alternatives to reduce the

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t ecological and genetic
ten attempted. Here, we
with escaped fish size, the
rs varied among species,
Recapture success was
d, regardless of species.
ous tracking studies of
cape incident for highest
n recapture efforts rarely

marine habitats, with rare
ge-scale recapture efforts
tively. We suggest three
lations of predatory fish
t impact offset programs
asure technical standards
capes.

wherever fish are farmed
& Joyce 2005, Morris et
Blanchfield 2013, Serra-
07-2009, some 9 million
t al. 2015). As escapees
ing grounds, a range of
e transfer from escapees
troggression from farmed
ed survival and lifetime
lations (McGinnity et al.
g of wild fish (Lura &
4, 2006).

ative in nature, through
n the implementation of
escape (Damsgård et al.
ts of escapees once they
ed with wild fish (Fraser
from the environment.
is (Supplementary Table
local fisheries operators.
ow recapture must occur,
stipulates the amount of

l. No synthesis exists of
o make evidence-based
e and recapture studies

with species farmed and
tive to when the escape
id how escapes enter the
y to succeed. Two recent
to hundreds of thousands
e events from September
n Norway revealed that
r trout and Atlantic cod
f the number of escaped
al failures of entire cages
estimated to have escaped
ng mass escape incidents
l. 2015). These analyses
estimate the true level of
ither not detected and/or
er, less detectable escape
true number of escapees,
e point of escape, as this
plan.

scaped from aquaculture
and a meta-analysis of
e likelihood of recapture
ake recommendations to
regulators to: 1) improve
ceed; and alternately, 2)
successful, while negative
ents that may reduce the
re of escapees that require

scholar with the following
lture*) AND (escape* OR
n the field. Results were
one as they were from an
led after accessing the full

on recapture success rates
the location and recapture
idents from marine sea-
properly estimate recapture
as their main objective is
at for extended periods to
such cases, each release
fic event once recaptured.
ocation, country, region,
capture success rates and
it through correspondence
lues to mean length using
r variables were $\log(x+1)$
t regression or ANOVA.
els constructed using the
www.R-project.org/).

ese papers described 123
in the meta-analysis.

scapees remain around the
nd the position of the farm
ave documented that fish

z Skilbrei 2010), most fish
Lopez- et al. 2011, 2012,
ecapture at the escape site
e potential for successful
et al. 2011). Post-escape
istic telemetry (Skilbrei et
012). This has assisted in
ensen 2010, Chittenden et
opez et al. 2012), while in
d the reach of traditional
hittenden et al. 2011).

a-cage aquaculture occurs.
Skilbrei et al. 2006; Green
ound in landings of many
tured by local fisheries in
; Arechavala-Lopez et al.
gears have been used to
pelagic trawlers and long-
g are common techniques

reefs and spear fishing to
es that usually aggregate
; Santos et al. 2006; Grati
limited. However, several
that released fish moved
at beach-seines or beach-
ć & Dulčić 1997; Bayle-

recapturing escapees (e.g.
some kind of herding or
rapped. Examples of such

in traditional commercial
unharmful, which may be
Norwegian fjords; Serra-
salmon, but with varying
.

h in Norway (Furevik &
e been tested for live re-
ifferent sizes and designs,
ent entrances (Figure 2c).
t the target fish. Similarly,
ces either in the bottom or
2013) have been tested to
pees. Floating traps were
tract and capture the wild
010). Similarly, a standard
s been tested to recapture
i were captured (Sanchez-

been designed to capture
he fisheries context in the
e certain methodologies
re used, as they allow for

: that is representative of
uropean waters (Figure 1-
), $n = 123$), with limited
od: $8 \pm 10 \%$, $n = 46$; sea
recapture rates are linked
ffort. In general, reported
h fish size (Table 3). This
apees compared to large

1). Highest recapture rates (Morgan et al. 2010), and 69 % releases of <100 large fish were significantly lower in Clark et al. 1990; McKinell & Morgan 2009; studies where >10 000 fish were released. Success after large scale releases may result from the lack of experience due to limited adaptation to the release site, as large releases are rare (Morgan et al. 2009). Further, during storms, when most releases occur (Clark et al. 2015) for logistical reasons, 1) escape event, rather than recapture after storms; and 2) better weather conditions for captures, when just a few fish are released (e.g. Uglem et al. 2008,

