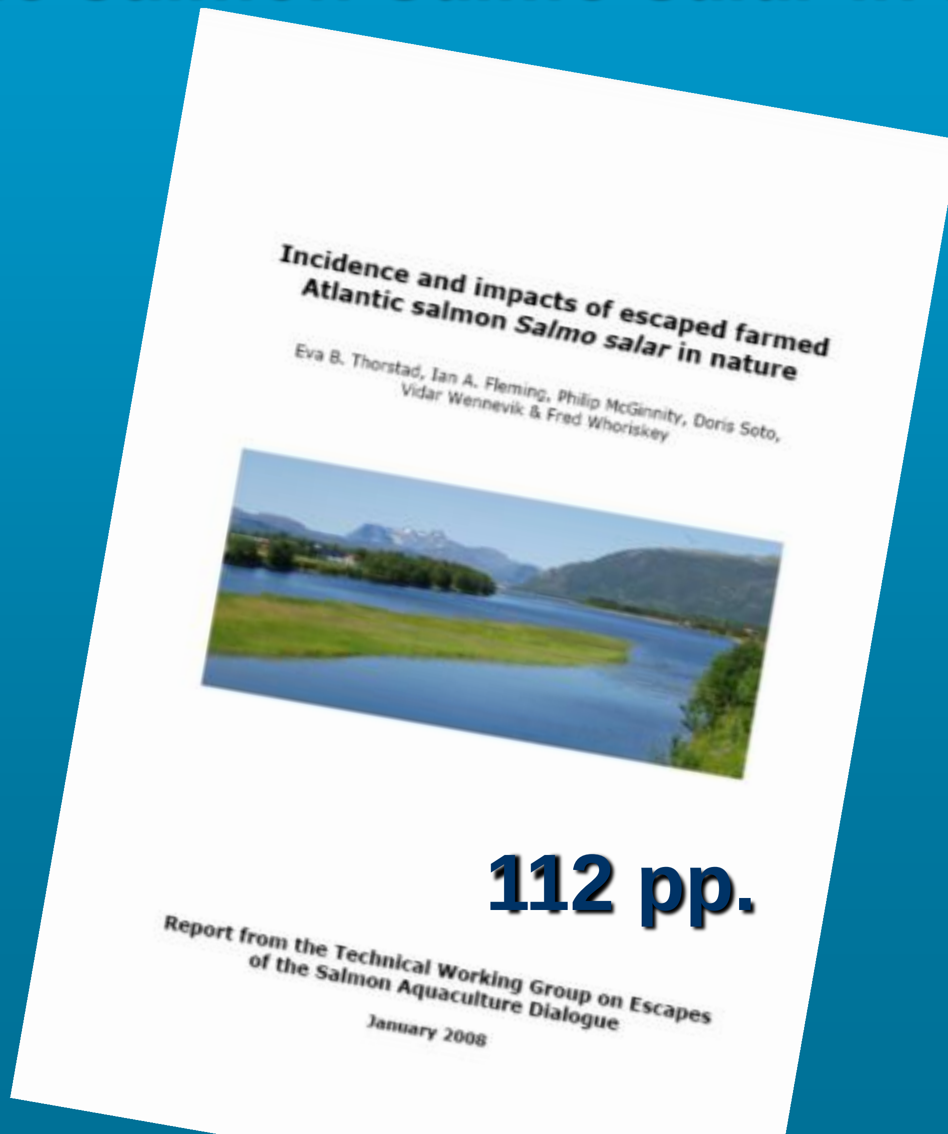
Incidence and impacts of escaped farmed Atlantic salmon *Salmo salar* in nature

Report from the Tecnical Working group on Escapes

Incidence and impacts of escaped farmed Atlantic salmon *Salmo salar* in nature



112 pp.

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AIMS

Examine:

i) incidence and impacts of escaped salmon in nature

ii) technologies and efforts to prevent escapes and their impacts

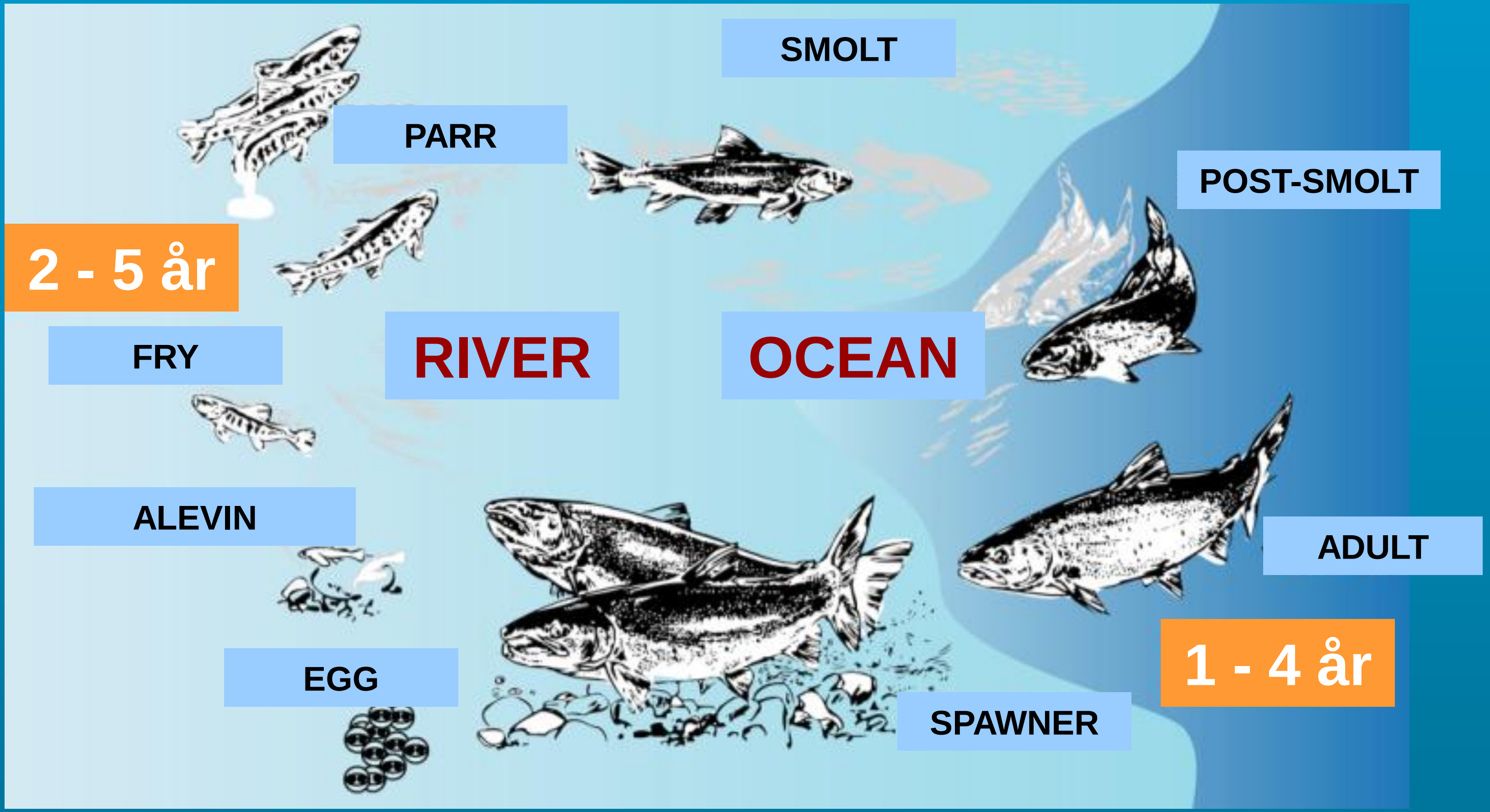
- **Reviewing status of current research**
- **Identifying conclusions resolved by past research**
- **Identifying knowledge gaps and research needs**

- Science based review (establishing today's scientific knowledge base)
- Based on peer-reviewed scientific publications
- Other sources (”grey literature”) to cover local and regional aspects

Contents

- Trends in numbers and proportions of escaped salmon
- Ecological and behavioural interactions
- Genetic differences and effects of inter-breeding
- Atlantic salmon as an exotic
- Technologies and efforts for escape prevention
- Technologies and efforts to reduce impacts of escapes
- Main conclusions

