Estuary Dynamics and Implications

Drew Lucas
Scripps Institution of Oceanography
ajlucas@ucsd.edu

THE 2017 NICHOLAS P. FOFONOFF AWARD

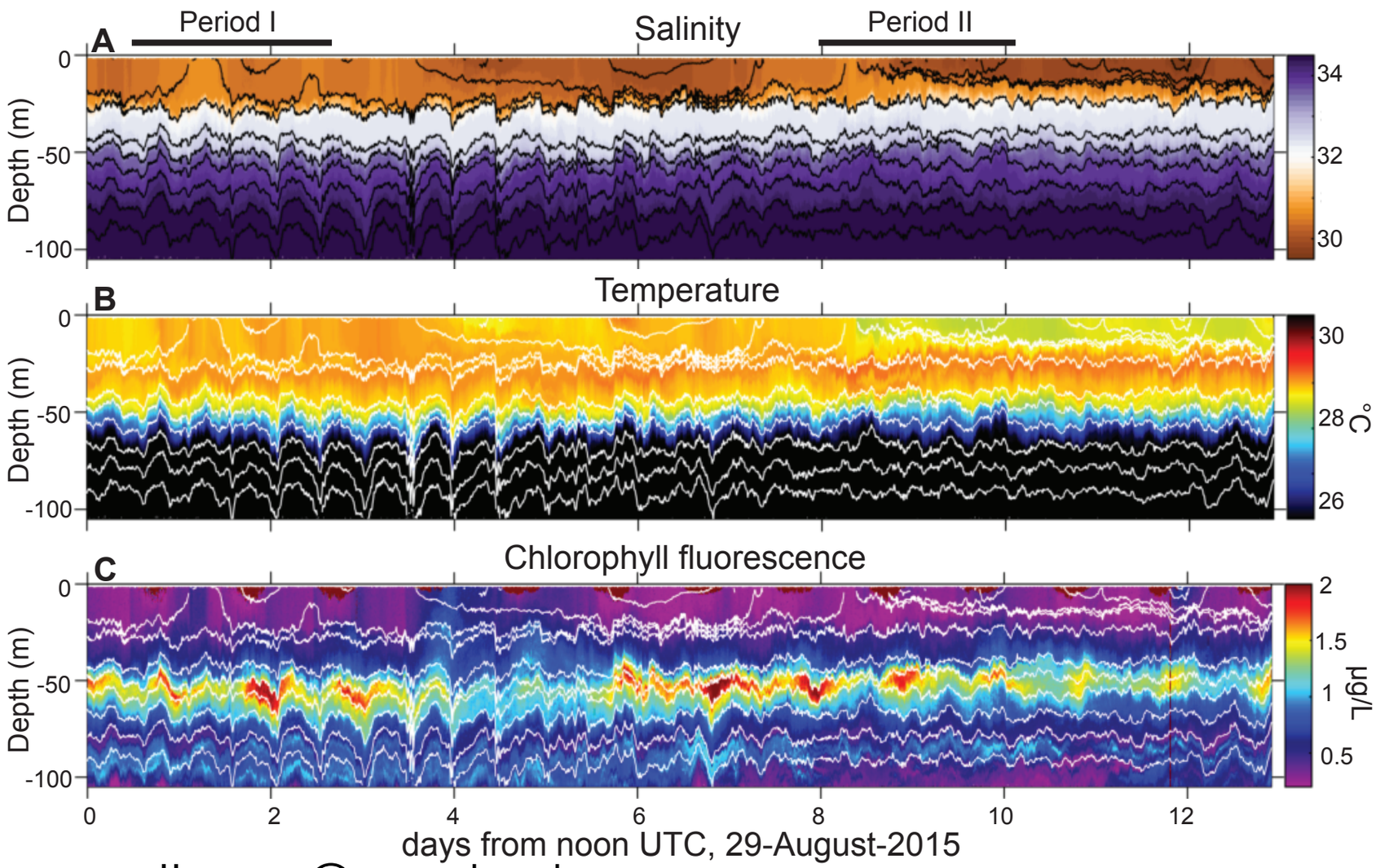
Prof. **Emily L. Shroyer**

“For developing clear and quantitative understanding of a range of ocean processes that shape the marine environment and its coupling to the atmosphere”

Andrew J. (Drew) Lucas
Asst. Prof., Scripps Institution of Oceanography

Platforms and sensors
for upper ocean research →

ocean boundary layer physics
coastal oceanography
effluent dispersal
bio-physical interactions



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Definitions…

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Estuaries provide many important ***ecosystem services,*** including habitat/nurseries for commercially valuable species, improve coastal water quality, support tourist actives, form the basis of many major shipping lanes.

Motivations…

Container ship in a US estuary

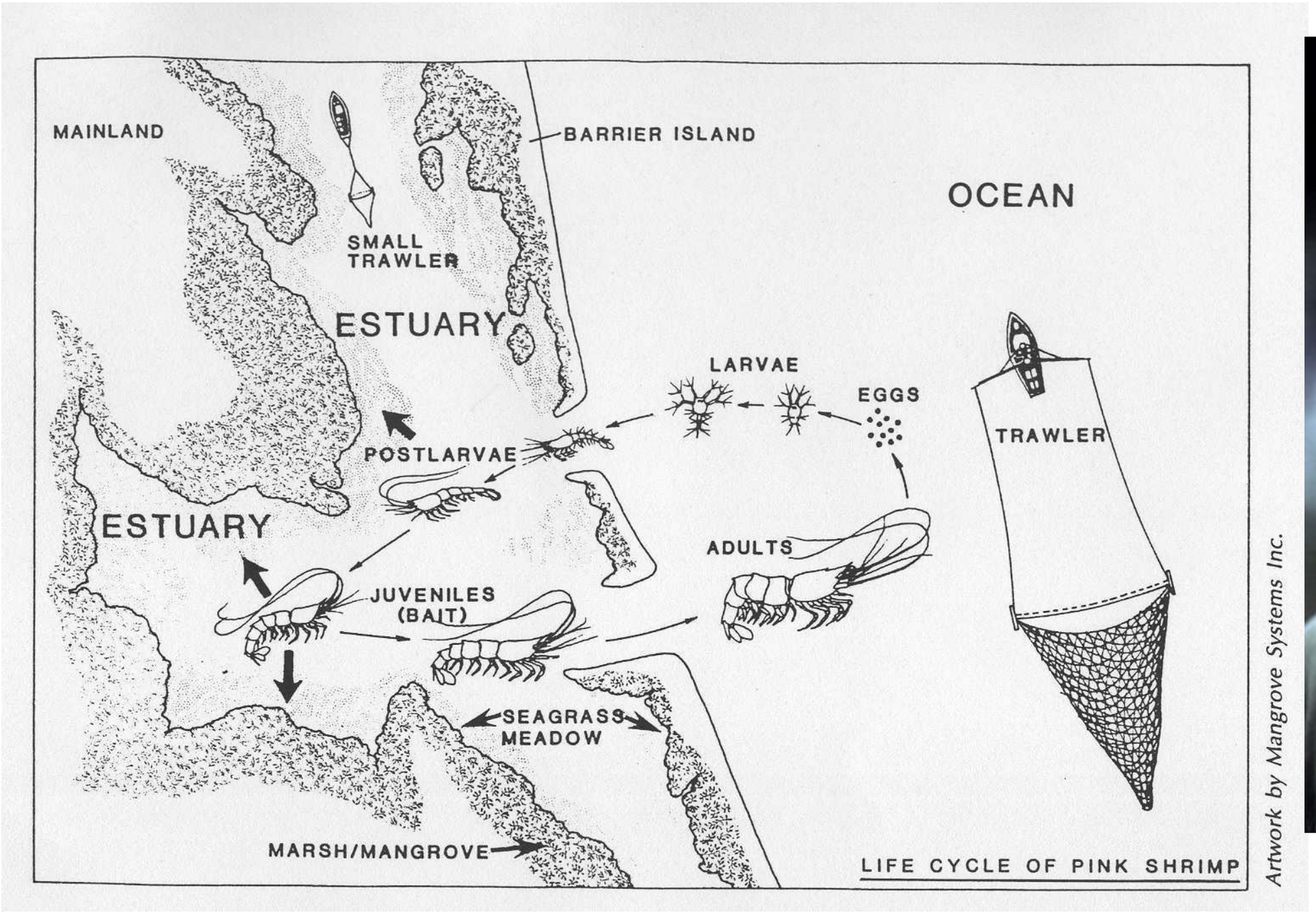
Many of the largest coastal cities are located where rivers meet the sea. Estuaries are major routes of transport and are often heavily influenced by human activities.

Motivations…

"After Blaze, Sewage Floods City Rivers" – *New York Times* 07/22/2011

Estuaries often receive intentional and unintentional discharge of effluent (sewage), industrial waste, storm water, and other pollutants.

Motivations…



your professor for today

Many commercially valuable fish, shrimp, crab species, etc. live or breed in estuaries. Also home to many birds and marine mammals. Human activities include fishing and tourism.