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fishermen in Norwegian

small scale releases/escape
large numbers of smaller
incidents from commercial
312 escapees in Finnmark,
Lofoten, Norway (recapture
in Canada (recapture rate
on occasion it may be high:
4.

and systems in Norway and
cod tagged with acoustic
while Zimmermann et al.
commercial fisheries during a
similarly, Serra-Llinares et al.
of thousands of juvenile
annual 0.1-4.5 % recapture.
in cod (Kristiansen 1999;
0.1–8.6 %).

salmon: simulated escapes
higher recapture rates
higher mortality rates of
Serra-Llinares et al. 2013), although
at liberty (> 5 months;

sea bass (Table 1), which
to be made where these
already carried out on escaped

commercial trammel-netters
Arechavala-Lopez et al. 2012).
Studies of hatchery-reared sea
bass, Strait of Gibraltar and
Algarve. Although no studies exist
on *Diplodus sargus*), which is
abundant (0.4-6.7 %) by local

over 1200 fish in the Western
by professional fishermen
capture rate after simulated
recreational and professional
in the Canary Islands (Atlantic
sea cages resulted in 20 %
de la Haza-Guedes et al. 2013).
who intensively fished the
data is more limited for sea
cages; recapture rates were
size (Figures 2, 3).

Estimates of real escape

and recapture success draw
that escape from sea-cage
was < 100 fish, with some
and individuals. A central
behaviours and dispersal of
in 2011, Arechavala-Lopez
, detailed and informative
small or so-called 'leaky'
cages, when most fish escape
from them. Most large scale escape
from sea-cage structures fail, compared
to other reasons. How the chaotic

1 kg salmon or 10 000 0.5
spectively, based on 2013
recapture success of fish
isdictional prohibitions on

are undertaken and where
ted salmon escapes have
as the bulk of production
on predominantly swim in
s fish are less bound by
losed fjord environments,
rapid and widespread, and
At present, there is limited

ags that enable company-,
000; stable-isotope otolith
2015c). For the first time,
escape from mass escape
escape characteristics.

lividuals post-escape, will
the possibility to mix and
ear the point of escape, in
le a broad range of papers
wild in the long-term (e.g.
ge remains concerning the
term following an escape

ape, is substantial.

om tags retrieved from the
st 1 % of recaptures came
ale aggregations of saithe
2009), initial predation of
ares et al. (2013). High
ustic tags occurred in the
release farm (Arechavala-
around sea bream and sea
08; Fernandez-Jover et al.

l management mechanism
ing the ‘wall of predatory
redators can provide the
; capture 10 to 100 times
deployed in the vicinity of
al predation by removing

ses, such as reducing the
fish to reduce the benthic
ste feed and thus reducing
ning predator populations
poor recapture rates with
, reducing the success of
; critical to reducing their
g and dispersing as if they
vers, where they may be

where escapees can be

mandatory mechanism by
tal damage by paying for
could be location-specific

act economic incentive for
ficiently low across many
compensation generated
s of greatest conservation
nsatory mechanisms have
have proved effective for

environmental offsetting
waters than in the marine
awning season. A total of
Statistics Norway, 2013).
and 72 000 escaped salmon
ned salmon were reported
underestimate given the
reported escapees were
mately 50 % of salmon in
2-3 times higher than that
aped salmon enter rivers.
breeding between farmed
nservatively, equivalent to

rivers to remove farmed
l river barrier traps. The
e as high as in the regular
bility of fishers to visually
wild fish can be released
awning rivers exist, but a
ed and wild from visual
fish during capture and
ty similar to that resulting
cumented success rates of
e management option in
success in separating wild
ented to visually identify

ieved and the basis upon

early identifiable and have
es of tens of thousands of
here this species does not
)13). Directed removal of
e occur with near 100 %
es are invasive and clearly
ld.

ction in Norway, revealed
g and operation of for sea-
n declined from >600 000
er of salmon held in sea-
success of this measure to
ould introduce a technical
ns to enforce the standard.
have legislated technical
with sufficient strength to
neasures elsewhere would

ms in marine habitats and
ing fish after escape, at or
r, the weight of evidence
e efforts are often delayed
ese two factors mean that
ms have been successful.
only in specific instances
fish escape restricting the

they can be targeted; and
sh or have the capacity to
ie wild through promoting
ure activities into habitats
echnologies that minimize
sures. All three have the
appropriate.