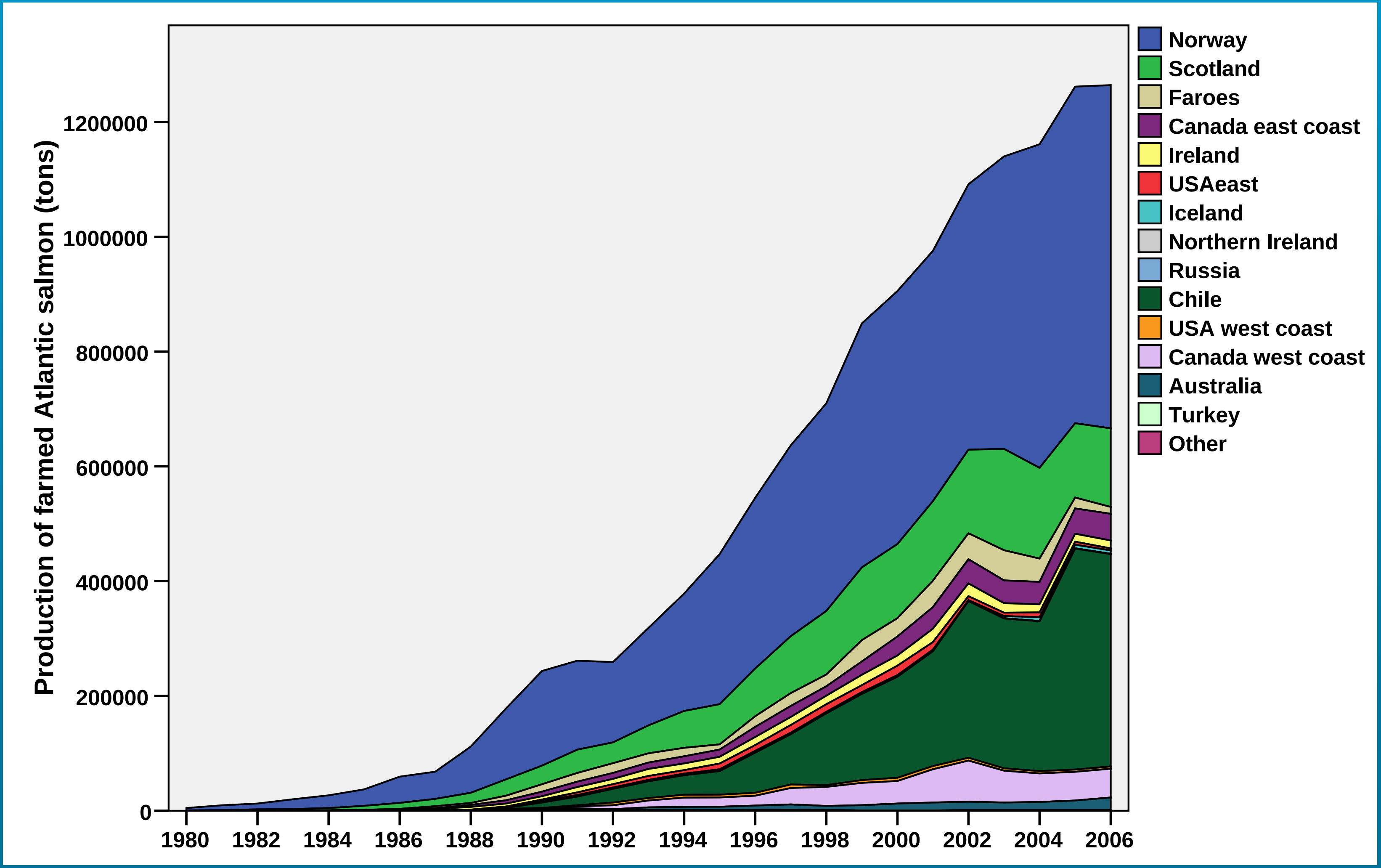
Anadromous life cycle



World production

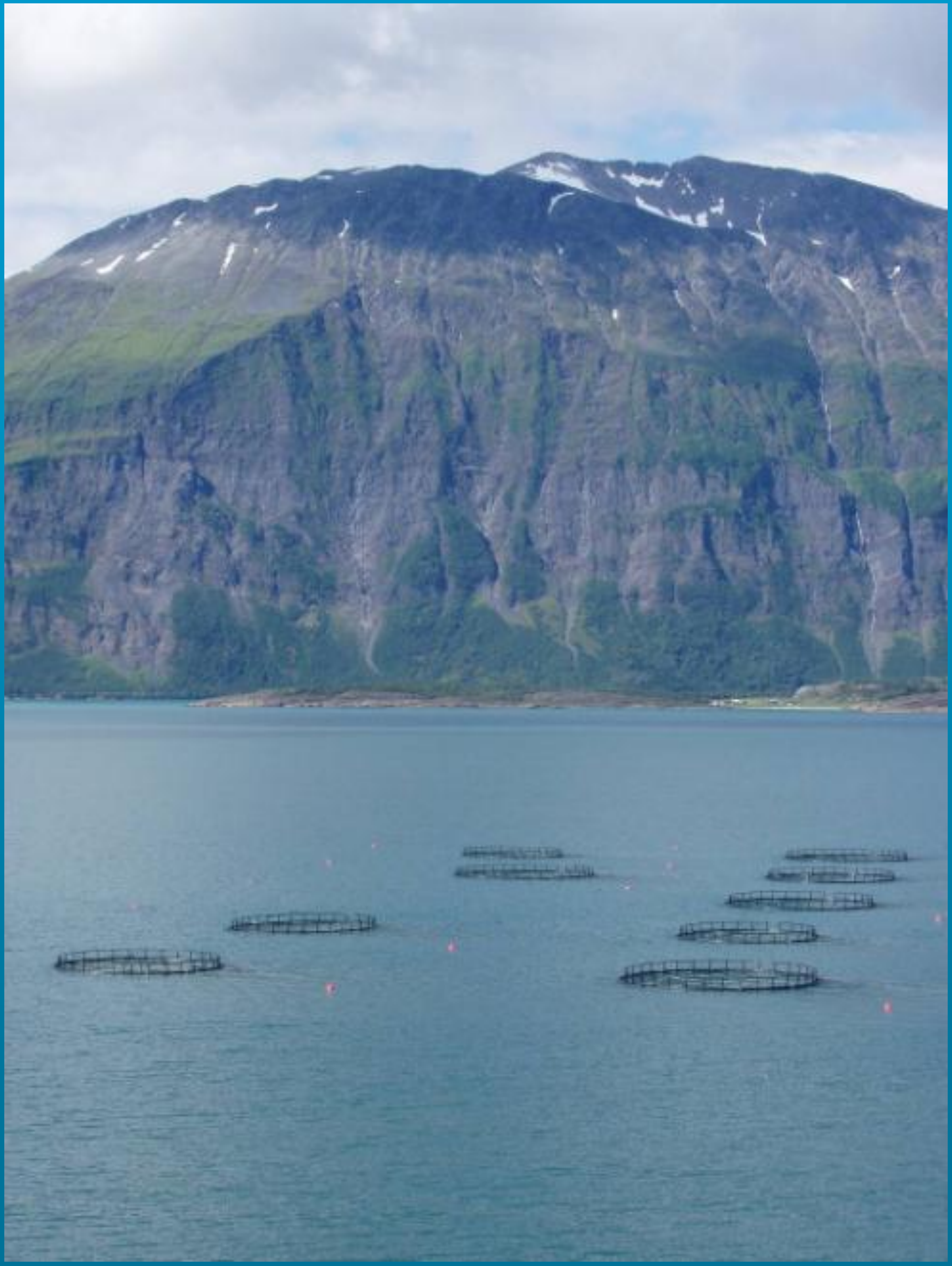
(2005, reported to ICES)

Annual production increased from 5000 to 1262000 metric tons (1980-2005)



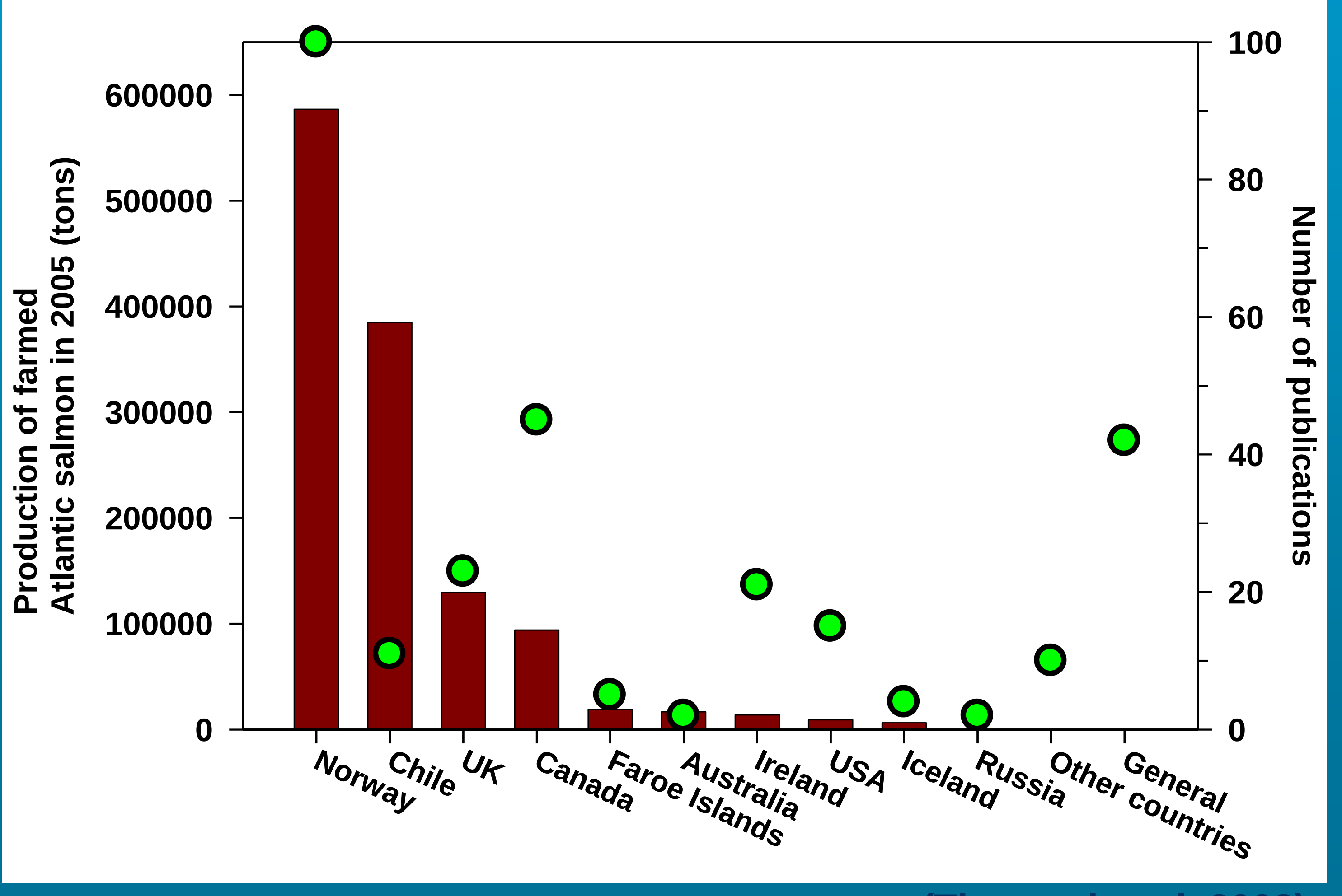
(2005, reported to ICES)

With net-pen culture, some salmon escape into the wild



The most extensive and thorough review on salmon escapes

- covers 274 scientific papers and reports



(Thorstad et al. 2008)

2 Geographical and temporal trends in numbers and proportions of escaped farmed salmon in nature

2 Geographical and temporal trends in numbers and proportions of escaped farmed salmon in nature

- Country specific overview
- Methods to identify escaped farmed salmon
- Migration, dispersal and survival

Nearly all countries

- farmers required to report escapes
- statistics available to public

Exceptions

NEW BRUNSWICK and NORTHERN IRELAND

Required to report, but statistics not available

FAROE ISLANDS

Required to report from 2007? Statistics available

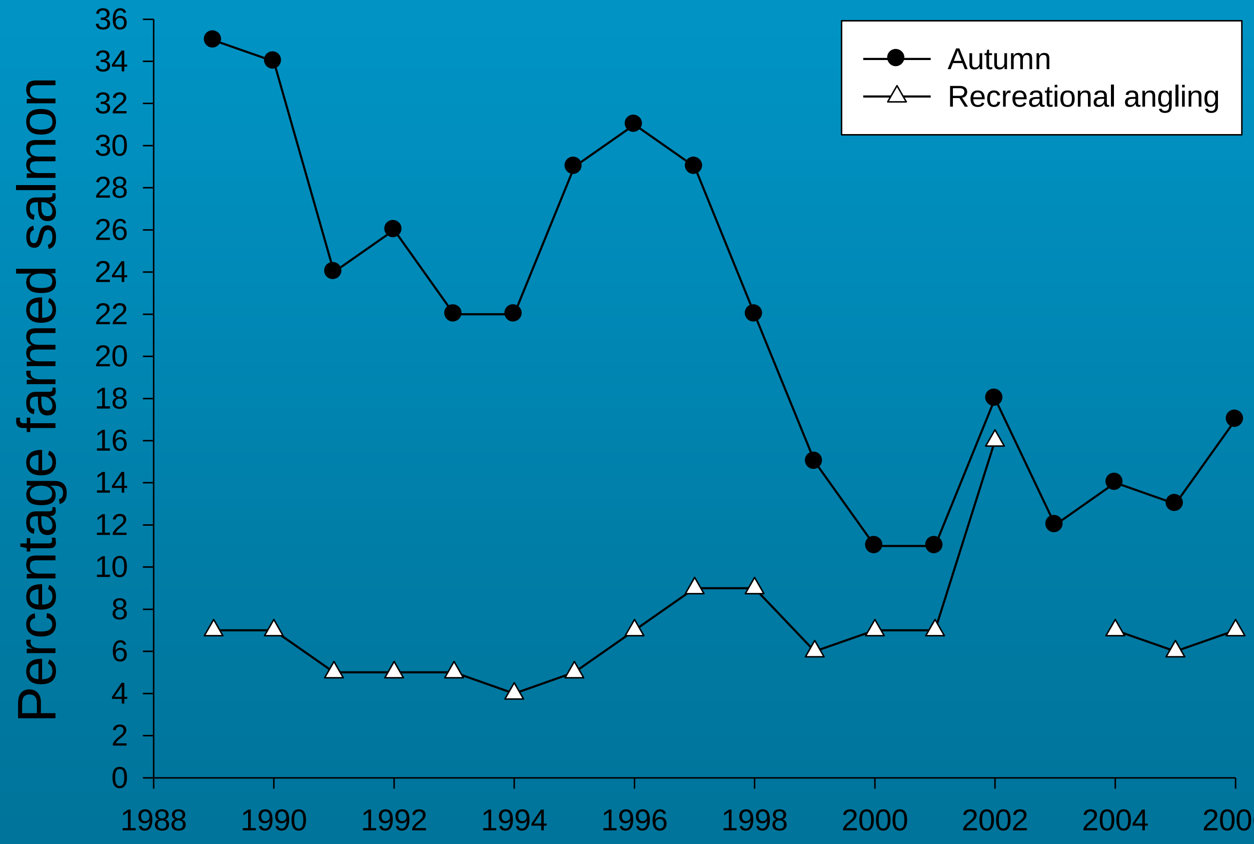
Occurrence of escaped salmon in nature that are not from reported large-scale events: proportion of unreported losses unknown

