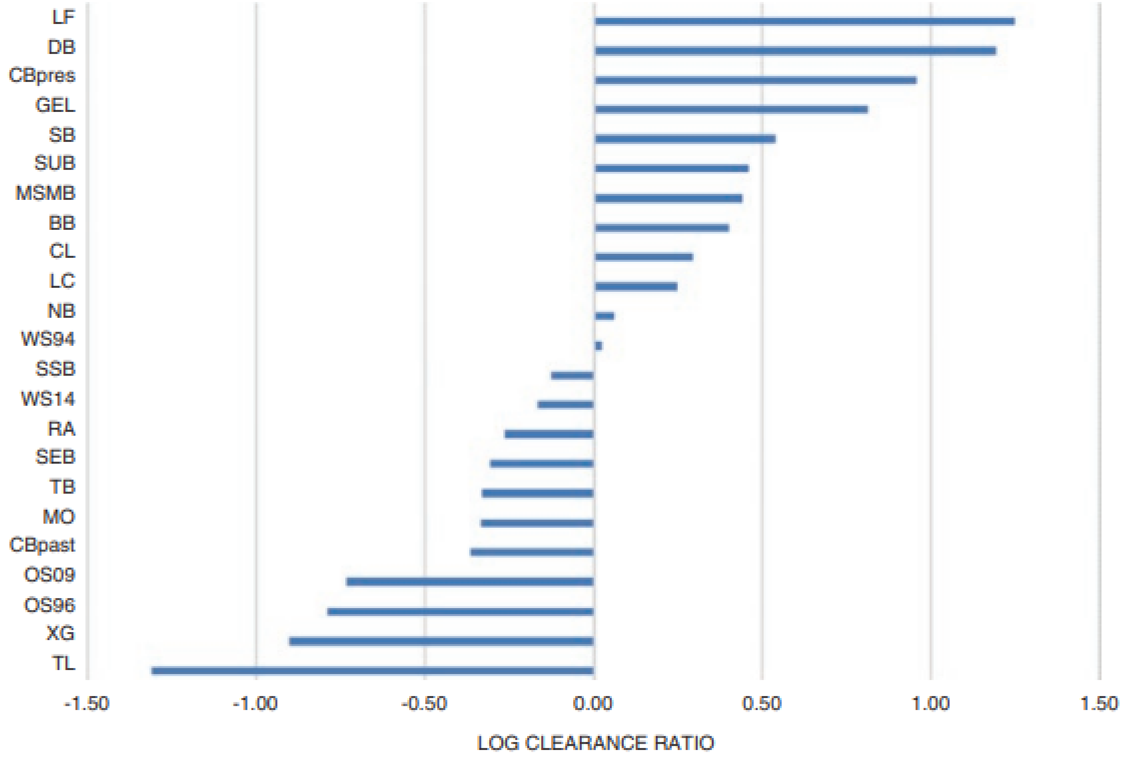



**Fig. 23.4** Log Clearance Ratio (CT/RT) of areas with bivalve aquaculture. Values >0 show areas with faster water renewal than water potentially cleared by the bivalves. This holds for Lysefjord (LF, Norway), Delaware Bay (DB, USA), Chesapeake Bay present (CBpres, USA), Grand Entree Lagoon (GEL, Canada), Saldanha Bay (SAB, S-Africa), Sungo Bay (SB, China), Mont St Michel Bay (MSMB, France), Beatrix Bay (BB, N-Zealand), Loch Creran (LC, UK), Narragansett Bay (NB, USA) and Wadden Sea 1994 (WS94) (see Annex I for details and references)
Values <0 show areas where bivalve filtration potentially regulates water column processes as clearance time is shorter than residence time; this is the case for South San Francisco Bay (SSB, USA), Western Wadden Sea 2014 (WS14, The Netherlands), Ria de Arosa (RA, Spain), Sechura Bay (SEB, Peru), Tracadie Bay (TB, Canada), Marennes-Oleron Bay (MO, France), Chesapeake Bay past (CBpast, USA), The Oosterschelde in 1996 and 2009 (OS, The Netherlands), Xiangang Bay (XG, [illegible]) and Thau Lagoon (TL, [illegible])

# Exempel på välkända modeller

FARM™, Farm Aquaculture Resource Management; www.farmscale.org
Beräknar tillväxt och odlingskapacitet samt ekonomiska värden
Kommersiella varianter av FARM
FARM | Aquaculture Modelling | Products and Services | Longline.co.uk

www.shellsim.com
Beräknar tillväxt och flöden av näringsämnen

Box modell för fiskodlingar MOM
Beräknar production carrying capacity inom givna FQS och EQS
www.ancylus.net