Jerez P (2011) Immediate
editerranean Sea. J Appl

erez P (2012) Post-escape
fisheries in the Western

2013) Reared fish, farmed
Mediterranean aquaculture

014) Simulating escapes of
shermen. J Appl Ichthyol

acent to fish farm cages.

ar J, McKinley SR (2011)
n Interact 1:215-224

ic salmon recovered from
s. Fish Res 46:267-278

es associated with salmon
(Culver and Castle, eds.).

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st traits. *Aquacult Environ*

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J Mar Sci 71:2530-2538

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and short-term variability.

from sea-cage aquaculture
onograph 32: 55–60

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cosystem effect. *Mar Ecol*

al. (2011) Proxy measures
gical traps for wild gadoid

07) Possible influence of
essolonghi lagoon (Ionian

08) Seasonal patterns and
CES J Mar Sci 65: 1153-

farmed Atlantic salmon,
1989–2004. ICES J Mar
he reproductive behaviour
00) Lifetime success and
1517-1523
s of triploid fish. Fish Sci
vtail kingfish via natural
SØ (2012) Three decades
population genetic structure
netic analysis of stomach
atlantic salmon originating
lar L.) released from two
mo salar, from simulated
ects of salmon farming on
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ageorgiou N, Karakassis
cape events from sea cage

and farmed Atlantic salmon
ult Environ Interact 3:223-

fishes from Norwegian sea-
1:71-83

mon (*Salmo salar*). Can J

ir ecology and interaction

l farmed female Atlantic

salmon (*Salmo salar*) and
172

er D, O'Hea B, Cooke D,
n of wild populations of
non. Proc R Soc Lond B

ings JA (2008) Prevalence
h American rivers. Can J

capture rates of North-east
fish Biology 54: 213-217

on *Salmo salar* following
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ial freshwater aquaculture

Tuya F, Juanes F (2008)
in the Mediterranean Sea.

le C (2013) Post-escape
s and their potential for

idance of escaped farmed

l' farmed Atlantic salmon
si 66:278-288

simulated escaped farmed
!06-1215

st-smolts from a simulated

-scale escape experiment.

-season smolts of farmed

he annual numbers and
in Norway. ICES J Mar

differences between wild

ile: facing ecological and

on C&R story. In: Global
ng.

) Detecting the degree of
Centrarchus labrax escapes
23:203-212

raped introduced sea bass
maturity in coastal habitats

aculture escape event on

Havbruk 2007:11-12 (in

iotemporal distribution of
58-170

astal and oceanic Atlantic
t 1:11-19

and survival of sonically
ar Sci 63:1218-1223

4) Stable isotope marking
viron Interact 5:143-154

rsion during egg swelling
quat Sci 72: 722-727

lustry-scale mass marking

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marking farmed Atlantic
Aquacult Environ Interact

ries bycatch–biodiversity

f net cage biting and the
ling and cage enrichment.

wild and escapee farmed

ed farmed fish (either real
tic salmon, (*Salmo salar*),
(*Sparus aurata*) and sea
apture rate (%) and fishing
ies; (3) Unknown fishing

Species	Location / Country	Average fish size (cm)	Number of fish escaped	Recapture success (%)	Capture methodology	Reference
<i>D. labrax</i>	Western Mediterranean Sea / Spain	26	1186	1.3	Anglers/ fishing rods (2)	Arechavala-Lopez et al. 2014
<i>G. morhua</i>	North Atlantic fjord system/	27	1000	5.4	Local fishermen (3)	Otterå et al. 1999

Norway

25	1500	0.8	Local fishermen (3)
27	1000	8.6	Local fishermen (3)
25	1500	4.0	Local fishermen (3)
54	25	28	Local fishermen (3)
60	25	52	Local fishermen (3)
69	45	33.3	Local fishermen (3)
25	1033	0	Local fishermen (3)
		0	Gill-nets (4)
		0	Fish traps and pots (4)
29	874	0.6	Local fishermen (3)
		4.5	Gill-nets (4)
		0	Fish traps and pots (4)
36	870	0.3	Local fishermen (3)
		0.1	Gill-nets (4)
		0	Fish traps and pots (4)
Coastal waters/ Canada	46-49	52	Gill-nets (1), hand lines (2).