(lew level leakage, freshwater hatcheries, non-reported events)

(e.g. Stokesbury & Lacroix 1997, Clifford et al. 1998, Lund 1998, Stokesbury et al. 2001, Lacroix & Stokesbury 2004, Skilbrei & Wennevik 2006, Fiske et al. 2005, 2006b, 2007, Carr & Whoriskey 2006)

Actual numbers of escaped salmon is not known for any locality or geographic area

Monitored rivers in Norway:
7% in summer, 21% during spawning



(Hansen et al. 2007)

Distribution and survival after escape depends on life-stage and time of the year

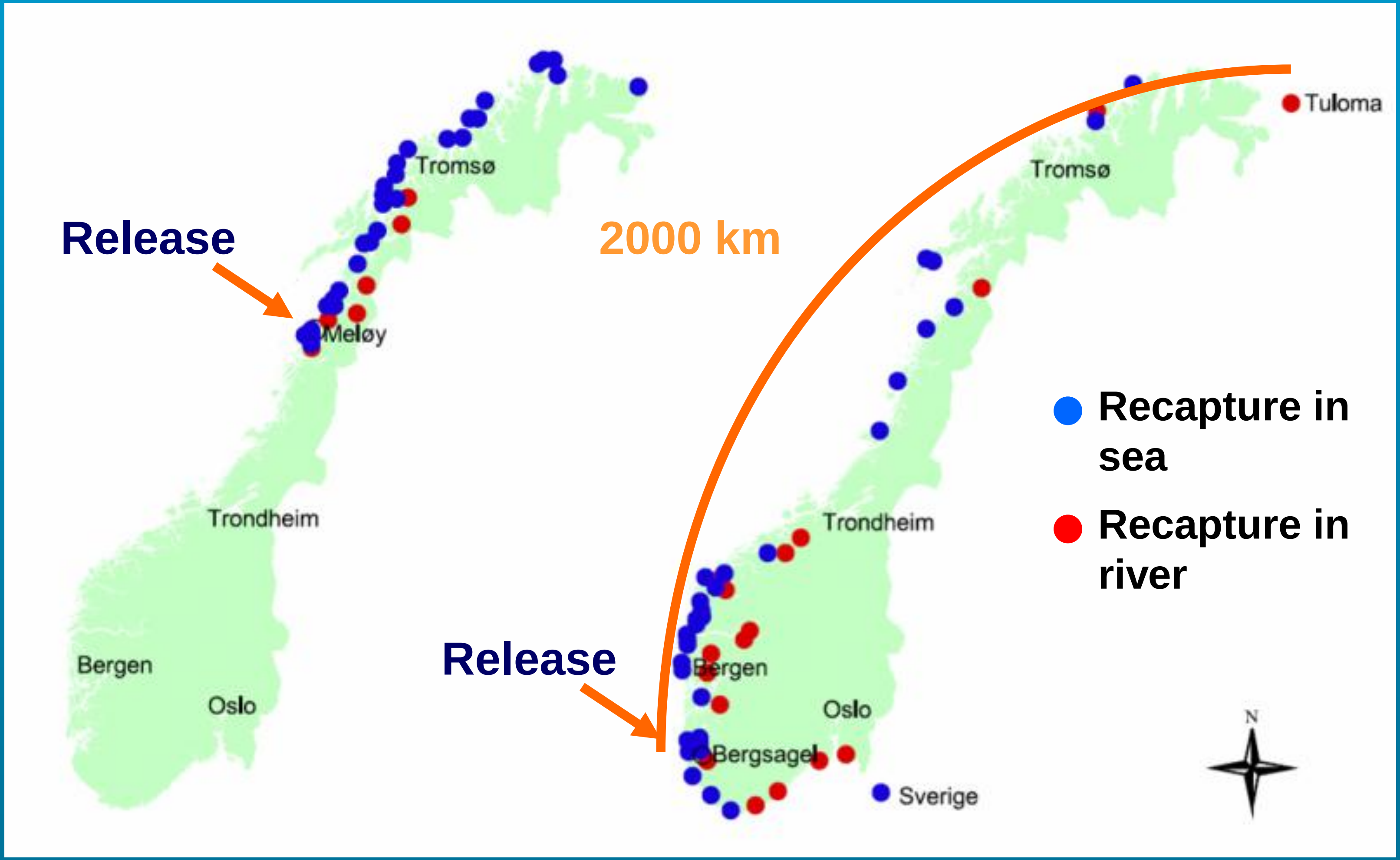
- Juveniles from freshwater hatcheries generally home as adults to the river they escape into
- Salmon released as smolts tend to home to release area and enter nearby rivers
- Pre-adults seem to have a weak homing instinct and appear to move with the current
- Near mature fish escaping close to spawning period seem to enter nearby rivers

(e.g. Hanssen & Jonsson 1991, Heggberget et al. 1991, Heggberget et al. 1993, review by Jonsson 1997, Skilbrei et al. 1998, Hansen 2006a, Whoriskey et al. 2006)

Distribution and survival after release depends on life-stage and time of the year

- Survival rates are not known for any of the groups

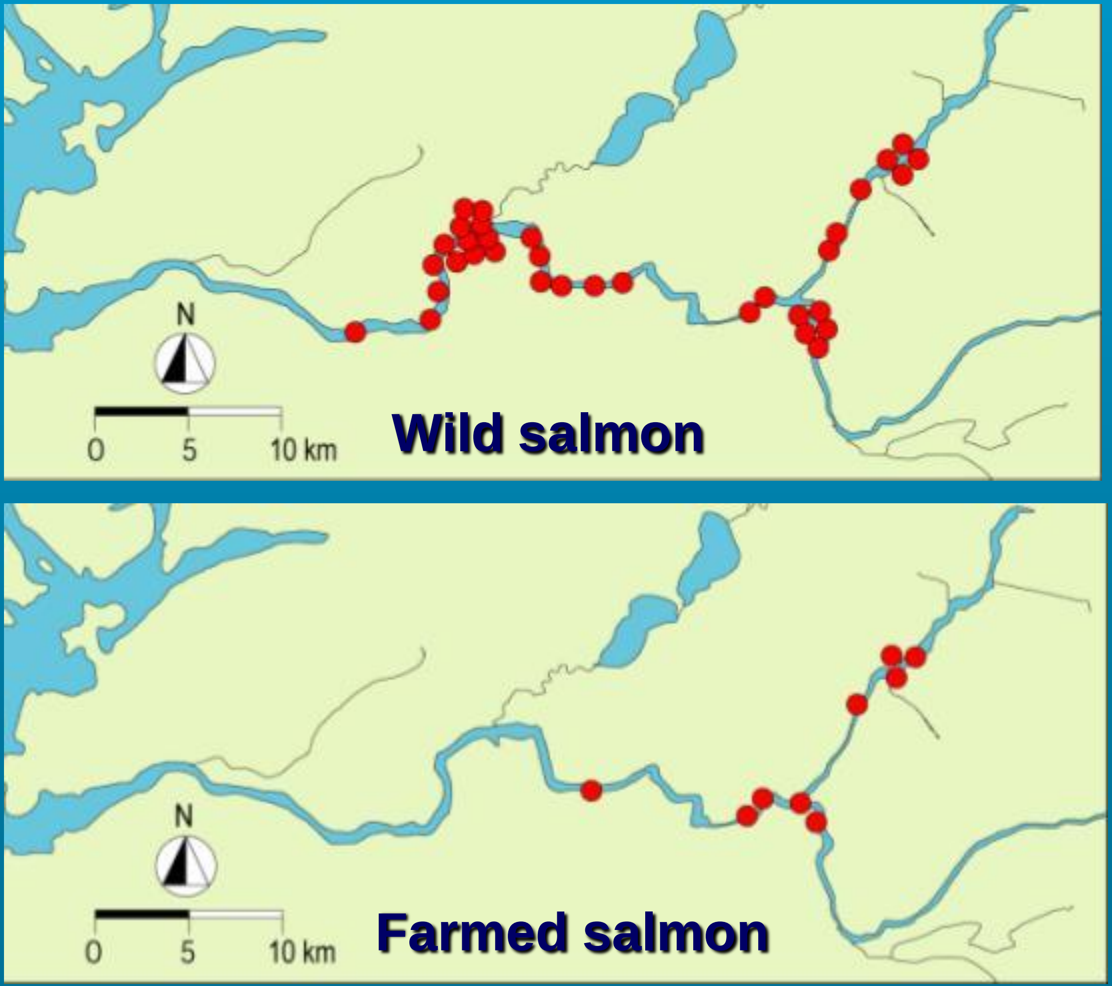
Pre-adults have a weak homing instinct



(Hansen 2006)

Escaped farmed salmon entering rivers:

distribution high up in the rivers and present on spawning grounds together with wild salmon



(Thorstad et al. 1998)

Knowledge gaps and resource needs

- The actual numbers of salmon escaping from farms is not known for any geographical area. More information on why, which (e.g. life stage) and how many fish are escaping is needed.
- Information on the survival and dispersal of escaped farmed salmon at different life stages, different sites and different times of the year is still missing.