Motivations… GHANA

An ***estuary*** is a semi-enclosed region influenced by both **fresh** water from the land and **salty** water from the sea.

Motivations… GHANA

Akwidaa Estuary, Western Region, Ghana

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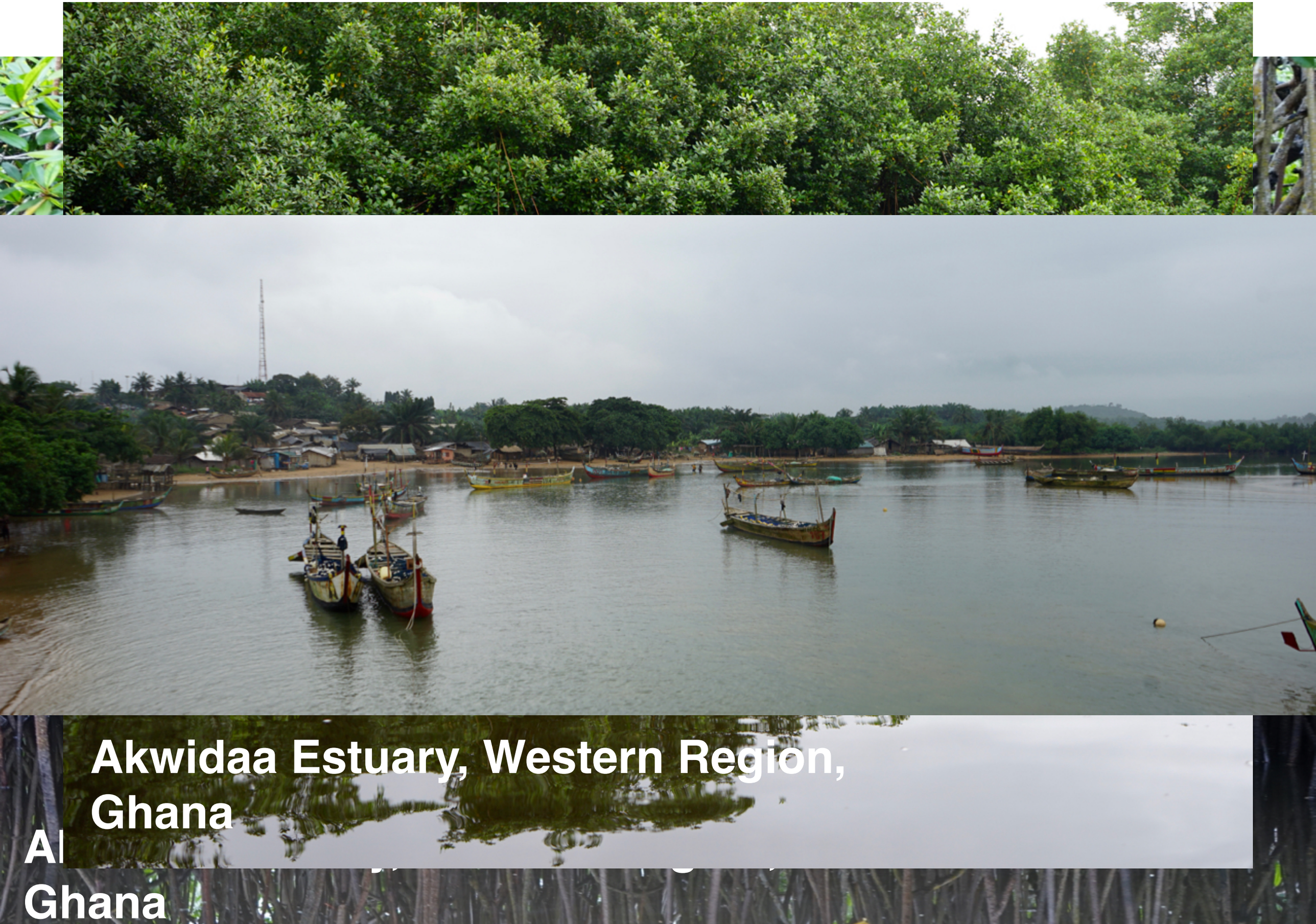
Ghana

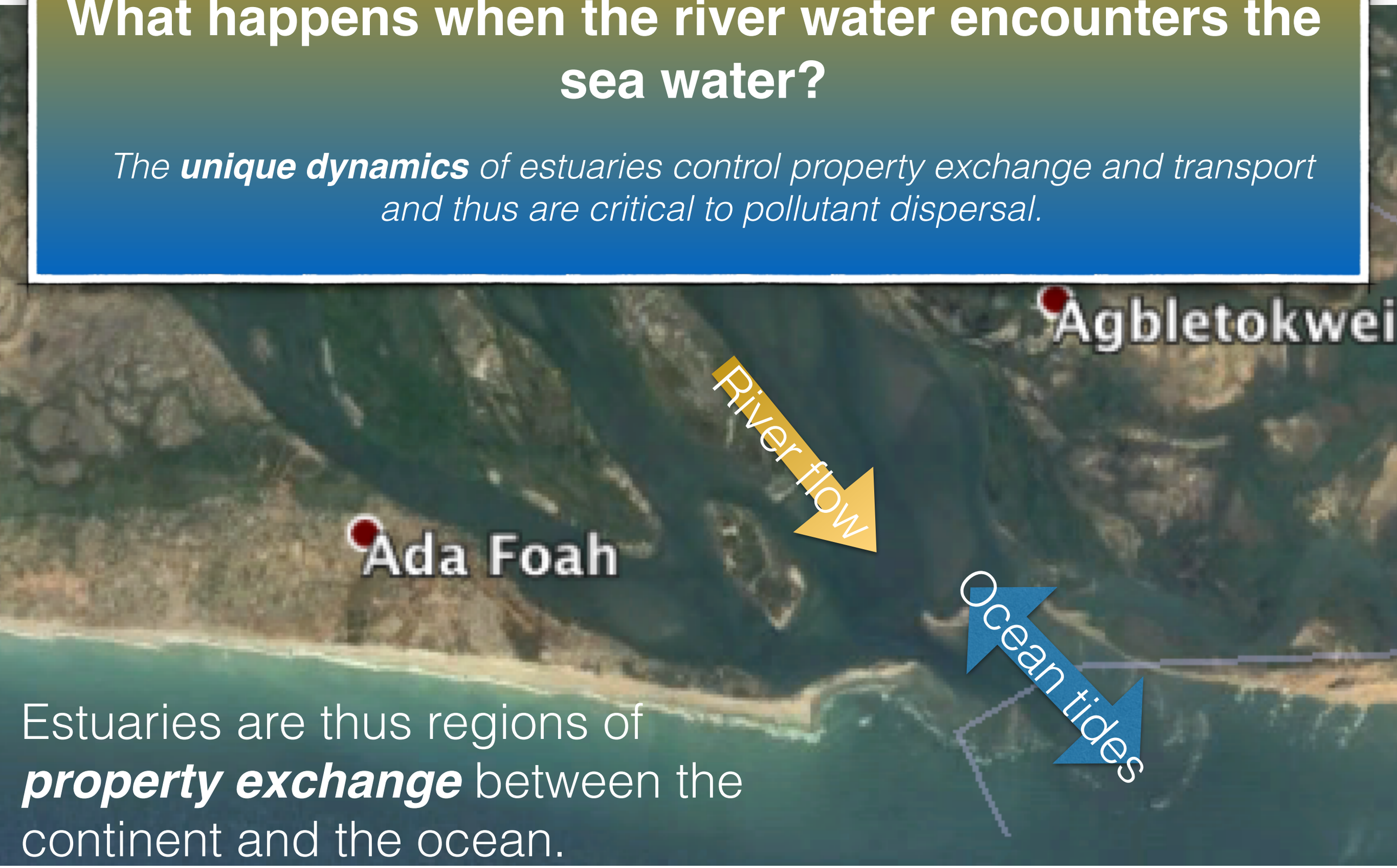


Akwidaa Estuary, Western Region, Ghana

Al
Ghana

The river water is fresh and the sea water is salty. What happens when the river water encounters the sea water?

*The **unique dynamics** of estuaries control property exchange and transport and thus are critical to pollutant dispersal.*



Estuaries are thus regions of ***property exchange*** between the continent and the ocean.

Akwidaa Estuary, Western Region, Ghana

Estuary Classification: Geological

- **Coastal plain estuaries** were formed at the end of the last ice age. As the ice melted and the waters warmed, sea level rose. The rising seas invaded low-lying coastal river valleys. These valleys are usually shallow with gentle sloping bottoms. Their depth increases toward the river's mouth.

- **Bar-built** Bar-built estuaries are formed when sandbars build up along the coastline. These sand bars partially cut off the waters behind them from the sea. Bar-built estuaries are usually shallow, with reduced tidal action. Wind is frequently the most important mixing tool for the fresh and salt water.