Ex på ecosystem modeller med hydrodynamiska modeller

www.shellgis.com
Ecosystem modell med MIKE hydrodynamisk 2D modell och shellsim

MIKE Eco Lab
https://mikepowerbydhi.com/products
3D modellering för ekosystem, odlingar, spridning mm

Software Simulation Products and Solutions – Deltares
Delft3D and Habitat tex, open source

# Övningar

www.farmscale.org

www.shellsim.com

Gå till http://shellsim.com/Demo/Register.aspx och registrera

MOM

www.ancylus.net

# MOM Modelling – Ongrowing fish farm- Monitoring system

The model was developed for estimating the holding capacity of sites for fish farming with regard to three basic requirements:

1. The benthic fauna must not dissappear due to accumulation of organic material
2. The water quality in the net pens must meet the needs of the fish
3. The waters in the areas surrounding the farm must not deteriorate

Carrying Capacity definition: *"the maximum population size of the species that the environment can sustain indefinitely"*

or

*The maximum quantity of fish that can be farmed at a site without the environmental impacts exceeding agreed tolerance limits*

# MOM Modelling – Ongrowing fish farm- Monitoring system

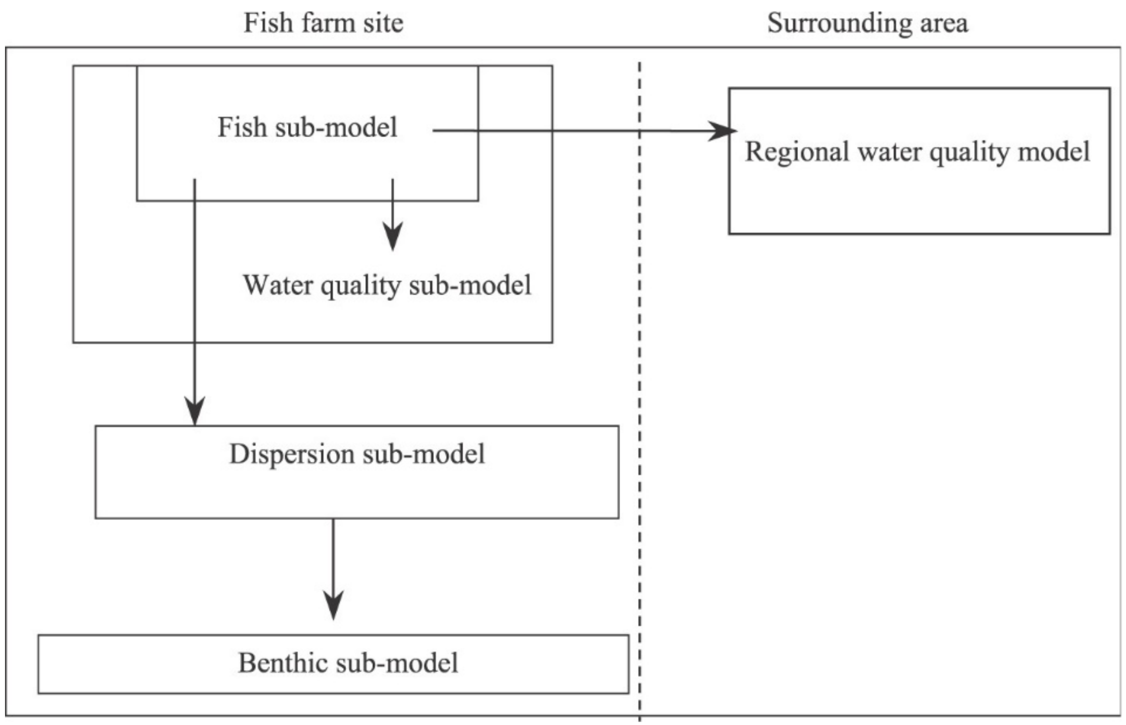



**Table 1.** Overview of standards (EQS, FQS) used in MOM

| Standard | Description | Scale | *CC* | Status |
|---|---|---|---|---|
| 1. EQS | At least two living species of benthic infauna everywhere in the farm area | Local | $CC_{bent}$ | Norwegian Standard* |
| 2. FQS | Oxygen concentration in the cages >60% saturation and >5 mg $O_2$ $L^{-1}$ | Local | $CC_{O_2}$ | Recommended† |
| 3. FQS | UIA ($NH_3$) concentration in the cages <0.020 mg $L^{-1}$ in seawater | Local | $CC_{UIA}$ | Recommended† |
| 4. EQS | Secchi depth should not decrease by >10% due to eutrophication | Regional | $CC_{reg}$ | Suggested‡ |
| 5. EQS | Minimum oxygen concentration in the basin water of a fjord >3.0–3.5 mL $O_2$ $L^{-1}$ | Regional | $CC_{reg}$ | Suggested§ |

* Norwegian Standards Association (2000).