3 Ecological and behavioural interactions between wild and farmed Atlantic salmon in nature

- Morphological characteristics and physical condition of farmed salmon

3 Ecological and behavioural interactions between wild and farmed Atlantic salmon in nature

- Food competition in coastal areas and in the ocean

3 Ecological and behavioural interactions between wild and farmed Atlantic salmon in nature

- Interactions during spawning, spawning success and production

3 Ecological and behavioural interactions between wild and farmed Atlantic salmon in nature

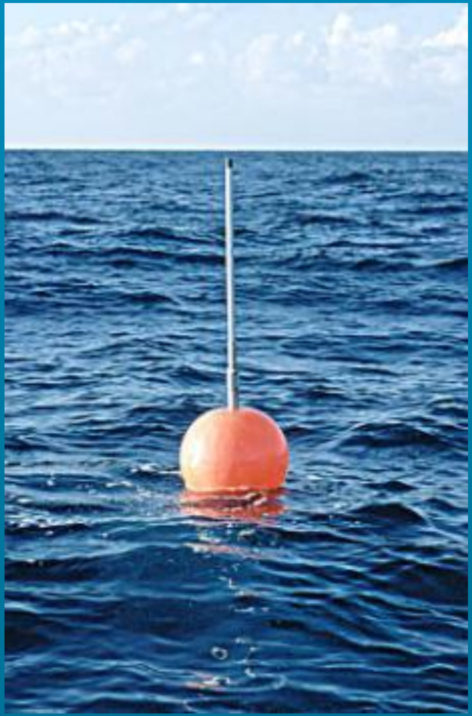
- Performance of farmed salmon offspring and effects on wild populations

Wild and farmed fish differ morphologically and in physical condition

likely affect behaviour, competitive ability and spawning success

(e.g. Aksnes et al. 1986, Fleming et al. 1994, Fleming et al. 1996, Fleming & Einum 1997, Thorstad et al. 1997, Dunmall & Schreer 2003, Poppe et al. 2003, Enders et al. 2004, Fiske et al. 2005a, reviewed by Jonsson & Jonsson 2006)

Unlikely that food competition from escaped farmed salmon is a problem in the Atlantic Ocean



(Jacobsen & Hansen 2001, Hislop & Webb, Jonsson & Jonsson 2004, Jonsson & Jonsson 2006)

Escapees entering rivers

Spawning, but with reduced success - especially males

(Lura & Sægrov 1991, 1993, Webb et al. 1991, 1993a,b, Crozier 1993, Lura et al. 1993, Fleming et al. 1996, 1997, 2000, Sægrov et al. 1997, Clifford et al. 1998a,b, Crozier 2000, Garant et al. 2003, Weir et al. 2004, 2005)

Escapees entering rivers

Salmon escaping at early life stages have likely a higher spawning success than recently escaped salmon

(Lura & Sægrov 1991, 1993, Webb et al. 1991, 1993a,b, Crozier 1993, Lura et al. 1993, Fleming et al. 1996, 1997, 2000, Sægrov et al. 1997, Clifford et al. 1998a,b, Crozier 2000, Garant et al. 2003, Weir et al. 2004, 2005)

Escapees entering rivers

Genetic component to breeding time. Escapees may spawn before, at the same time as or after wild salmon

(Lura & Sægrov 1991, 1993, Webb et al. 1991, 1993a,b, Crozier 1993, Lura et al. 1993, Fleming et al. 1996, 1997, 2000, Sægrov et al. 1997, Clifford et al. 1998a,b, Crozier 2000, Garant et al. 2003, Weir et al. 2004, 2005)

Juvenile stages

- Farm salmon and hybrids (farm x wild) can be expected to interact and compete directly with wild fish for food, habitat and territories.
- Farm juveniles are generally more aggressive and consume similar resources as wild fish. They grow faster than wild fish, which may give them a competitive advantage at some life stages.
- The outcome of aggressive interactions vary and depend on the environment and the genetic background of the competitors

(McGinnity et al. 1997, 2003, Einum & Fleming 1997, Fleming & Einum 1997, Thodesen et al. 1999, Fleming et al. 2000, 2002, Johnsson et al. 2001, Handeland et al. 2003, Metcalfe et al. 2003, Weir & Fleming 2006)

Large-scale whole river experiments

Highly reduced survival and lifetime success of farm and hybrid salmon

Burrishoole, Ireland

Imsa, Norway

(McGinnity et al. 1997, 2003, Fleming et al. 2000)

Large-scale whole river experiments

- **Burrishoole: 15-30% reduction in juvenile recruitment. Farmed smolt output only 56% relative to the wild.**

**Burrishoole,
Ireland**

**Imsa,
Norway**

(McGinnity et al. 1997, 2003, Fleming et al. 2000)

Large-scale whole river experiments

- Imsa: Lifetime success of farm salmon 16% of that of wild. Overall production reduced by 30%.

Burrishoole, Ireland

Imsa, Norway

(McGinnity et al. 1997, 2003, Fleming et al. 2000)

Conclusions

- **Invasions of escaped farmed salmon have the potential to impact the productivity of wild salmon populations negatively through juvenile resource competition and competitive displacement**

Conclusions

- The outcome of ineractions between farm and wild salmon will be context-dependent, varying with a number of environmental and genetic factors, but will frequently be negative for wild salmon

Knowledge gaps and research needs

Spawning success of farmed salmon likely varies at different competition levels (densities of spawners), but this has not been quantified.

It is not known how a continuous influx of escaped farmed salmon influences wild salmon production over many years/generations in different rivers. Only studies of the ecological impacts over a single generation have been performed.

4 Genetic differences between farmed and wild Atlantic salmon and the effects of inter-breeding on wild populations

- Population structure and local adaptations in wild Atlantic salmon
- Genetic differences between wild and farmed salmon
- Genetic impact of inter-breeding on wild salmon
- Genetic impact of inter-breeding on wild brown trout



Several recent reviews/books

- Garcia de Leaniz, C., Fleming, I.A., Einum, S., Verspoor, E., Jordan, W.C., Consuegra, S., Aubin-Horth, N., Lajus, D., Letcher, B.H., Youngson, A.F., Webb, J., Vøllestad, L.A., Villanueva, B., Ferguson, A. & Quinn, T.P. 2007. A critical review of inherited adaptive variation in Atlantic salmon. Biological Reviews 82: 173-211.
- Verspoor, E., Stradmeyer, L. & Nielsen, J.L. (eds) 2007. The Atlantic salmon. Genetics, Conservation and Management. Blackwell Publishing, 500 pages.
- Verspoor, E., Beardmore, J.A., Consuegra, S., García de Leániz, C., Hindar, K., Jordan, W.C., Koljonen, M.-L., Mahkrov, A., Paaver, T., Sánchez, J.A., Skaala, Ø., Titov, S. & Cross, T.F. 2005. Population structure in the Atlantic salmon: insights from 40 years of research into genetic protein variation. Journal of Fish Biology 67 (Supplement A): 3-54.
- Svåsand, T., Crosetti, D., García-Vásquez, E. & Verspoor, E. 2007. Genetic impact of aquaculture activities on native populations. Final scientific report. The GENIMPACT project funded under the EU Framework Programme 6.

Population structure and local adaptations in wild Atlantic salmon

- Natal homing: Structured in populations and meta-populations with little gene flow between
- Evidence for local adaptation is compelling, though its degree and spatial scale remain unclear

(e.g. Ståhl 1987, Taylor 1991, King et al. 2001, Primmer et al. 2006, Verspoor 1997, 2005, Verspoor et al. 2005, 2007, Garcia de Leaniz et al. 2007)

Population structure and local adaptations in wild Atlantic salmon

- **Local adaptations most likely varies spatially and can be ecpected to be lower within meta-populations**

(e.g. Ståhl 1987, Taylor 1991, King et al. 2001, Primmer et al. 2006, Verspoor 1997, 2005, Verspoor et al. 2005, 2007, Garcia de Leaniz et al. 2007)

Genetic differences between wild and farmed salmon

- **World farmed salmon is largely based on a few breeding strains**

(e.g. Cross & Challanain 1991, Skaala et al. 2005, Gjøen & Bentsen et al. 1997, Verspoor et al. 2006, Ferguson et al. 2007)

Genetic differences between wild and farmed salmon

- Differentiation of farmed strains from wild populations expected due to:
  - effects of limited numbers in establishing strains
  - domestication selection
  - loss of variability by genetic drift
  - selective breeding for economic traits

(reviewed by Ferguson et al. 2007)

Genetic differences between wild and farmed salmon

- **Differences due to domestication, trait selection and unintentional correlated changes for**

growth rate, body size, survival, delayed maturity, stress tolerance, temperature tolerance, disease resistance, flesh quality, egg production, deformity, spawning behaviour and success, spawning time, morphology, fecundity and egg viability, aggression, risk-taking behaviour, sea water adaptation and growth hormone production

(Einum & Fleming 1997, Fleming & Einum 1997, McGinnity et al. 1997, Clifford et al. 1998a,b, Thodesen et al. 1999, Johnsson et al. 2001, Fleming et al. 2002, Singer et al. 2002, Garant et al. 2003, Handeland et al. 2003, McGinnity et al. 2003, Metcalfe et al. 2003, Enders et al. 2004, Weir et al. 2005, reviewed by Ferguson et al. 2007)

Genetic impact of interbreeding

- Two main types of genetic change can occur due to hybridisation of farmed with wild salmon and gene flow from farmed to wild salmon through backcrossing of these hybrids in subsequent generations:

1) a change in the level of genetic variability

2) changes in the frequency and type of alleles present

(reviewed by Ferguson et al. 2007)

Genetic impact of interbreeding

- Hence, hybridisation can genetically alter native populations, reduce local adaptation and negatively affect population viability and character

Genetic impact of interbreeding

- **Changes in the genetic composition of some wild populations are documented**

(Crozier 1993, 2000, Clifford et al. 1998a,b, Skaala et al. 2006)

Genetic impact of interbreeding

- **Large-scale experiments undertaken in Ireland and Norway gave similar results, showing highly reduced survival and lifetime success of farm and hybrid salmon compared to wild salmon**

(McGinnity et al. 1997, Fleming et al. 2000, McGinnity et al. 2003)

Genetic impact of interbreeding

- **The estimated lifetime success ranged from lowest for the farm progeny to highest for the local wild progeny with intermediate performace for the hybrids**

(McGinnity et al. 1997, Fleming et al. 2000, McGinnity et al. 2003)

Farmed salmon inter-breeding with wild brown trout

- **Escaped farmed salmon increase rates of hybridisation between Atlantic salmon and brown trout**
- **Salmon-trout hybrids survive well but rarely reproduce and, thus, may lower the productivity of local populations, and in very rare cases lead to introgression of genetic material from one species into the other**

(Youngson et al. 1993, Hindar & Balstad 1994, Mattews et al. 2000, Hindar & Fleming 2005)

Knowledge gaps and research needs

- **Shown that inter-breeding of farm with wild salmon can result in reduced lifetime reproductive success, lowered fitness and decreased population productivity over at least two generations, however, no data on the long-term effects beyond the second generation**
- **Not known whether these effects will lead affected populations into extinction vortices, or whether a balance between changes caused by inter-breeding with escaped farmed salmon and the natural selection counteracting these changes might be reached**

Knowledge gaps and research needs

Likely different outcomes in different wild populations, dependent on e.g

- **type and numbers of escaped farmed salmon entering rivers**
- **whether escape events will be ongoing**
- **the genetic composition of the wild salmon**
- **the size and status of the recipient wild population**
- **the importance of local adaptations**

Knowledge gaps and research needs

- Given the length and cost of field experiments, the most realistic way forward is to continue the development of computer-based predictive models, which allow for risk assessment across the range of escape scenarios
- Realistic models can be used to both assess risks of direct genetic interactions, and to identify further research priorities

Knowledge gaps and research needs

- **Systematic monitoring of possible genetic changes in wild populations with continuous incursions of escaped salmon can give insights into which are the most vulnerable wild populations and the reason for their vulnerability**