Uglen et al. 2008

Uglen et al. 2010

Serra-Llinares et al.
2013

Zimmermann et al.
2013

<i>S. aurata</i>	Western Mediterranean Sea / Spain	21	2191	3.8	Trammel-nets (1)	Arechavala-Lopez et al. 2012
				1.3	Gill-nets (1)	

				1.1	Anglers/ Fishing rods (2)	
				1.1	Spear-fishing (2)	
<hr/>						
<i>S. salar</i>	Arctic fjord system/ Norway	86	39	69	Coastal bag nets (1)	Chittenden et al. 2011
				10	Anglers/ Fishing rods (2)	
	Baltic Sea / Sweden	15-16	~15000	~10	Professional fisheries (3)	McKinell & Lundqvist 2000
		14-15	~13500	~3	Professional fisheries (3)	
		14-16	~15000	~1.5	Professional fisheries (3)	
	North Atlantic fjord system/ Norway	60	1012	5.5	Gill-nets (4)	Furevik et al. 1990
				1.3 0	Gill-nets (1) Fish traps (4)	
		73	1996	4.6	Local fishermen (1,2)	Hansen 2006
		72	2499	4.6	Local fishermen (1,2)	
		24	3700	0	Anglers/ Fishing rods (2)	Skilbrei 2010a
				0	Gill-nets (1)	
		26	2000	0	Anglers/	

				Fishing rods (2)	
			0.2	Gill-nets (1)	
33	2000	12.3	Anglers/ Fishing rods (2)		
			2.2	Gill-nets (1)	
40	2000	12.7	Anglers/ Fishing rods (2)		
			22.4	Gill-nets (1)	
45	1780	2.9	Anglers/ Fishing rods (2)		
			26.2	Gill-nets (1)	
17	1936	0.3	Local fishermen (3)	Skilbrei 2010b	
	2002	0.9	Local fishermen (3)		
18	1978	0.9	Local fishermen (3)		
	2000	0.9	Local fishermen (3)		
21	2000	1.0	Local fishermen (3)		
	1999	0.8	Local fishermen (3)		
64	19	15.8	Local fishermen (3)	Skilbrei et al. 2010	
72	24	62.5	Local fishermen (3)		
54	29	37.9	Local fishermen (3)		
61	30	50	Local fishermen (3)		
70	30	20	Local fishermen (3)		

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		76	25	76	Local fishermen (1, 2)	Skilbrei & Jørgensen 2010
		49	23	57	Local fishermen (1, 2)	
		75	468	42.8	Gill-nets & anglers	
				0.2	Pelagic trawl (4)	
		49	515	36.1	Gill-nets & anglers	
				0.9	Pelagic trawl (4)	
	North Atlantic Ocean and fjord system/ Norway & Scotland	72	678	0.2	Anglers/ Fishing rods (2)	
				0.3	Professional fisheries (1)	
		72	597	4.5	Anglers/ Fishing rods (2)	
				2.5	Professional fisheries (1)	
<hr/>						
<i>O. mykiss</i>	North Atlantic fjord system/ Norway	50	20	25	Local fishermen (3)	Skilbrei 2012
		42	30	43	Local fishermen (3)	

Species	Fish size: means ($\pm$ SD) or ranges			Dispersal from farms		References
	No. fish released	SL (cm)	W (kg)	First move away (hours)	~50% dispersed	
Atlantic salmon (<i>S. salar</i>)	9-10	86 $\pm$ 5	7.4 $\pm$ 1.4	<24	48-96	Chittenden et al. 2011
	19-30	51-78	2.3-5.1	<24	<48	Skilbrei et al. 2010
	9-20	20-30	0.07-0.25	<24	<24	Skilbrei 2013
	15-20	20-54	0.09-2.3	<24	<24	Skilbrei 2010
	23-25	45-81	1.2-6.0	<24	<24	Skilbrei & Jørgensen 2010
	37	54	1.4	<24	<24	Solem et al. 2012
	50	188 $\pm$ 12	71 $\pm$ 14	<24	48-72 *	Uglen et al. 2013
	48	189 $\pm$ 7	66 $\pm$ 8	<24	<24*	Uglen et al. 2013
	21-50	40-58	-	<12	<24	Whoriskey et al. 2006
	17	60 $\pm$ 6	2.6 $\pm$ 0.8	0-6	0-6	Furevik et al. 1990
Rainbow trout (<i>O. mykiss</i>)	20-30	40-56	0.8-3.7	<24	48-120	Skilbrei 2012
	40	-	0.8	<24	24-48	Blanchfield et al. 2009
	66-68	-	1.5-2.0	<24	96-816 *	Bridger et al. 2001
	10-30	35-44	0.8-1.5	<24	24-168*	Patterson & Blanchfield 2013
	48	48-58	~2	<24	<72*	Lindberg et al. 2009
Atlantic cod (<i>G. morhua</i>)	14-21	44-50	-	2-3	5-19	Zimmerman et al. 2013
	24	31 $\pm$ 2	0.4 $\pm$ 0.1	<24	48-72	Serra-Llinares et al. 2013
	5-25	47-66	-	<24	<24	Uglen et al. 2008
Sea bream (<i>S. aurata</i>)	14-24	26-29	0.4-0.6	<24	96-120*	Arechavala-Lopez et al. 2012
Sea bass (<i>D. labrax</i>)	10	28 $\pm$ 1	0.4 $\pm$ 0.04	<24	120*	Arechavala-Lopez et al. 2011
Meagre (<i>A. regius</i>)	16	33-49	-	<12	48	Arechavala-Lopez et al. 2015a