Estuary Classification: Geological

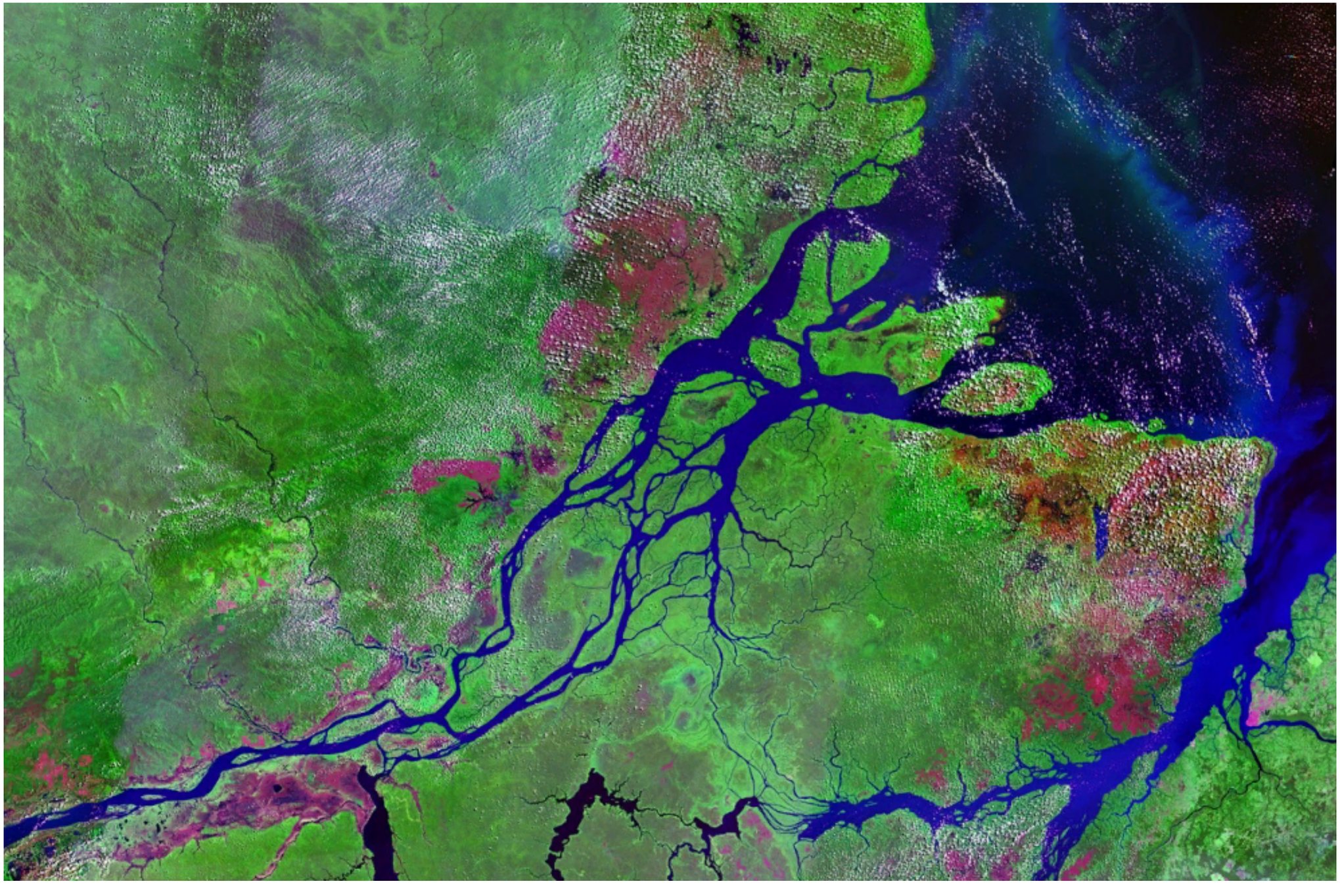
- **Tectonic:** Tectonic estuaries are created when the sea fills in the "hole" or basin that was formed by the sinking land. San Francisco Bay is a good example of this type of estuary.

San Francisco Bay

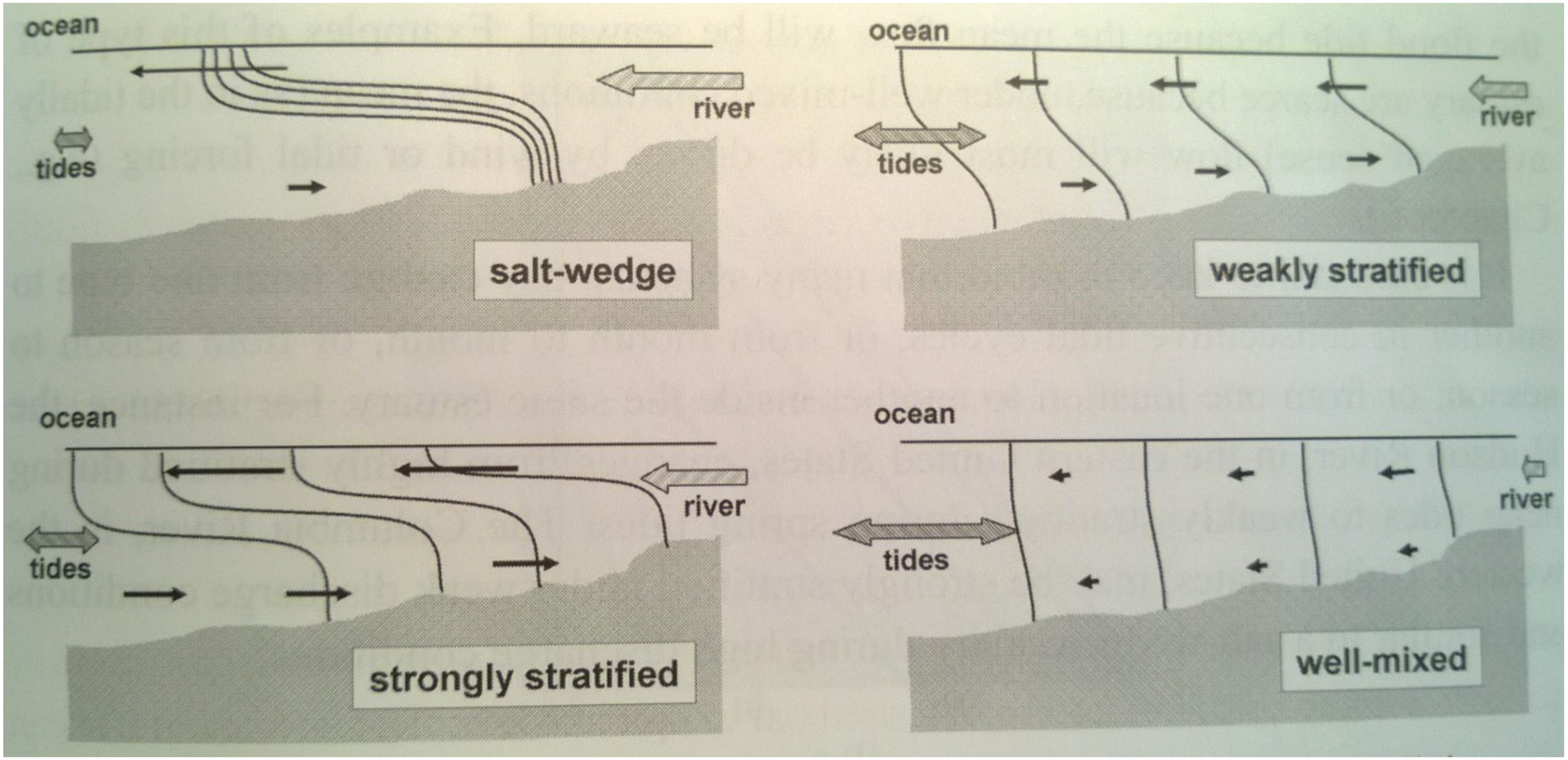
- **Fjords:** Fjords are valleys that have been deepened by moving glaciers. They have a shallow barrier at their mouth that limits exchange between the waters of the fjord and the sea. They are narrow with steep sides and usually straight and long.

Estuary Classification: Geological

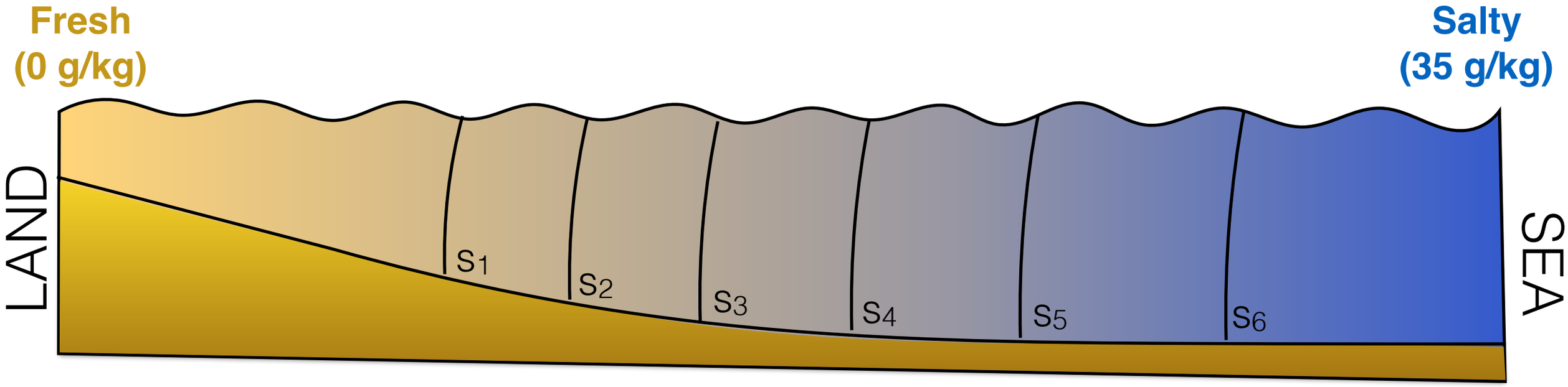
- Delta: Tectonic estuaries are created when the sea fills in the "hole" or basin that was formed by the sinking land. San Francisco Bay is a good example of this type of estuary.