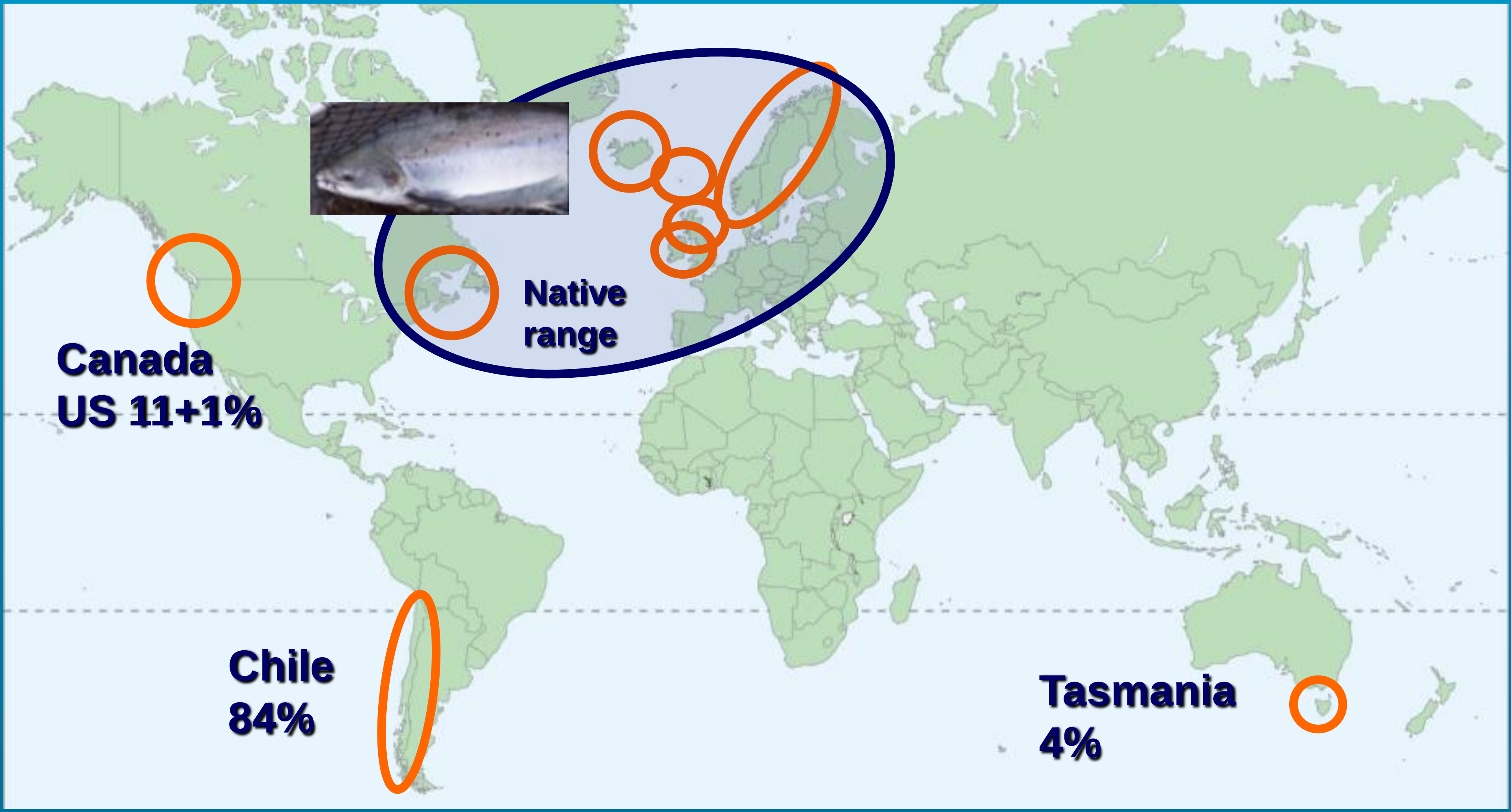
Knowledge gaps and research needs

- **Meta analyses are needed to look for broad scale indications of declines in population productivity. The coupling of information on intrusion rates (or even genetic change) with long-term population dynamics could provide invaluable insight. While research has shown case specific indications of declines (e.g. Burrishoole and Imsa experiments), little is known with regards to broad scale patterns over multiple generations. Long term data sets should be able to provide such insight, especially if examined across broad geographical regions.**

5 Effects of escaped farmed salmon in regions where the Atlantic salmon is an exotic species

- Are escaped farmed salmon able to establish self reproducing populations?
- Are escaped farmed salmon likely to hybridize with native salmonids?
- Ecological effects on native species and ecosystems

36% of world production outside native range



(ICES 2007)

Are escaped farmed salmon able to establish self reproducing populations?

Poor colonizer:

- **Introduction to > 60 lakes and streams in British Columbia failed**
- **> 130 attempts to introduce Atlantic salmon across 32 states in the US failed**
- **Only one self-sustaining population of anadromous salmon established outside native range (Faroe Island)**

(McCrimmon & Gots 1979, Lever 1996, Nash 2001, Ginetz 2002, Waknitz et al. 2002)

Are escaped farmed salmon able to establish self reproducing populations?

- Evidence of succesful spawning in three streams (BC)
- More favourable conditions where native salmonids are in decline?
- No documented reports of escaped Atlantic salmon spawning in the wild in Chile or Tasmania (however spawning of coho and self-sustained populations of Chinook in Chile)

(McKinnell et al. 1997, Volpe 1999, 2000, Volpe et al. 2000, Soto et al. 2001, 2006, DPIW 2006)

Are escaped farmed salmon able to establish self reproducing populations?

- The probability that escaped Atlantic salmon will establish populations where the species is exotic seems low, but the possibility cannot be ruled out

Are escaped farmed salmon likely to hybridize with native salmonids?

- Hybridization with Pacific salmonids unlikely

(Refstie & Gjedrem 1975, Sutterlin et al. 1977, Blanc & Chevassus 1979, 1982, Chevassus 1979, Longinova & Krasnoperova 1982, Gray et al. 1993, Nash 2001, Waknitz et al. 2002)

Ecological effects on native species and ecosystems

- Juveniles can act as competitors to Pacific salmonids, but difficult to predict competition outcomes should Atlantic salmon establish populations in areas with Pacific salmonids

(Gibson 1981, Hearn & Kynard 1986, Beall et al. 1989, Jones & Stanfield 1993, Volpe 2001a, Blann & Healey 2006)

Ecological effects on native species and ecosystems

- Escaped Atlantic salmon do feed and prey on native species, but gut analyses suggest they have greater difficulties adapting to marine life than in the Atlantic Ocean

(McKinnell & Thompson 1997, McKinnell et al. 1997, Morton & Volpe 2002, Soto et al. 2001, DPIW 2006)

Knowledge gaps and research needs

There have been no clearly documented impacts of escaped farmed Atlantic salmon on native fauna in regions where it is an exotic. This may be because there is only limited research being conducted to study impacts.

Generally little knowledge on performance of Atlantic salmon where it is exotic, and on possible interactions and impacts on native species and ecosystems.

7 Technologies and other efforts for escape prevention

7 Technologies and other efforts for escape prevention

- Why, when and from where do salmon escape?
- Management measures – some examples
- Farming technologies

Farming and cage technologies is beyond the expertise of this working group

Technical improvements to facilities and operations to prevent escapes are tremendously important

Information on why, when and from where salmon escape

- Prerequisite for escape prevention
- Needed to identify relationships between particular culture technologies, techniques, site locations and escapes
- Can be used for risk analyses and identifying high priority areas for improvement in containment

Statistics on causes of reported escapes

- At least from British Columbia (since 1987), Norway (since 1993) and Scotland (since 2002)

(Valland 2005, NASCO 2005, 2007, Rist et al. 2004, Jensen 2006, Whoriskey 2001)

Scotland 02-06: 86 incidents (ex 14 during January 05 storms)

- 27% predation, 23% equipment failure, 16% weather, 16% human error, 14% hole in net, 2% vandalism, 1% other

(NASCO 2007)

Management measures – some examples

- Collaboration bewteen salmon farmers and non-governmental agencies in Maine:

Hazard Assessment Critical Control Point (HACCP) approach

Site-specific evaluation of preventive measures

Aim at designing better equipment and operating procedures

Management measures – some examples

- Norwegian Standard developed for design, dimensions, performance, installation and operation of farms
- Working on internationalization of the standard through the ISO

There has been continuous research and development underway for improved cage technologies and operating methodologies

Knowledge gaps and research needs

- Information on why, when and from where salmon escape is commonly lacking for all farm salmon producing countries, even though statistics exist on reported large-scale escapes from several countries.
- There seem to be large uncertainties regarding the contribution of non-reported escapes, both from freshwater hatcheries and sea cages. Such information is needed to identify critical factors related to culture technologies, techniques and sites.

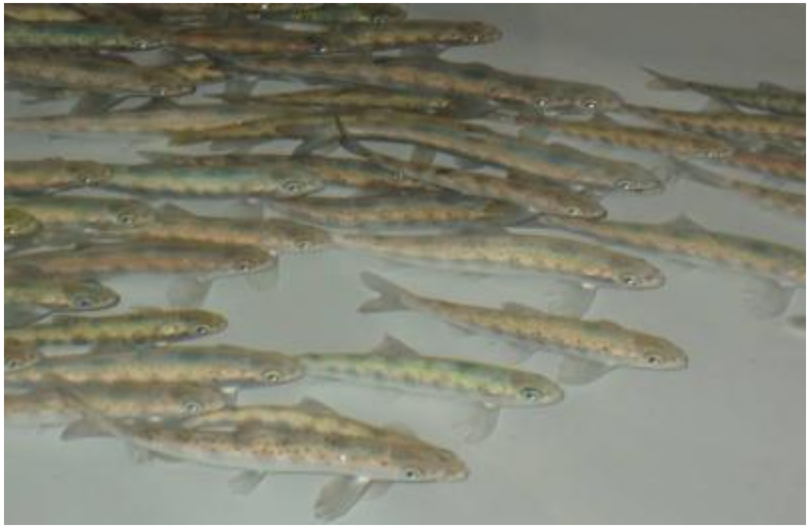
Knowledge gaps and research needs

- Technological and operational research to prevent escapes is needed (refinement of existing technologies and operation procedures, and the development of novel and alternative technologies), and evaluation of standards and management measures to reduce number of escapees.