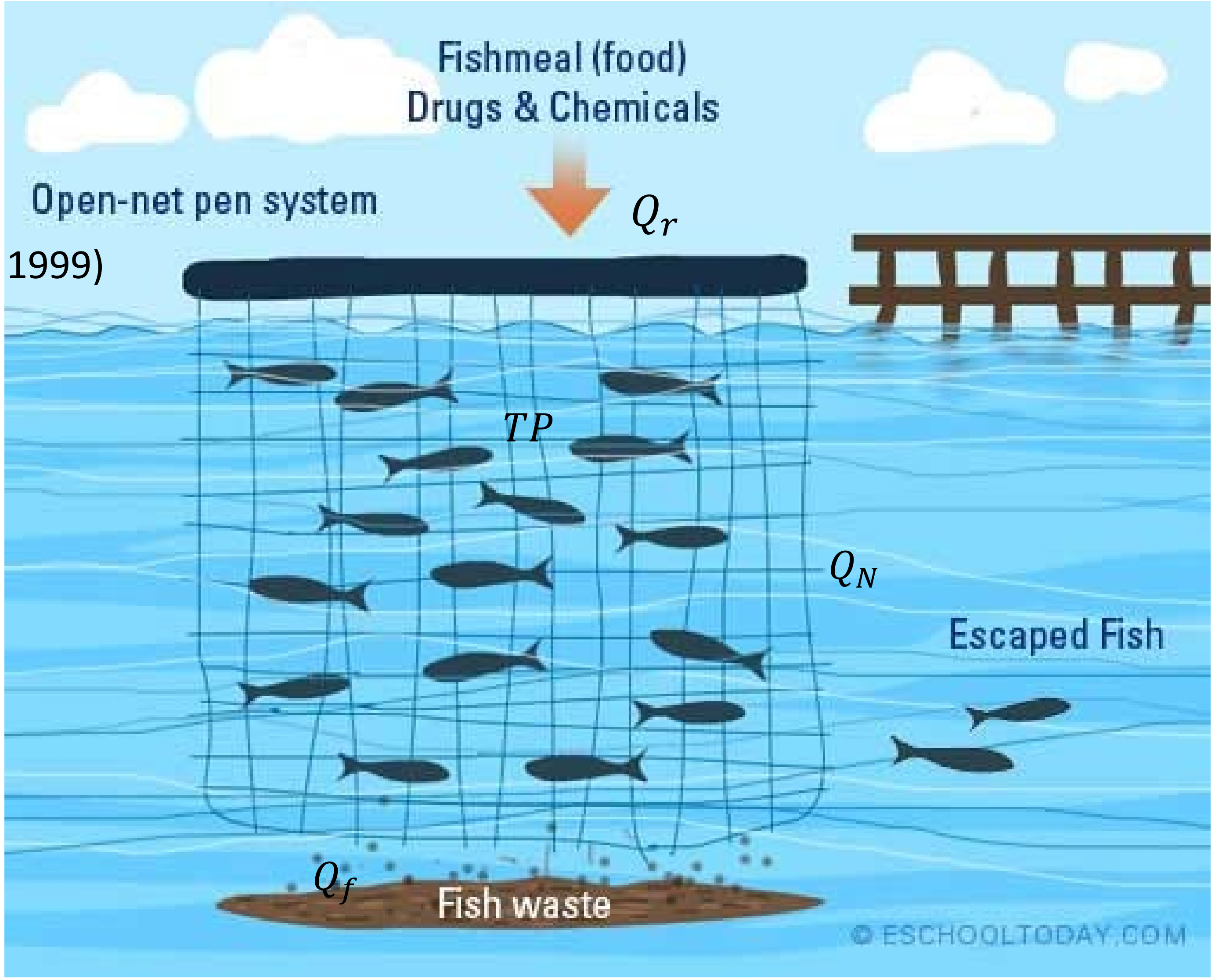
† Ervik, Agnalt, Asplin, Aure, Bekkvik, Døskeland, Hageberg, Hansen, Karlsen, Oppedal and Strand (2008).

‡ Aure and Stigebrandt (1990).

§ Buhl-Mortensen, Oug and Aure (2009).

EQS, environmental quality standards; FQS, farm water quality standards; *CC*, carrying capacity.