Estuary Classification: Hydrodynamics



Schematic estuaries: Vertically homogenous

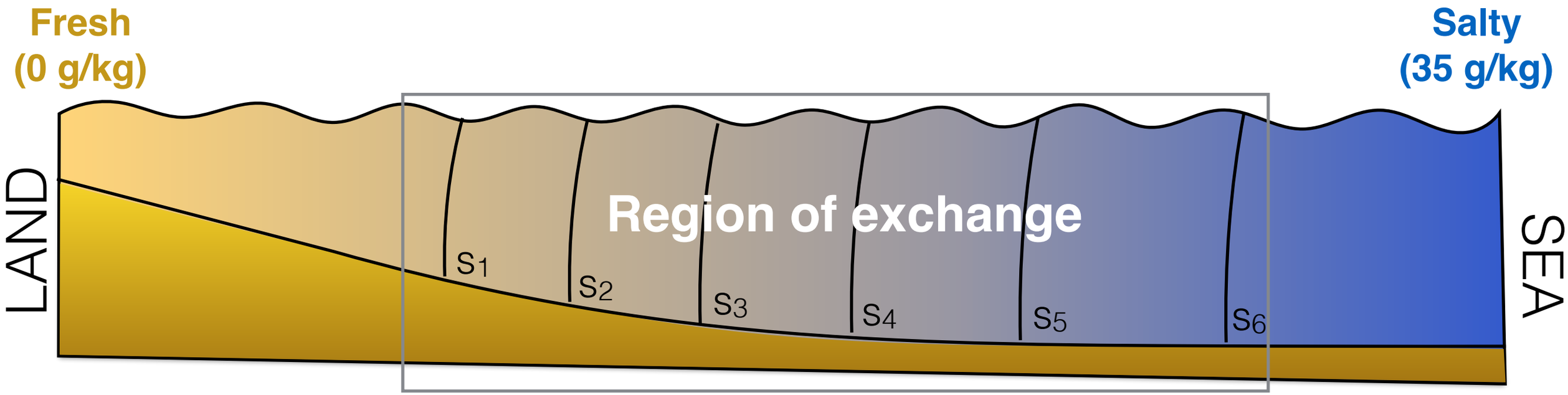


“Well-mixed estuary”

$S_1 < S_2 < S_3 < S_4 < S_5 < S_6$

The Hudson River Estuary, New York City, USA

Schematic estuaries: Vertically homogenous



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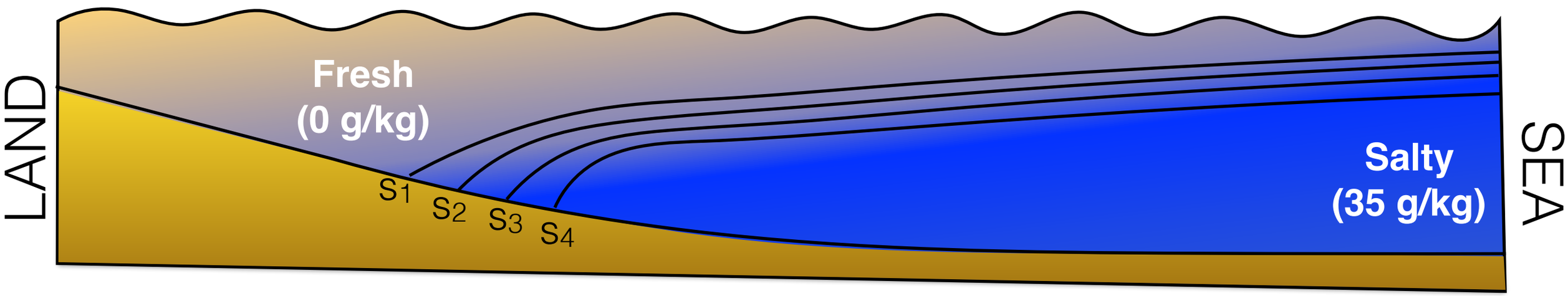

“Salt wedge estuary”

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The Rio de la Plata, Argentina

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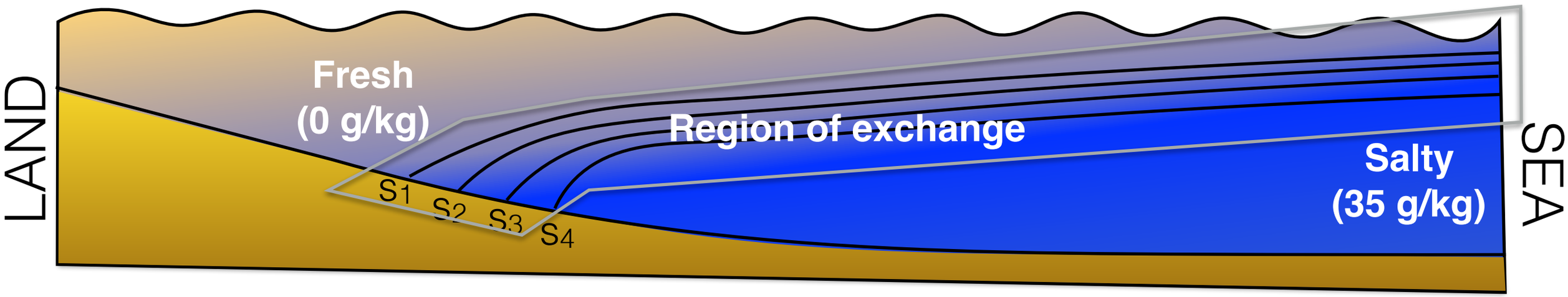

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The Rio de la Plata, Argentina

Newton's 2nd Law recast for fluids
(the Navier - Stokes equation)

$$\frac{D\vec{u}}{Dt} + 2\vec{\Omega} \times \vec{u} = -\frac{1}{\rho_o}\nabla p + \frac{\rho}{\rho_o}\vec{g} + \vec{F}$$

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$$\frac{D\vec{u}}{Dt} + 2\vec{\Omega}\times\vec{u} = -\frac{1}{\rho_o}\nabla p + \frac{\rho}{\rho_o}\vec{g} + \vec{F}$$

Acceleration
(local + nonlinear terms)

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Rotation

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Pressure gradient

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Pressure gradient

Buoyancy

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Acceleration
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Rotation

Pressure gradient

Buoyancy

External forces
(wind, friction, tidal, etc)

Newton's 2nd Law recast for fluids
(the Navier - Stokes equation)

$$\frac{D\vec{u}}{Dt} = -\frac{1}{\rho}\nabla p + \nu\nabla^2\vec{u} + \vec{g}\left(\frac{\rho - \rho_0}{\rho_0}\right) + \vec{F}$$

HELP THIS IS TOO COMPLICATED!!!!
WHAT DO WE DO?