8 Technologies and efforts to reduce impacts of escapes

8 Technologies and efforts to reduce impacts of escapes

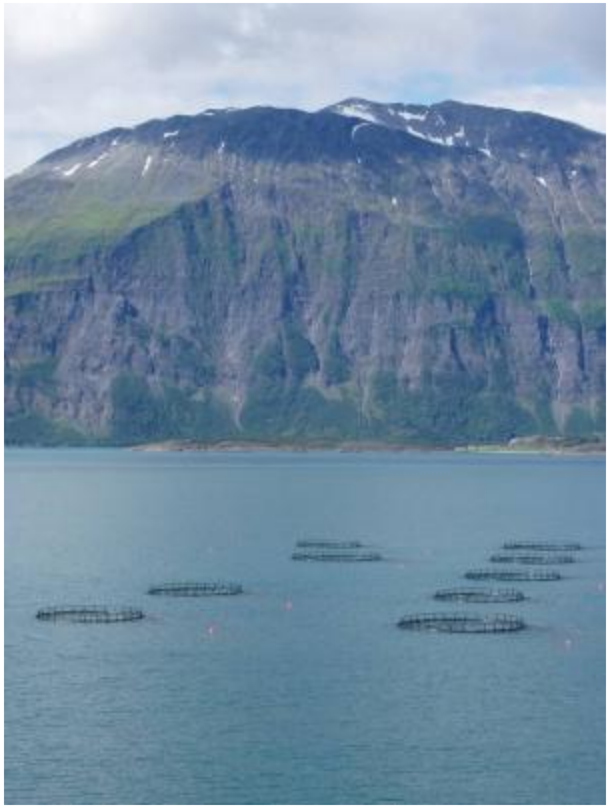
- Sterilization
- Domestication
- Site selection
- Areas without Atlantic salmon farming – protection zones
- Gene banks
- Efforts to recapture escaped farmed salmon



Sterilization

Only effective method today:

- high pressure induction of triploidy in newly fertilised eggs

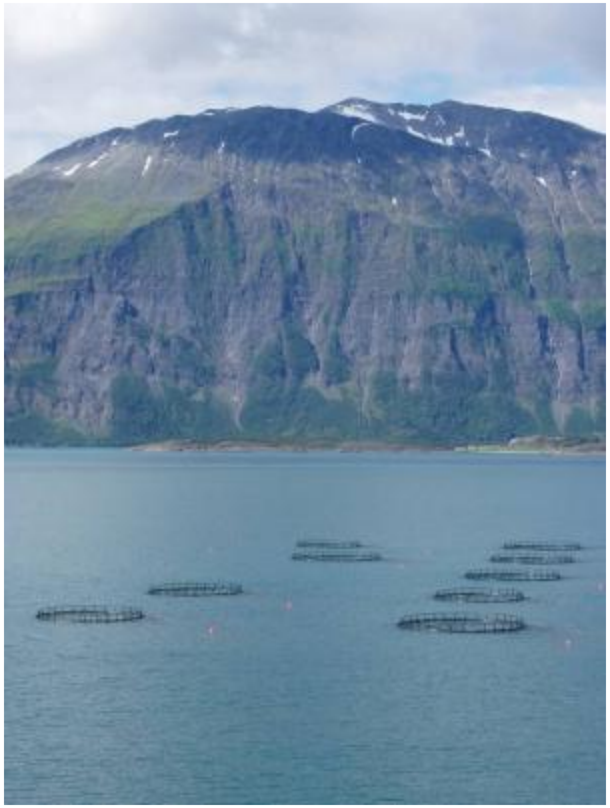


(Benfey 1999, 2001, Sadler et al. 2001, Johnstone 2005, Wilkins 2005, Webster 2005, Benfey 2005, Ferguson et al. 2007)

Sterilization

Pros and cons

- Effective way of reducing direct genetic effects from interbreeding
- Will likely reduce ecological effects (e.g. linked to competition)

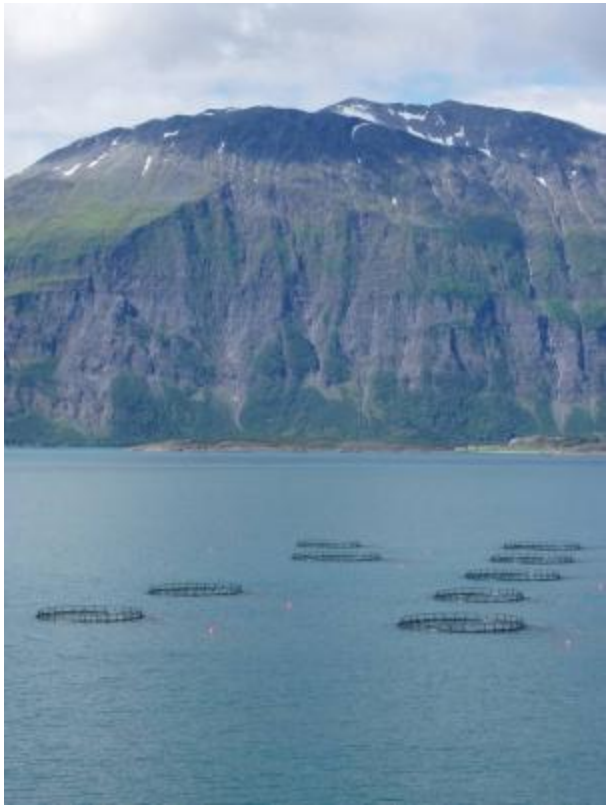


(Benfey 1999, 2001, Sadler et al. 2001, Johnstone 2005, Wilkins 2005, Webster 2005, Benfey 2005, Ferguson et al. 2007)

Sterilization

Pros and **cons**

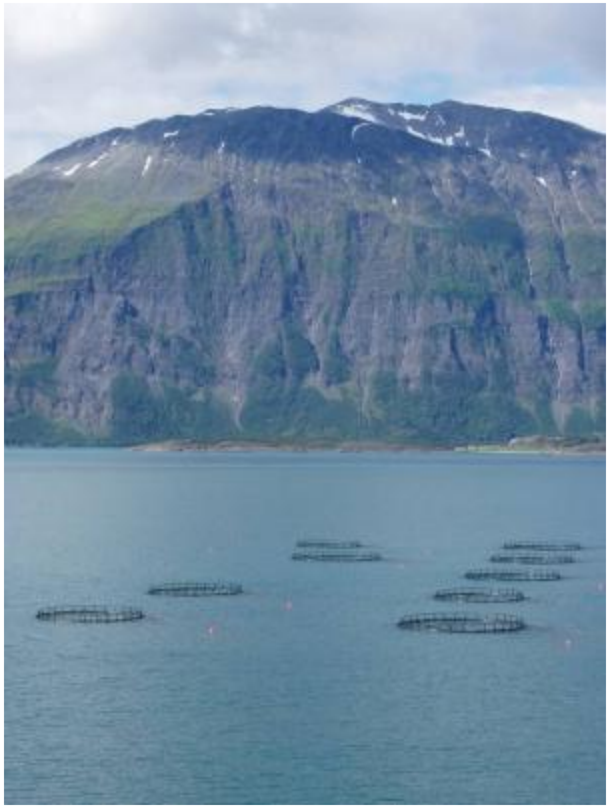
- disadvantages in commercial aquaculture
- concern about reduced growth and survival and increased freq of deformities and susceptibility of diseases
- worries about market reactions



(Benfey 1999, 2001, Sadler et al. 2001, Johnstone 2005, Wilkins 2005, Webster 2005, Benfey 2005, Ferguson et al. 2007)

Sterilization

Pros and **cons**



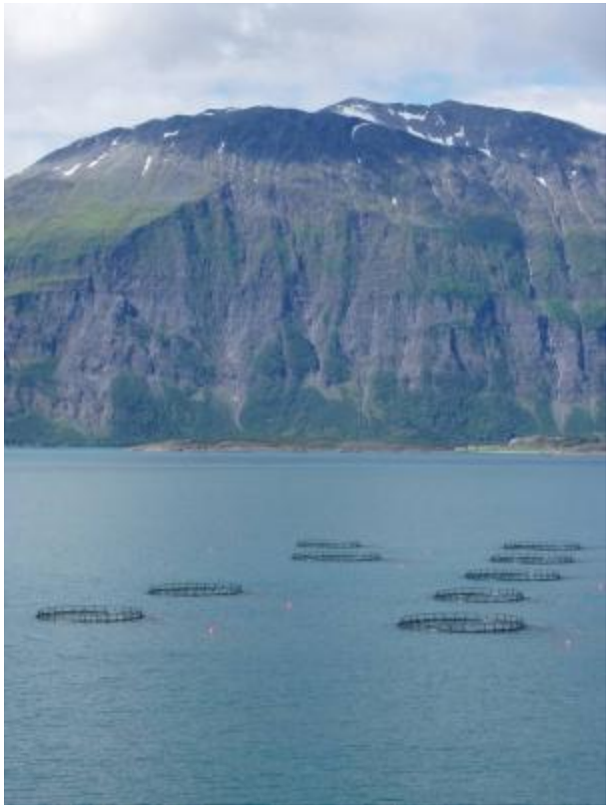
- commercial culture of triploid Atlantic salmon abandoned in the Fundy region of Canada due to high susceptibility to infectious salmon anemia virus

(Benfey 1999, 2001, Sadler et al. 2001, Johnstone 2005, Wilkins 2005, Webster 2005, Benfey 2005, Ferguson et al. 2007)

Sterilization

Triplods not commercially raised today, except

10 % of commercially farmed salmon in Tasmania is triploid for salmon to be available for the marked year around

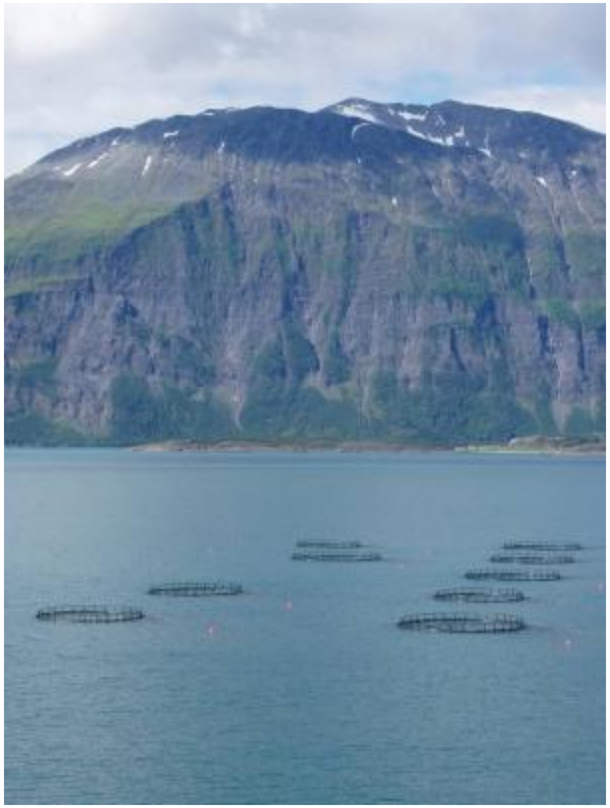


(Cotter et al. 2000, 2002, Wilkins et al. 2001)

Sterilization

Pros and **cons**

- will not completely eliminate ecological effects of escaped salmon
- little, if any effect on reducing the potential transmission of diseases and parasites

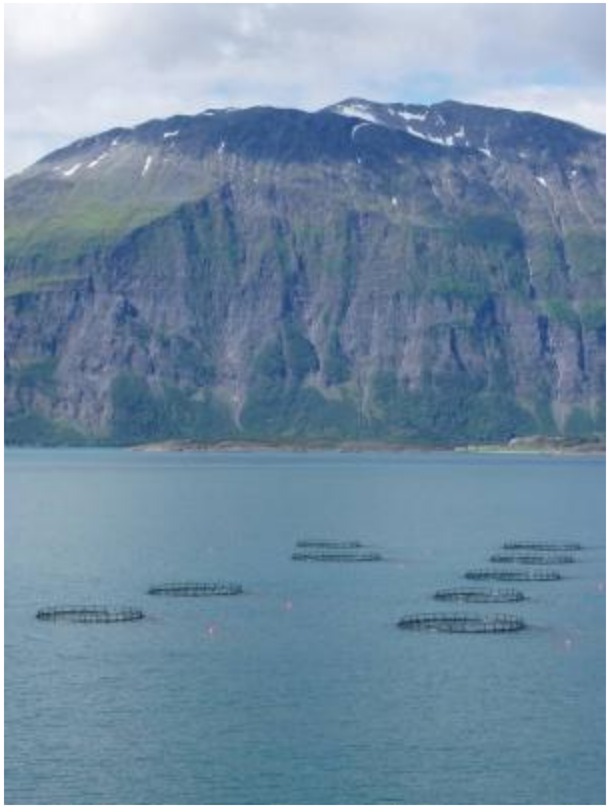


(Benfey 1999, 2001, Sadler et al. 2001, Johnstone 2005, Wilkins 2005, Webster 2005, Benfey 2005, Ferguson et al. 2007)