# Fish - model




Basic energy equation for fish (Webb, 1978, Stigebrandt, 1999)

$$Q_r - (Q_f + Q_N) = Q_s + Q_l + Q_{sda} + Q_g + Q_p.$$

Potential growth rate

$$\frac{dW}{dt} = aW^b$$ or in terms of energy $$Q_g = aC_{fi}W^b$$

When all terms are adressed

$$Q_r = \frac{1}{\mathcal{E}^*}(\alpha W^{\Upsilon} + aC_{fi}^*W^b)e^{\tau T}$$

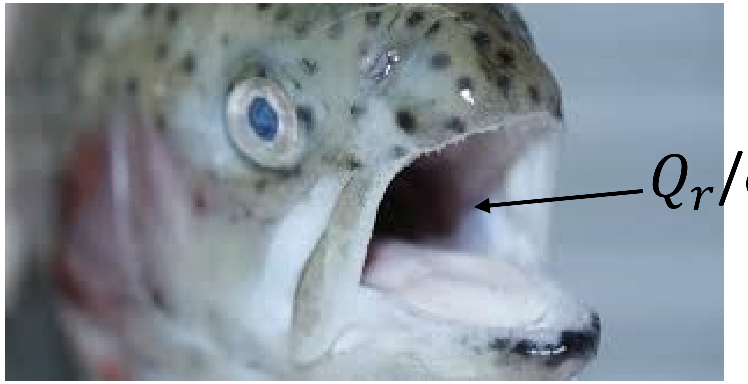
$$\frac{dW}{dt} = aW^b e^{\tau T}$$

For appetite and maximum growth

The specific energy content of feed is $\delta = F_p C_p + F_f C_f + F_c C_c$ i.e. the fractions of protein, fat and carbohydrates times the specific energy of protein, fat and carbs need be specified

Food conversion ratio, FCRt = appetite ($Q_r/\delta$) divided by the growth rate dW/dt

The wasted food is FCR – FCRt times $Q_r/\delta$ where FCR is the actual food given / fish mass increase




Emissions of ammonia, phospate:

$$EN = \left(\frac{F_p A_P Q_r}{\delta} - P_p \frac{dW}{dt}\right) N_P \qquad N_P \sim 1/6$$

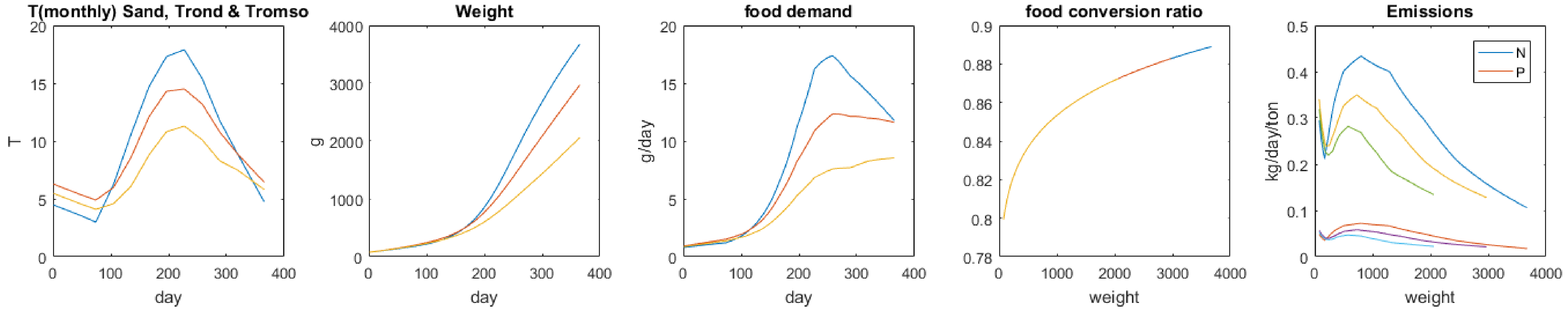
$$EP = \frac{EN}{6}$$

The respiratory oxygen demand by fish is

$$DO_2 = \left(\frac{F_p A_p Q_r}{\delta} - P_p \frac{dW}{dt}\right) O_p + \left(\frac{F_f A_f Q_r}{\delta} - P_f \frac{dW}{dt}\right) O_f + \frac{F_c A_c Q_r}{\delta} O_c$$

$O_p$=1.89 g $O_2$/g protein
$O_f$=2.91 g $O_2$/g fat
$O_c$=1.07 g $O_2$/g carbohydrate