1 farms. Quoted R^2 values

Model (y ~ x)	Test	df	Direction	Test stat	R^2	p	
Number released ~ mean size							
All species	Linear regression	120	-	t = 55.7	0.31	<0.0001	***
<i>S. salar</i>	Linear regression	62	-	t = 106.2	0.63	<0.0001	***
<i>G. morhua</i>	Linear regression	62	-	t = 53.2	0.54	<0.0001	***
Recapture success rate ~ mean size							
All species	Beta regression	120	+	z = 3.06	0.04	0.002	***
<i>S. salar</i>	Beta regression	61	+	z = 2.60	0.11	0.009	***
<i>G. morhua</i>	Beta regression	43	+	z = 5.55	0.16	<0.0001	***
Recapture success rate ~ environment (exposed or fjord)							
<i>S. salar</i>	Beta regression	61	+fjord	z = 1.66	0.06	0.098	

fish released, grouped by

grouped by species. Four
1 5.5 % recaptured; 50181
with 15.1 %). Linear lines

aped, grouped by species.

farm after an escape event
any person other than the
ing around a fish farm. The
es may occur even during
regulated by the local
ich escaped fish may be

who recaptures or attempts
writing the results of the
or attempted recapture”.

g of all escapes of farmed
sh is mandatory.

propriate, may assist with
ier and local wild fishery
or the use of gill nets to

ent of escapes, as regional
Plan for development of
tifies the prevention and
ween 2016-2018 (July
arage the development of

ensure actions to mitigate
ped a Regional Plan for
contingency plan against
apes in extreme weather
fisherman or other fishing
and Murcia, have regional
it preventative measures,
populations and fisheries
[/www.planacuicultura.es](http://www.planacuicultura.es)).
[ra/docs/pesca/proac/Doc](http://www.planacuicultura.es/docs/pesca/proac/Doc)

rine finfish aquaculture—
an escape event. Farmers
escapes may be recaptured

814 ch facility has a defined
815 kiffs, seines or nets and/or

816 For all reported escapes,
817 initiated in response to the
818 are required to implement
819 Failure to implement the
820 nvalidation of the marine

827 to B.C. Reg. 207/2011,
828 is must be in place for all
829 l duties. Time-frames are
830 ly states that ‘the licence
831 bia and local government
832 st stock, and (b) will not

833 [section3](#)

837 ws fish farmers to fish for
838 d Oceans, Government of
839 ne boat to fish within one
840 ve a live brailing ability –
841 caught incidentally. The
842 ssued for the recapture of
843 r to obtain, and fish under,
844 had applied for this ZZA

1 regulation (Art. 5° y 6°,
pture attempt set in place.
ngency plan (D.S. 320/01
h, food provided and then
ated for 5 days after the
eeding at the normal time.
tigation program has been

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while fish may remain in
ain for extended periods.
cial exemption granted by
only allows fishing where
tock due to size or colour
s are limited to acceptable
med fish are defined as a

[e_fish_policy_082008.pdf](#)

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Title:

Recapturing escaped fish from marine aquaculture is largely unsuccessful: alternatives to reduce the number of escapees in the wild

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2018-03-01

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