Sterilization

Studies in Ireland:

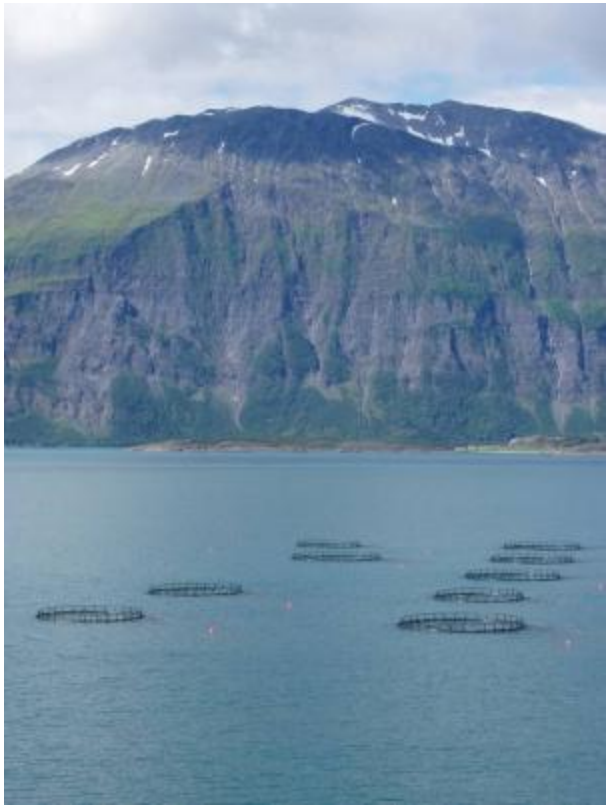
- more promising results than previous studies
- commercially acceptable in freshwater phase
- higher mortality in sea cages due to gill parasite
- low incidence of deformities



(Cotter et al. 2000, 2002, Wilkins et al. 2001)

Sterilization

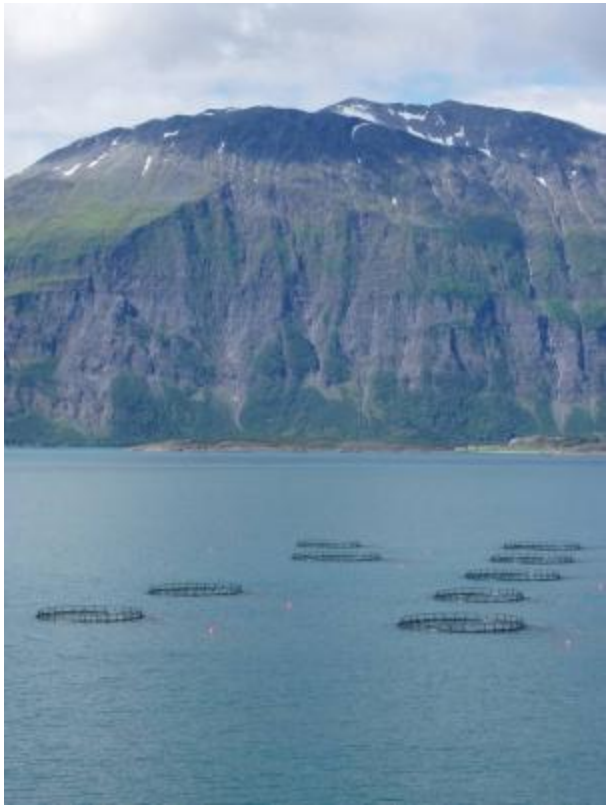
- When triploidy is applied to genetically divergent strains, the resultant fish may exhibit different morphological, behavioural and performance characteristics
- Technically incorrect to refer to triploid salmon as a single entity



(Friars et al. 2001, Webster 2005)

Sterilization

- The use of sterile salmon is a measure that should be carefully appraised, given its potential to reduce direct genetic effects of escapees on wild populations



Domestication

- Domesticating until unable to breed successfully in nature, or even to survive in nature, could be an effective means of reducing or eliminating genetic and ecological threats to wild populations.

(Fleming 1995, Balon 2004)

Domestication

Complicated and long-term process to select for a truly domesticated farmed salmon, while at the same time not affecting characteristics that may reduce the culture yield.

(Fleming 1995, Balon 2004)

Areas without Atlantic salmon farming – protection zones

- Protection zones where salmon faring is prohibited may be an effective way of protecting wild salmon populations.

Areas without Atlantic salmon farming – protection zones

National salmon fjords in Norway

- 1989: 52 protection zones in fjords to provide special protection for wild salmonids against diseases and genetic interaction from farm sites and escaped farmed fish

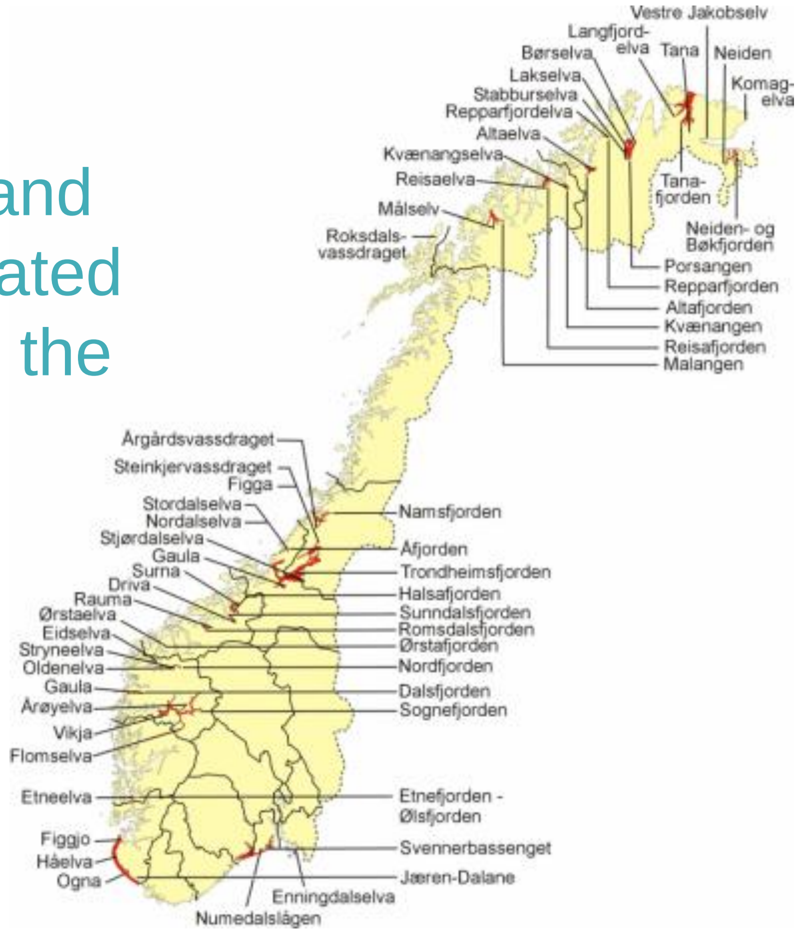
(Lund et al. 1994)

Areas without Atlantic salmon farming – protection zones

National salmon fjords in Norway

- 2003: 21 national salmon fjords and 37 national salmon rivers designated to protect wild salmon. Replaced the previous protection zones.

- Only 13 fjords/areas should be completely free of farming.



(Sivertsen 2006)

Areas without Atlantic salmon farming – protection zones

National salmon fjords in Norway

- 2007: 29 national salmon fjords and 52 national salmon rivers designated to protect wild salmon (50 populations protected; ¾ of wild salmon resource)

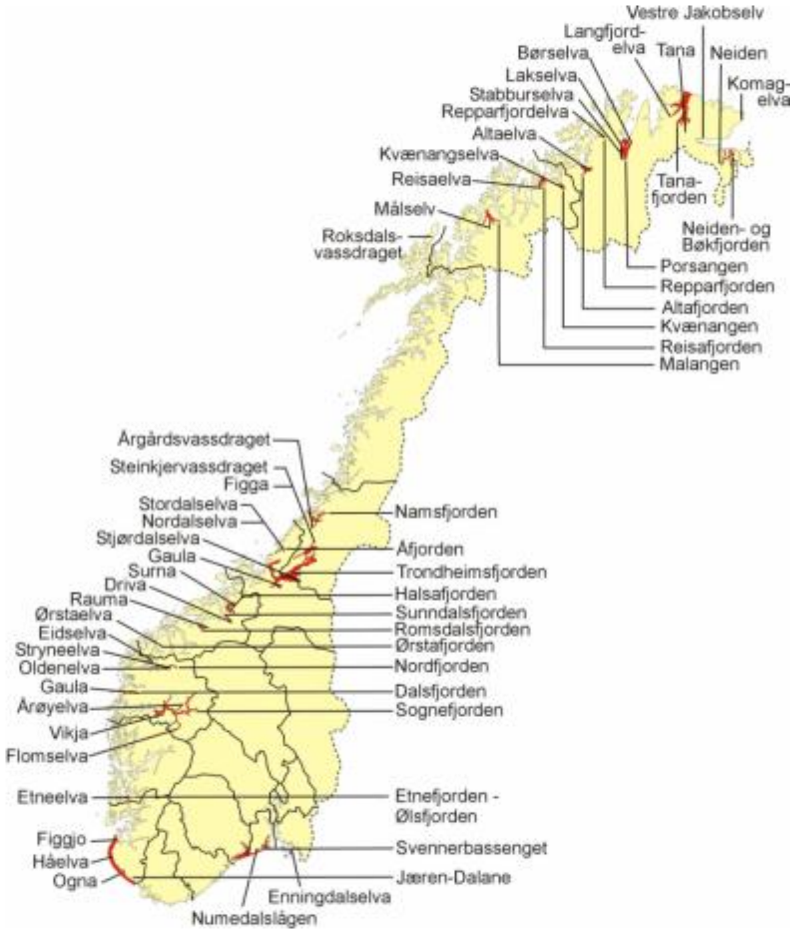
- Effects not evaluated, should be accomplished within ten years of their nomination

(Anon. 2006)

Areas without Atlantic salmon farming – protection zones

Evaluation of protection zones (Lund et al. 1994)