# Examples of output from MOM fish model using seasonal Temperatures from 3 locations




The calculated temporal mean particulate effluents of organic material from the whole farm:

$$F_{1feed} = \frac{T_p}{A_F}(FCr - FCRt)$$

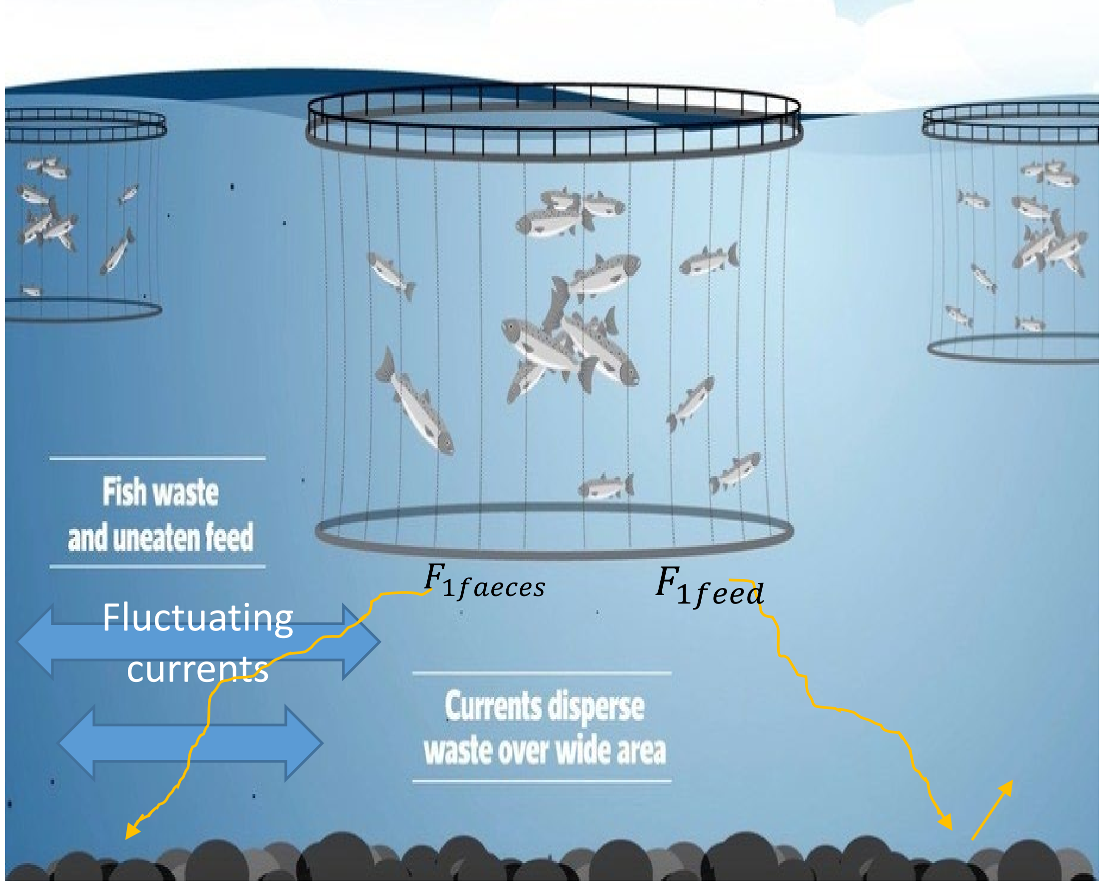
$$F_{1faeces} \sim 0.1\frac{T_P}{A_F}$$

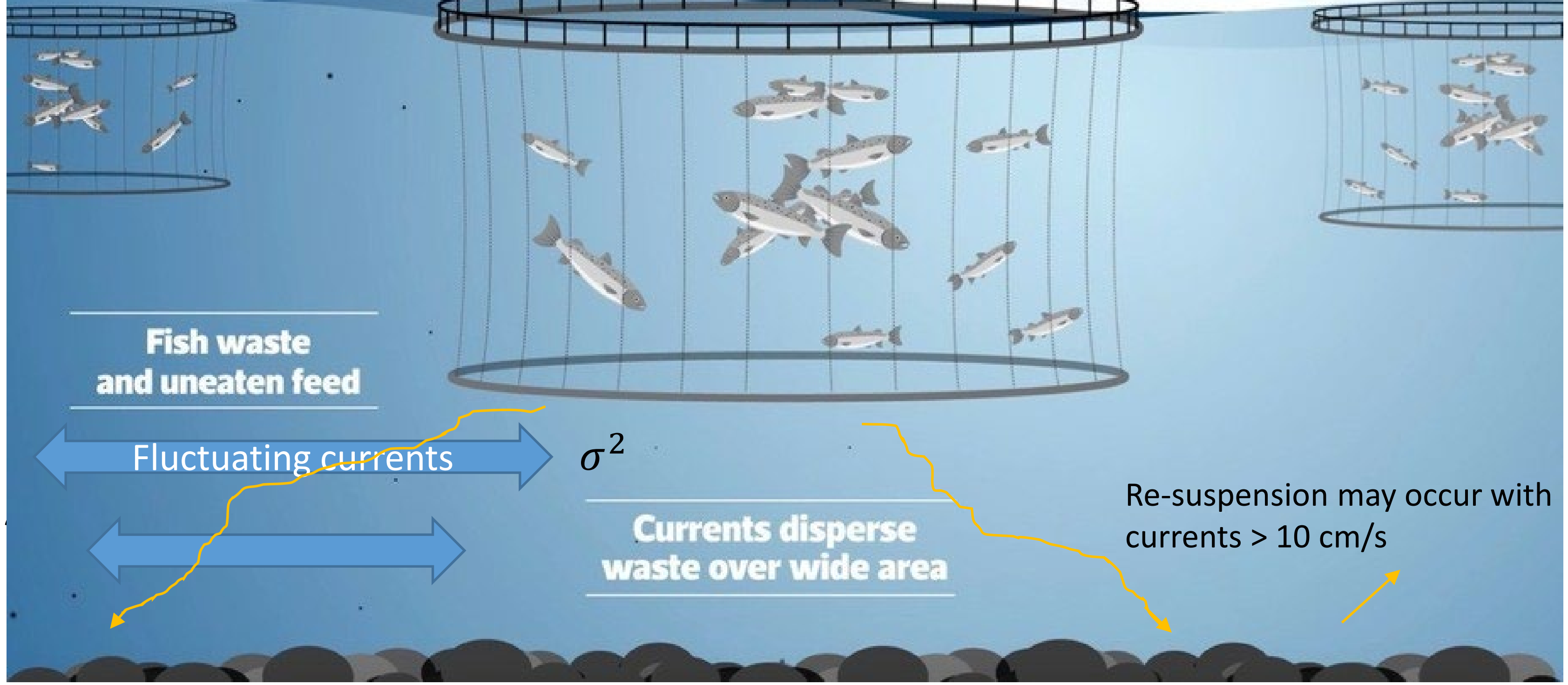
Where $T_p$, $A_F$ are fish production and total area of net pens

Assuming carbon content is 50% of excess feed and faeces

$$F_{1C} = 0.5(F_{1feed} + F_{1faeces})$$

The total carbon flux is input to the **Dispersion model**






the **Dispersion model**

The footprint of the sinking particles depends on how it is dispersed before hitting the bottom (Stigebrandt & Aure, 1995). Variance, $\sigma^2$, of the fluctuating currents at mid-depth and down to the bottom and perpendicular to the net pen rows should be used. The dispersion increases with variability and sinking time $T = H/w(s)$ where $H$ is distance to the bottom below the net pens and w is sinking velocity. The dispersion capacity of a site is given by its dispersion length $\sigma T = \sigma H/w$
Sedimentation at a distance r from the cage center, $F_2(r) = \mu(r)F_1$ ($\mu(r)$ is filed normalized loading function)
Max carbon flux $F_{2C}$ to the sediment under the farm is computed as

$F_{2C} = 0.5(\mu_{feed}F_{1feed} + \mu_{faeces}F_{1faeces})$ (gC $m^{-2}$ $day^{-1}$) is input to the **Benthic model**