Rotation

Buoyancy

External forces
(wind, friction, tidal, etc)

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Acceleration
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Rotation

Pressure gradient

Buoyancy

External forces
(wind, friction, tidal, etc)

Assume *steady state*, *neglect rotation*, *hydrostatic* and *spatial variability only in x (i.e. y-, z- uniform)*

Newton's 2nd Law recast for fluids
(the Navier - Stokes equation)

$$+2\vec{\Omega}\times\vec{u} = -\frac{1}{\rho_o}\nabla p + \frac{\rho}{\rho_o}\vec{g} + \vec{F}$$

~~**Acceleration**~~
~~**(local + nonlinear terms)**~~

Pressure gradient

Rotation

Buoyancy

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External forces (wind, friction, tidal, etc)

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$$0 = -\frac{1}{\rho_o}\nabla p + \frac{\rho}{\rho_o}\vec{g} + \vec{F}$$

~~**Acceleration**~~
~~**(local + nonlinear terms)**~~

Pressure gradient

~~**Rotation**~~

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Newton's 2nd Law recast for fluids
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$$0 = -\frac{1}{\rho_0}\frac{\partial p}{\partial x} + \frac{1}{\rho_0}\frac{\partial \tau_x}{\partial z}$$

~~Acceleration~~
~~(local + nonlinear terms)~~

Pressure gradient

~~Rotation~~

~~Buoyancy~~

Assume ***steady state***, ***neglect rotation***, ***hydrostatic*** and ***spatial variability only in x (i.e. y-, z- uniform)***

External forces
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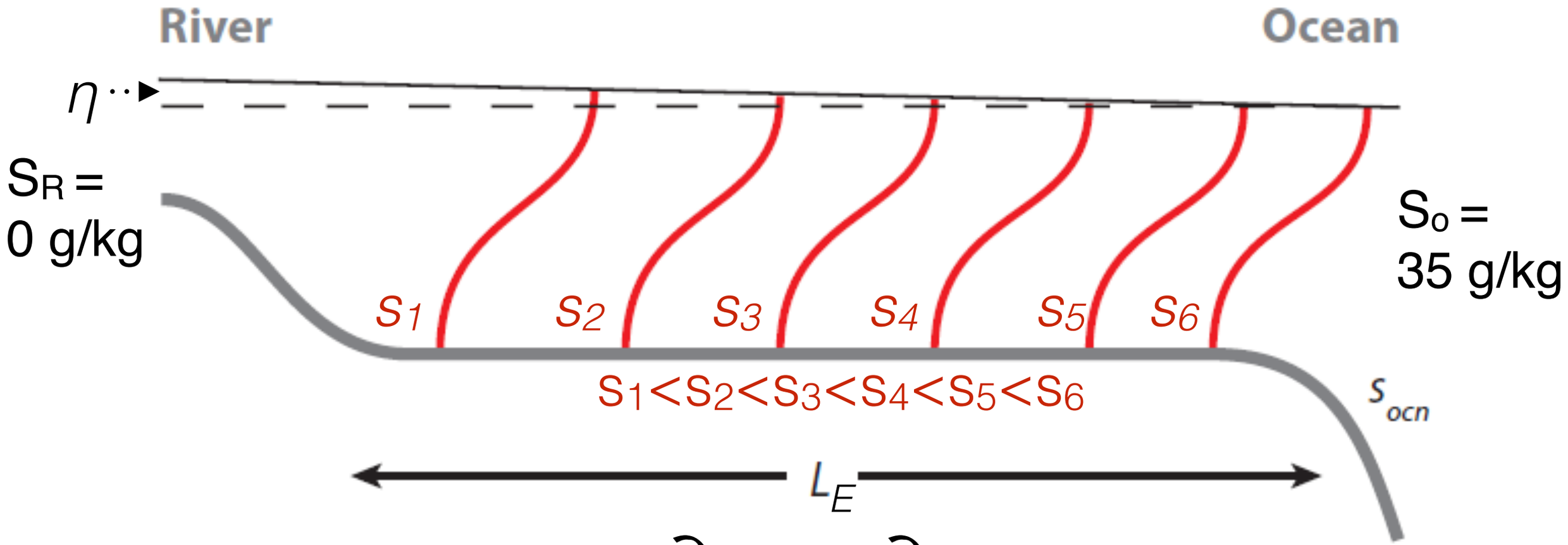
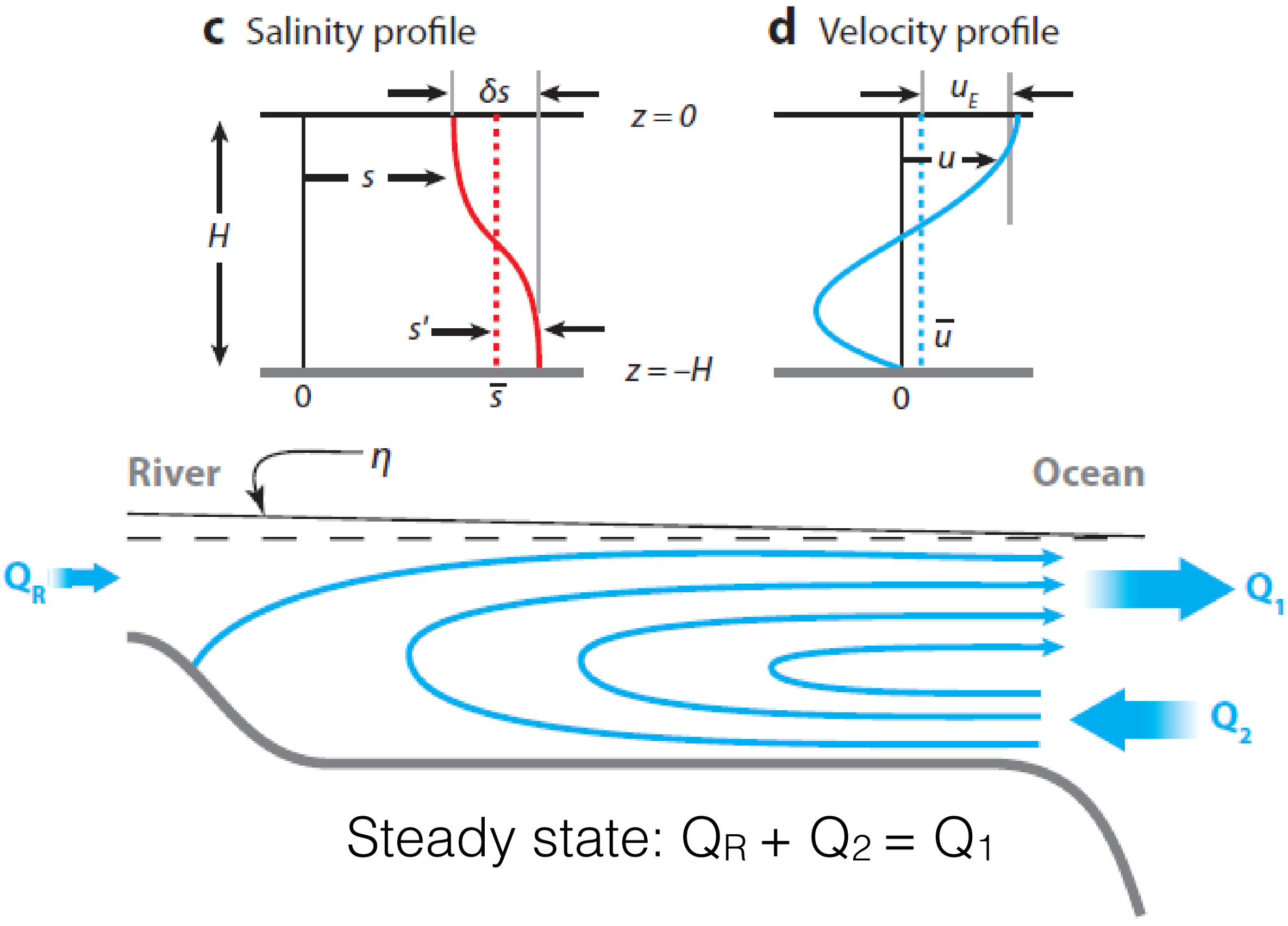
An idealized estuary:



$$\frac{\partial p}{\partial x} = \frac{\partial \tau_x}{\partial z}$$

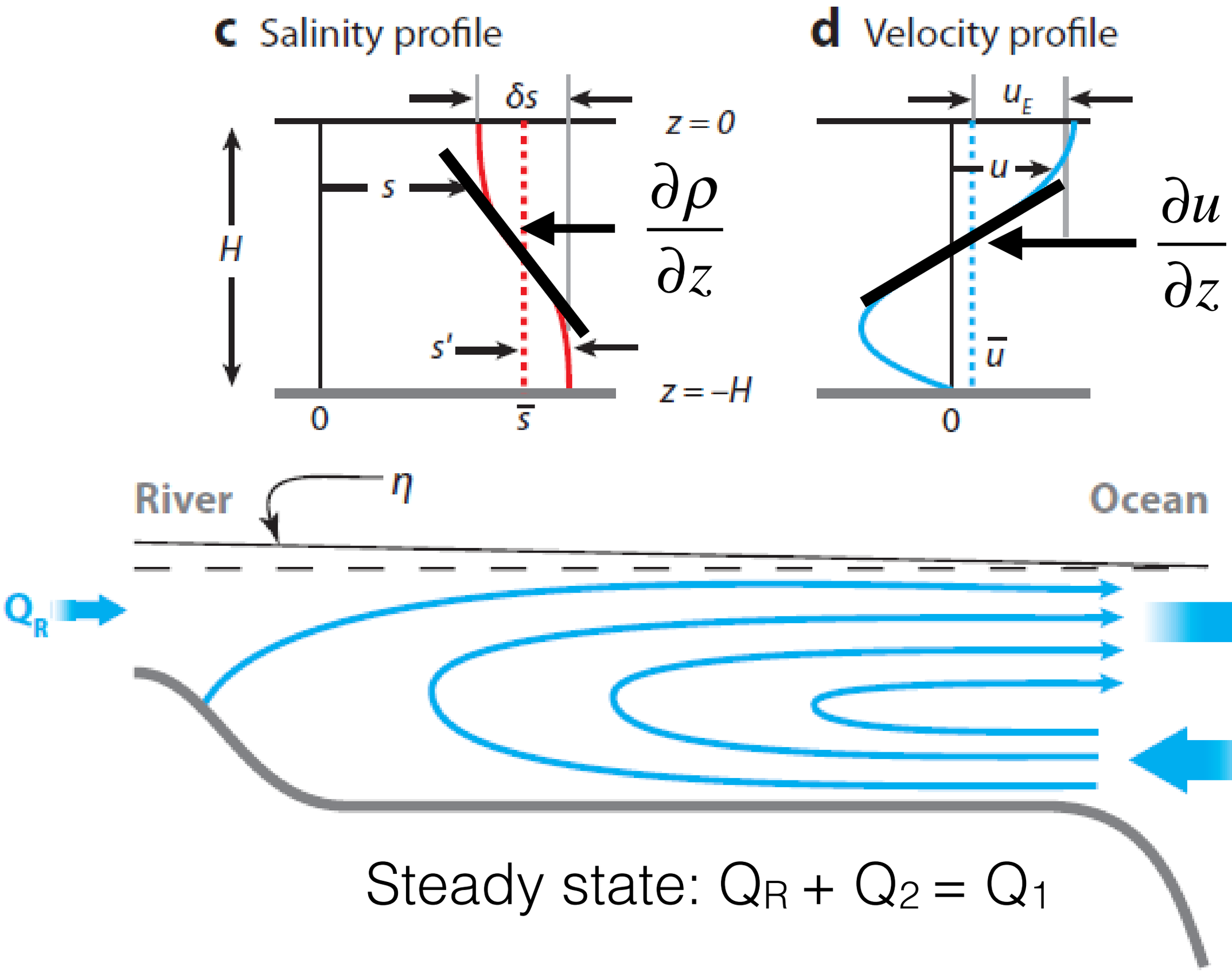
Details: the pressure gradient depends on both the sea surface slope (η) and the horizontal density gradient and the frictional term is really complicated