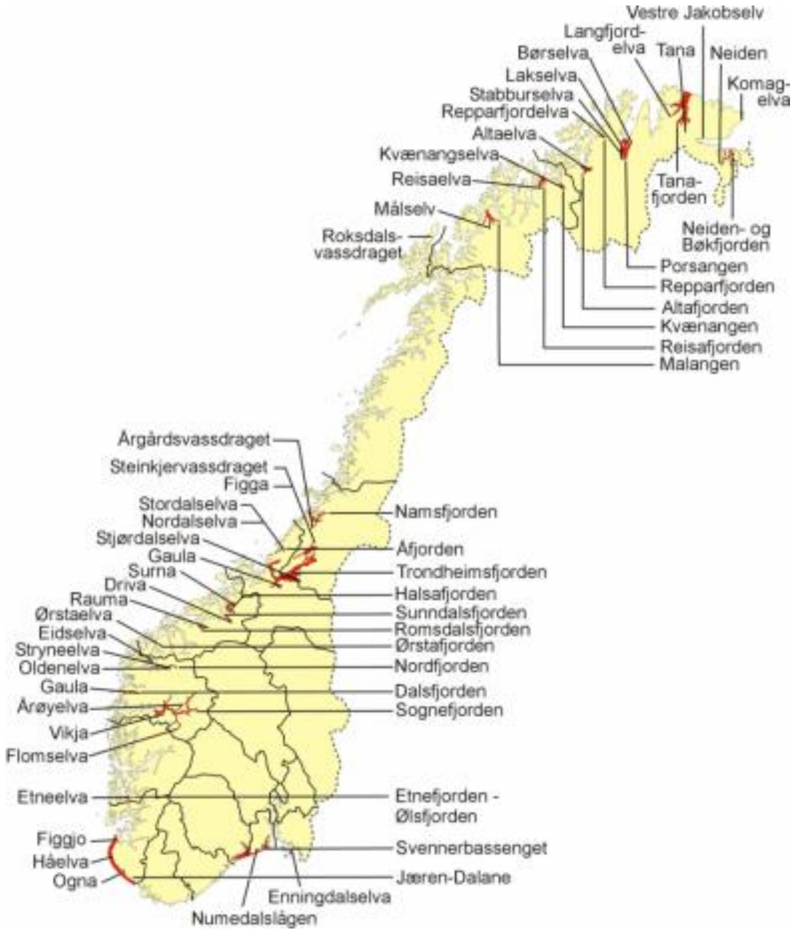
- Positive correlation between densities of salmon farm units and proportion escaped farmed salmon in fisheries
- However, no difference in proportion escaped farmed salmon in rivers inside and outside zones, with a few exceptions



Areas without Atlantic salmon farming – protection zones

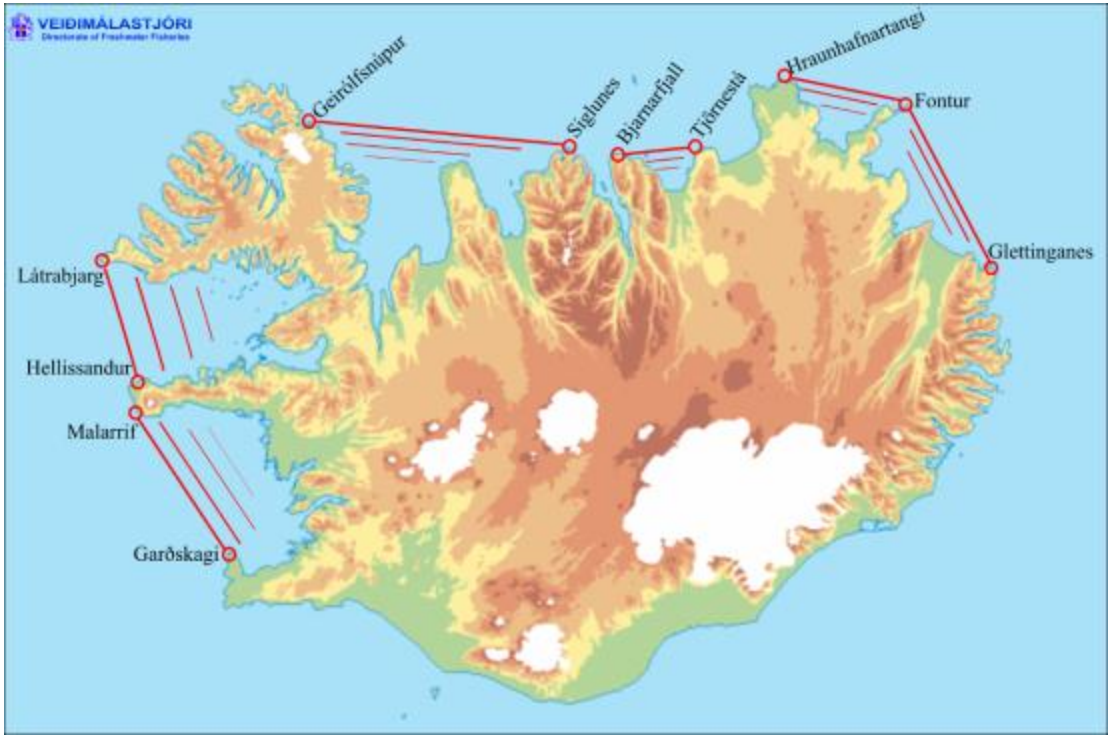
Evaluation of protection zones (Lund et al. 1994)

- Lack of positive effect: Small zones and presence of pre-existing farms within zones
- Only the largest zones without pre-existing farms had the intended effect



Protection areas in Iceland

- Salmon farming in sea cages prohibited in fjords and bays close to salmon rivers since 2004
- on basis of the precautionary approach



(NASCO 2004)

Gene banks

Norway

- salmon from > 30 rivers kept in living gene bank
- milt from > 170 populations kept frozen in a milt bank

- Similar programmes in Canada and the United States

- Conservation programmes using gene banks are time-limited, and the threat necessitating the use of the gene bank must be removed

(Directorate for Nature Management 2001, Skår 2005)

Gene banks

- Can only be expected to preserve a small fraction of the genetic characteristics of the wild salmon populations and to achieve this for only short periods of time
- Unrealistic to believe that gene bank material can be used as a long term conservation strategy for re-establishing wild populations following potential large scale genetic introgressions with farmed fish.

Efforts to recapture escaped farmed salmon

- Escaping post-smolts seem to move away from the release site within a few hours and even a huge effort over large areas may not effectively recapture salmon after large-scale escapes
- Only a small percentage (< 3%) of escaped salmon recaptured through organised fishing after large escape episodes.

(Whoriskey unpublished, Furevik et al. 1990, Anfinsen 2005, Skilbrei 2006, Whoriskey et al. 2006)

Efforts to recapture escaped farmed salmon

- Angling, or separation of escaped farmed when passing fish ways may be the most effective ways to recapture escapees after they have entered the rivers
- Labour intensive methods, and difficult to identify farmed salmon that have escaped at an early stage

Knowledge gaps and research needs

- Use of triploid (i.e. sterile) salmon in commercial farming would require research and development to determine optimum rearing conditions and boost triploid disease resistance. Ecological interactions of farmed sterile fish with wild fish must be critically evaluated before large-scale releases of sterile fish can be encouraged.

Knowledge gaps and research needs

- Research is needed into design of protection zones without fish farming to protect rivers from escaped farmed salmon.
- The numbers of escaped farmed salmon vary among rivers, and some large rivers seem to attract escaped salmon even though they are situated far from any fish farms. Information on what characterises rivers that attract a high number of escaped farmed salmon is needed to evaluate the effectiveness of different existing protection zones and to design new ones.

Knowledge gaps and research needs

- Models need to be developed that predict survival and migration pattern for escaped fish. Field data is required to parameterise these models. With such knowledge, measures to reduce impacts of escapes can more easily be identified.

9 General conclusions

Farm salmon are escaping into the wild in large numbers relative to the numbers of their wild conspecifics

- Clearly and international issue
- Nearly all salmon producing countries have routines for reporting large-scale escapes
- Information on the extent and causes of escapes is poor for all salmon producing countries (low-level leakage and freshwater hatcheries)

Potential negative effects by escaped farmed salmon on wild populations are well documented

- Negative effects are linked to both ecological interactions and genetic impacts of inter-breeding
- A large number of studies point to negative effects, and outcomes for wild populations are either mostly negative or neutral. It has been shown that inter-breeding of farm with wild salmon can result in reduced lifetime success, lowered fitness and production over at least two generations

Reviews:
Hindar et al. 1991, Heggberget et al. 1993, Jonsson 1997, Gross 1998, Youngson & Verspoor 1998, Whoriskey 2003, Huntingford 2004, Thorpe 2004, NASCO 2005, Naylor et al. 2005, Ferguson et al. 2006, Hansen & Windsor 2006, Jonsson & Jonsson 2006, Jonsson et al. 2006, Weir & Fleming 2007

Atlantic salmon pupulations in decline throughout their native distribution

- **Overexploitation, acid deposition, transfer of parasites and diseases, aquaculture, freshwater habitat degradation, hydropower development and other river regulations can be important contributors. In the future, under further pressure by climate change.**
- **Most factors affecting salmon numbers do not act singly, but rather in concert, which masks the relative contribution of each factor and may exacerbate the overall effects of the individual stressors.**

Atlantic salmon pupulations in decline throughout their native distribution

This has two important implications regarding escaped farmed salmon:

1) potential effects of escaped farmed salmon on population size and production are difficult to separate from other factors
2) wild salmon populations are likely to be more vulnerable to effects of escaped farmed salmon because of the synergistic effect of other negative pressures

36% of world production in regions where the species is exotic

- Atlantic salmon is a poor colonizer outside its native range. The probability that escaped Atlantic salmon will establish populations where the species is exotic seems low, but the possibility cannot be ruled out.
- It is difficult to predict if or how Atlantic salmon will adapt to the regions where they are exotic. This is partly because only limited research is being conducted to study potential impacts in many of these regions.
- The probability for hybridisation between Atlantic salmon and Pacific salmonid species seems small.

The most important issue at present is to implement measures reducing the numbers of escaped salmon in nature

Among technologies and efforts to reduce impacts of escapes, sterilisation and farm exclusion zones look to be among the most promising

KEY RESEARCH NEEDS

- As long as significant numbers of escapees continue to occur, there will be significant research needs regarding the ecological and genetic impacts of escaped farmed salmon on wild populations

KEY RESEARCH NEEDS

- However, given the compelling evidence pointing towards a high risk of negative impacts by escaped farmed salmon on wild salmon populations (or on native fish/other organisms in the case of escapes as alien species), and recognising the need to continually improve on our knowledge of the interactions between cultured and wild Atlantic salmon, the most pressing research priorities are linked to:

1. technologies and efforts for containment (escape prevention)
2. approaches to reduce impacts of escapees (sterilization and protectin zones)

KEY RESEARCH NEEDS

- There is generally little knowledge on the performance of escaped farmed salmon in regions where the Atlantic salmon is an exotic species. There is also little knowledge about the interactions of Atlantic salmon with native species in these regions, especially non-salmonids. This hinders our ability to predict the impacts, e.g. whether or not feral Atlantic salmon populations can become established.
- However, a focus in these regions on escape prevention would reduce the likelihood of potential impacts.

KEY RESEARCH NEEDS

- A prerequisite for escape prevention is knowledge on why, when and from where salmon escape. Such information is needed to identify critical factors related to culture technologies, techniques and sites.
- When this information is combined with knowledge of survival and distribution of escaped salmon at different life stages, times of the year and locations to identify the most critical escape periods, risk analyses can be performed and the high priority areas of improvement and development can be identified

KEY RESEARCH NEEDS

- More knowledge is required about the genetic population structure of wild populations, particularly the importance of local adaptation in determining their long-term productivity and resilience in natural environments.
- Also contemporary baseline genetic information, should be collected for all populations throughout the species distribution. This with the genetic analyses of archival material such as scale collections should be utilised to determine the impact of farm escapes in the past and as a basis to assess the genetic effect of future escapes.

Thank you for your attention

Photo: Irish Sea Fisheries Board (BIM)