## Benthic sub-model

$$\alpha\eta F_2 = F_{O_2}$$

$F_{O_2}$= oxygen flux needed to oxidise $\alpha F_2$

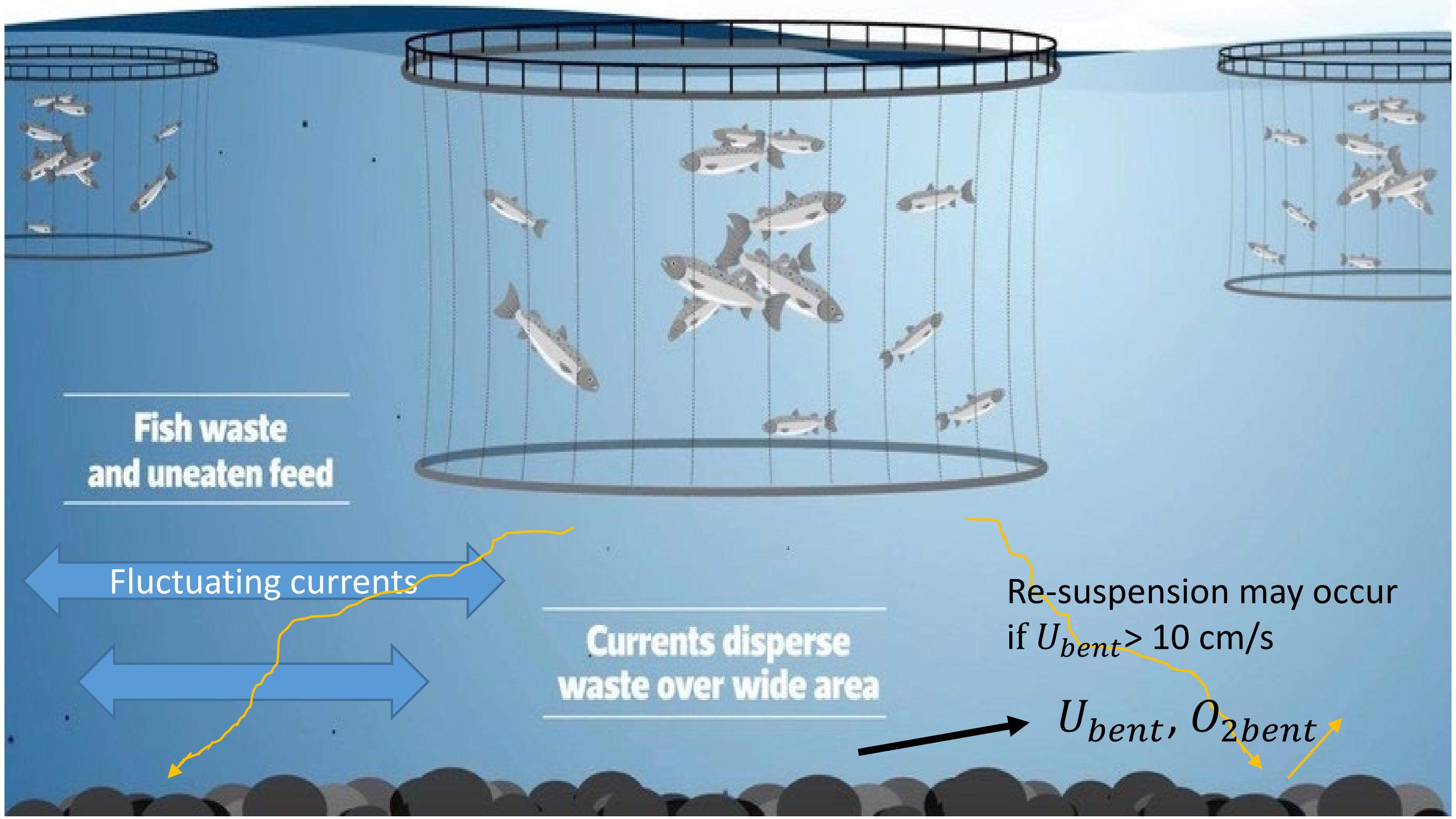
$\alpha$ =fraction organic matter reaching the bottom

η =3.5 g O2/g C

$$F_{O2} = \beta U_{bent}(O_{2i} - O_{2bent})$$

$$F_{2max} = \frac{U_{bent}\beta}{\alpha\eta}(O_{2i} - O_{2min})$$

Max acceptable organic sedimentation on the bottom




$\beta U_{bent}$ is effective vertical velocity that transfers oxygen to the bottom. The goal is to calculate maximum potential fish production, TPF, that does not lead to extinction of the benthic infauna

$$TPF_{bent} = \frac{2\beta A U_{bent}(O_{2i} - O_{2min})}{\alpha\eta((FCR - FCR_t)\mu_{feed} + 0.1\mu_{faeces})}$$

The effluents of nitrogen and the consumption of oxygen calculated by the **fish model** is used in the **sub-model of water quality in the fish cages**

The respiratory oxygen demand by the fish $DO_2$ was calculated in the fish model.