Idealized, tidally averaged, partially mixed estuary



Steady state: $Q_R + Q_2 = Q_1$

Idealized, tidally averaged, partially mixed estuary



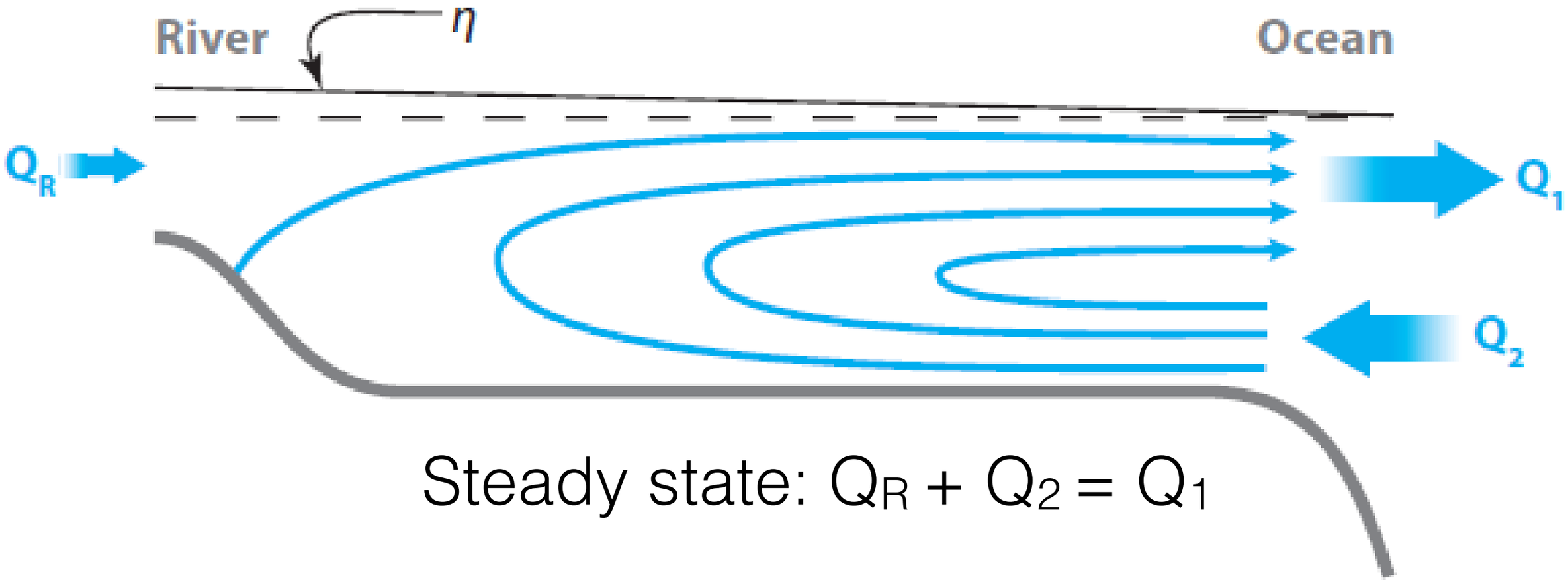
Steady state: $Q_R + Q_2 = Q_1$

Idealized, tidally averaged, partially mixed estuary

c Salinity profile

d Velocity profile

$$\textbf{Richardson Number (Ri)} = \frac{-\frac{g}{\rho_o}\frac{\partial \rho}{\partial z}}{\left(\frac{\partial \vec{u}}{\partial z}\right)^2}$$



Steady state: $Q_R + Q_2 = Q_1$

Idealized, tidally averaged, partially mixed estuary

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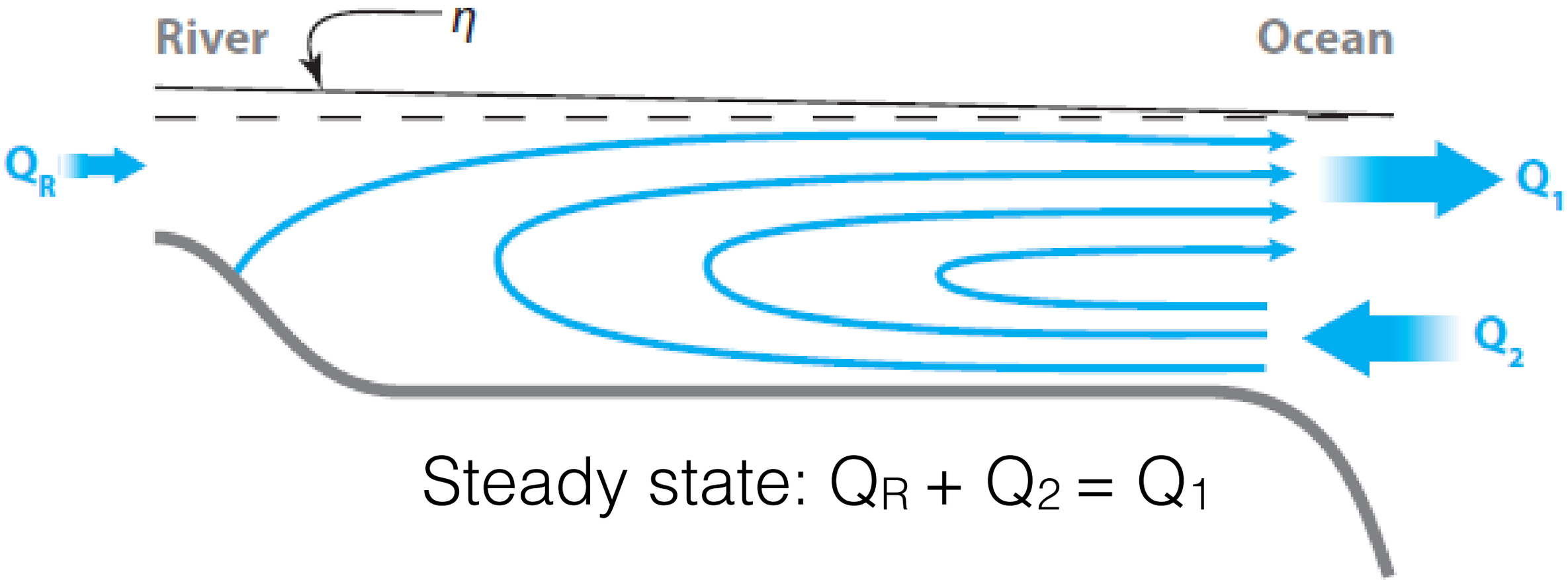
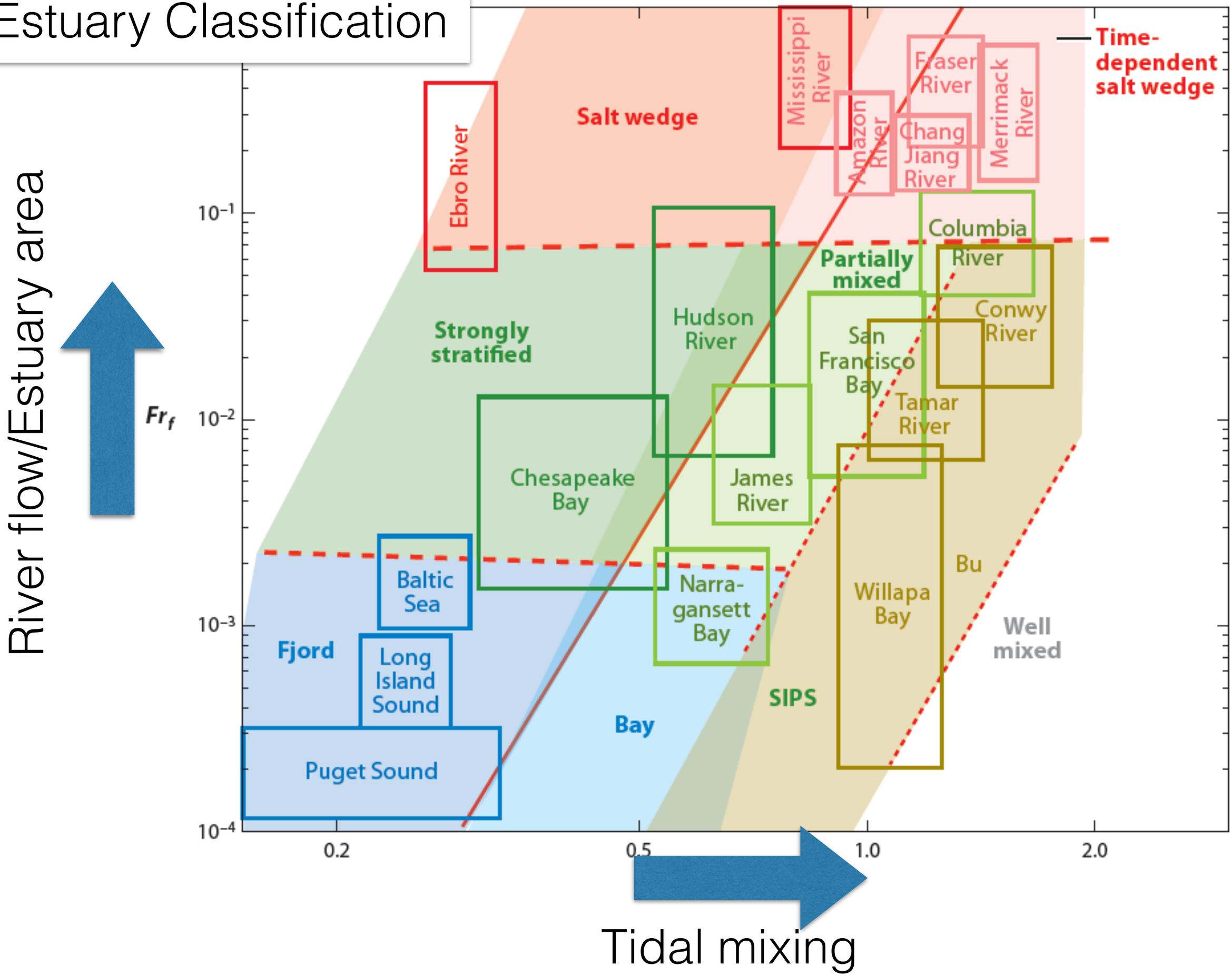
d Velocity profile