The rate of oxygen consumption of the fish in a farm of length $L_F$ and depth D by a current with speed $U_{min}$ equals:

$$OX1 = (O_{2in} - O_{2out}) L_F D U_{min}$$

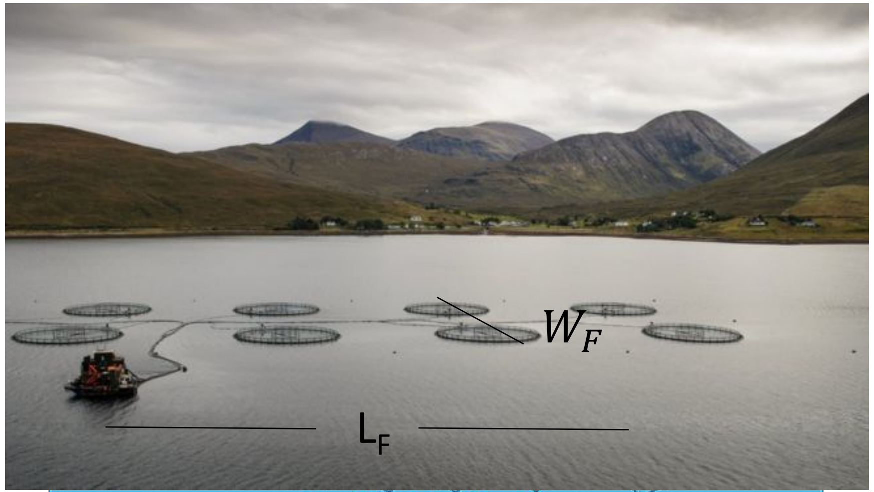
$$U_{min} \approx \frac{W_F}{TF_{max}}$$

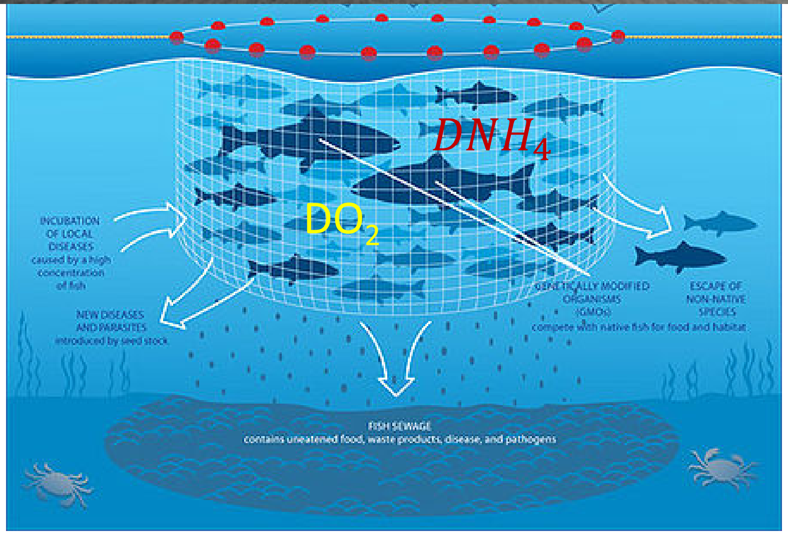
One may obtain for the maximum or critical total production using oxygen conditions in the farm

$$TPF_{O2} = \frac{(O_{2in} - O_{2min}) L_F D P_F U_{min}}{DO_2} \qquad O_{2in} > O_{2min}$$

$$TPF_{NH4} = \frac{(NH_{4max} - NH_{4in}) L_F D P_F U_{min}}{DNH_4} \qquad NH_4 < NH_{4max}$$

$P_F$ =permeability of the farm (0 – 1)



The holding capacity of a location, PROD, is determined by the minimum value of the TPFs

PROD = min($TPF_{bent}$, $TPF_{O2}$, $TPF_{NH4}$)

$TPF_{bent}$ is usually the smallest

Summary of inputs and outputs:

- Monthly surface temperatures
- Typical surface salinity
- Mean depth
- Oxygen concentrations at the bottom
- Ammonium concentrations in the area
- Current statistics (variance) from at least 3 depths
- $O_{2min}$ in the cages
- $NH_{4max}$ in the cages
- Geometry of the farm, nr of rows and pens and distance
- Net pen depths
- Through flow reduction factor
- Factual feed factor, FCR
- Feed composition fractions (fat, protein, carbs, ash)
- Feed sinking velocity
- Faeces sinking velocity
- Fractions of protein and fat in fish
- Start and harvest weight of fish

Outputs include:

- Theoretic feed coefficient, FCRt
- Feed specific energy
- Time to reach final weight
- Average weight of the fish
- Maximum flux of organic matter to the sediment
- Emissions of dissolved nutrients
- Theoretical current reduction factor
- Emissions of particular N and P
- Emissions of faeces and excess feed to the sediment
- Nr of net pens needed
- Density of fish (kg/m$^2$)
- Which of the criteria ($TPF_{bent}$, $TPF_{O2}$, $TPF_{NH4}$) that limits the production
- Seasonal production
- Maximum yearly production