$$\textbf{Richardson Number (Ri)} = \frac{N^2}{S^2}$$

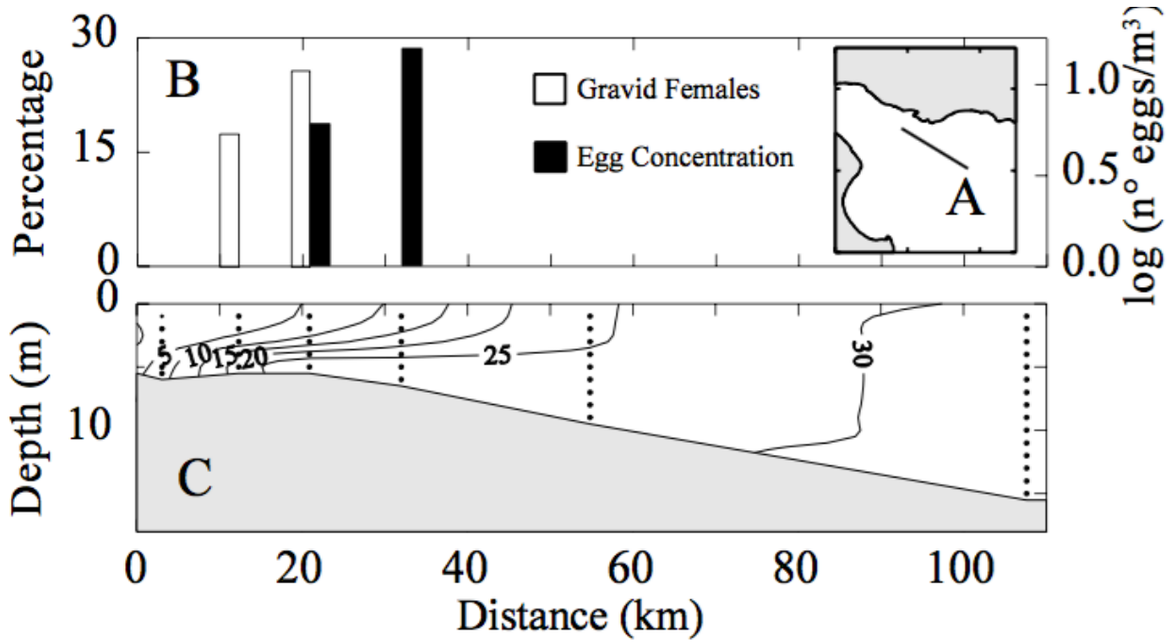


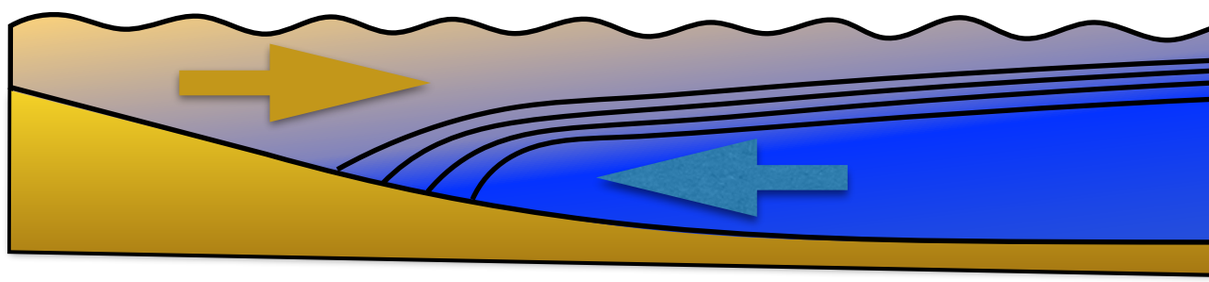
Steady state: $Q_R + Q_2 = Q_1$

Estuary Classification



An example of biological effects of estuarine processes: Spawning of the Whitemouth Croaker in the Rio de la Plata





Acha et al. Mar. Freshwater Res., 1999, 50, 57:65

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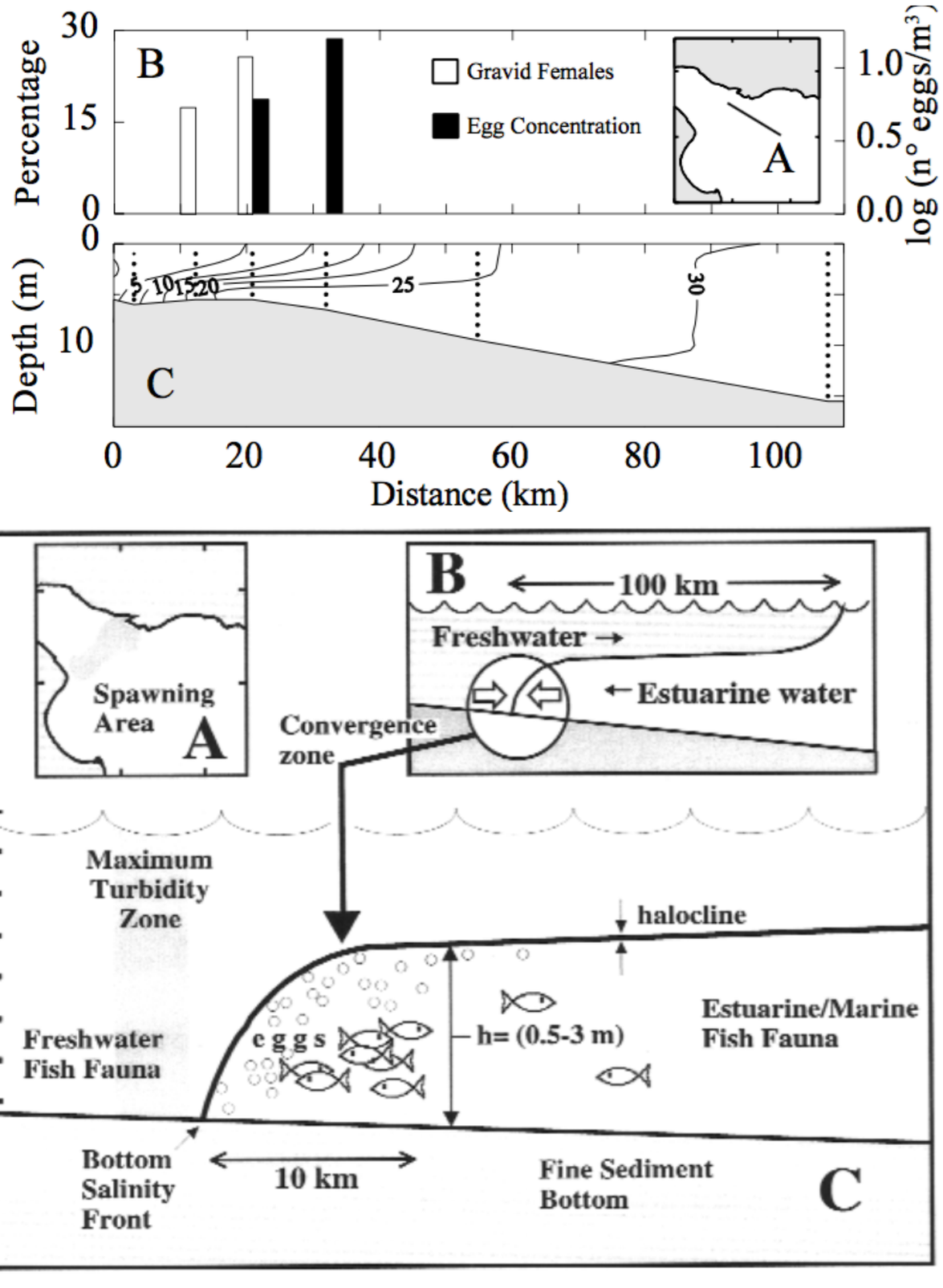
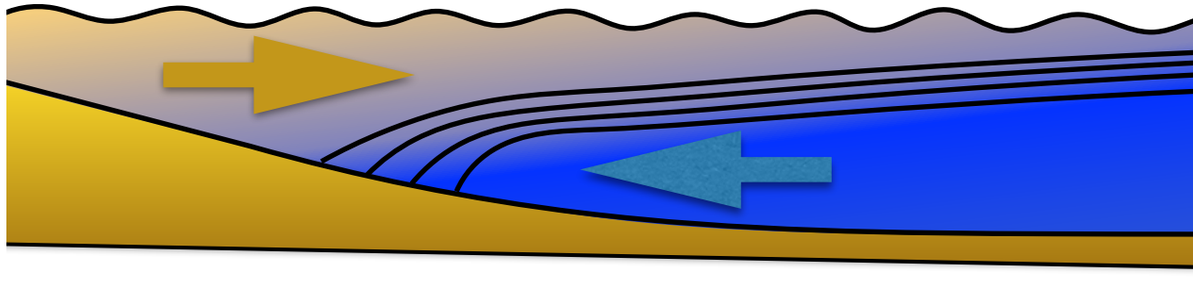




Acha et al. Mar. Freshwater Res., 1999, 50, 57:65

Bonus question:
River plumes— What is happening here?

Sampling an estuary: What do you need to know?

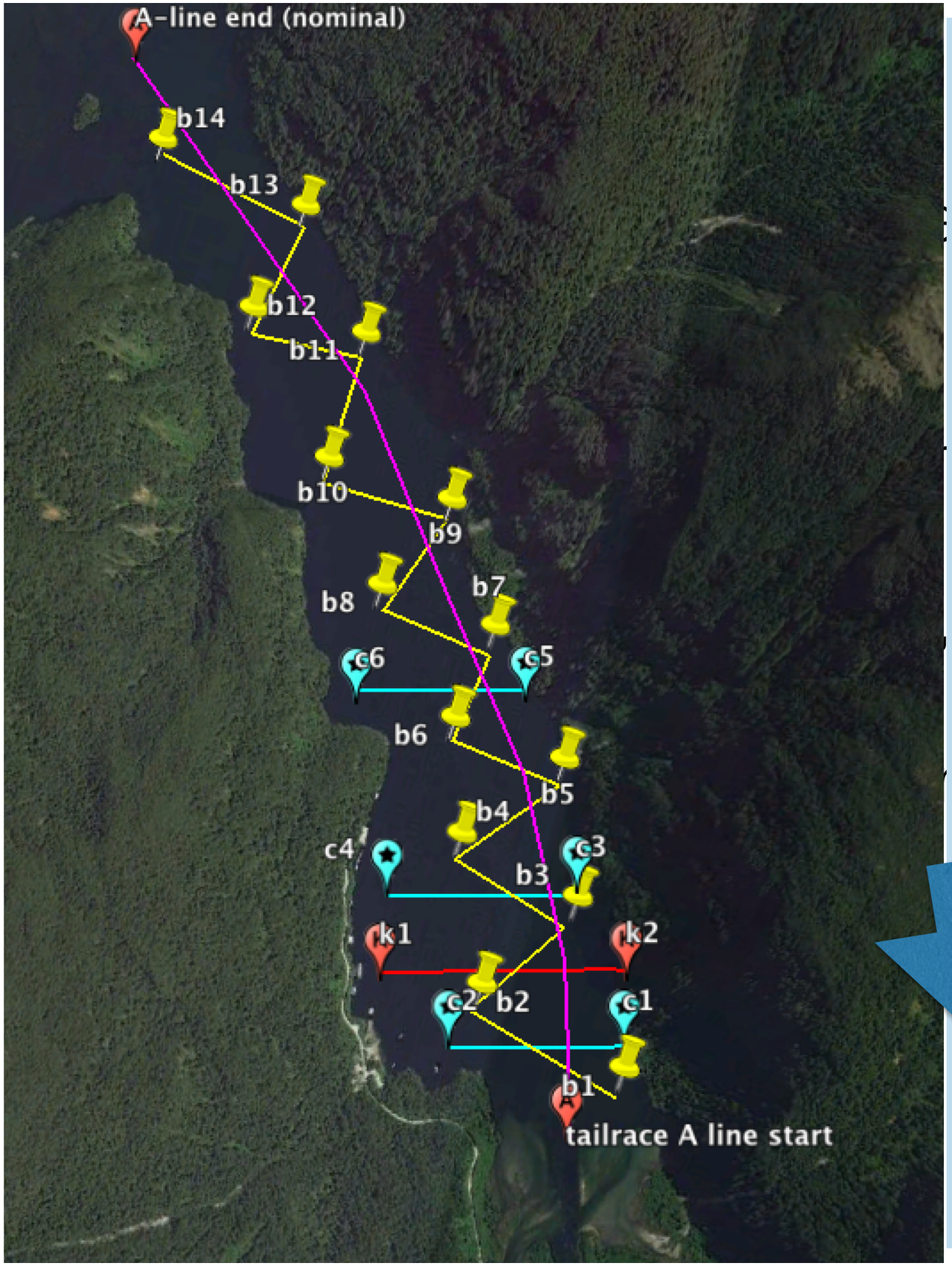
1) Vertical gradients in temperature, salinity, and currents

2) Horizontal gradients in T, S, and currents

3) Time variability in T, S, and currents

4) Vertical, lateral, and time distribution of mixing

5) River input and wind field


A-line end (nominal)
b14
b13
b12
b11
b10
b9
b8
b7
c6
c5
b6
b5
b4
c4
c3
b3
k1
k2
c2
b2
c1
b1
A
tailrace A line start


NORTH ISLAND
SOUTH ISLAND
STEWART ISLAND
Kaitaia
Kerikeri
Paihia
Whangarei
Dargaville
Warkworth
Helensville
AUCKLAND
Coromandel
Thames
Paeroa
Waihi
Katikati
Tauranga
Hicks Bay
Hamilton
Te Puke
Whakatane
Opotiki
Otorohanga
Rotorua
Tokoroa
Waikaremoana
Taupo
Gisborne
New Plymouth
Turangi
Wairoa
Waiouru
Napier
Hawera
Wanganui
Palmerston North
Woodville
Paraparaumu
Masterton
Collingwood
WELLINGTON
Motueka
Picton
Nelson
Blenheim
Westport
Reefton
Punakaiki
Springs Junction
Kaikoura
Greymouth
Lewis Pass
Hanmer Springs
Hokitika
Arthurs Pass
Waipara
Franz Josef
CHRISTCHURCH
Mount Cook
Haast
Ashburton
Akaroa
Timaru
Omarama
Wanaka
Kurow
Queenstown
Cromwell
Oamaru
Alexandra
Te Anau
Manapouri
DUNEDIN
Gore
Milton
Invercargill
Half Moon Bay

Sampling an estuary: What do you need to know?

Sampling an estuary: How?

Horizontal and vertical scales are small. You need **specialized instrumentation that samples quickly.**

Profiling mooring:
T, S, oxygen, currents, turbulence resolved in **time**

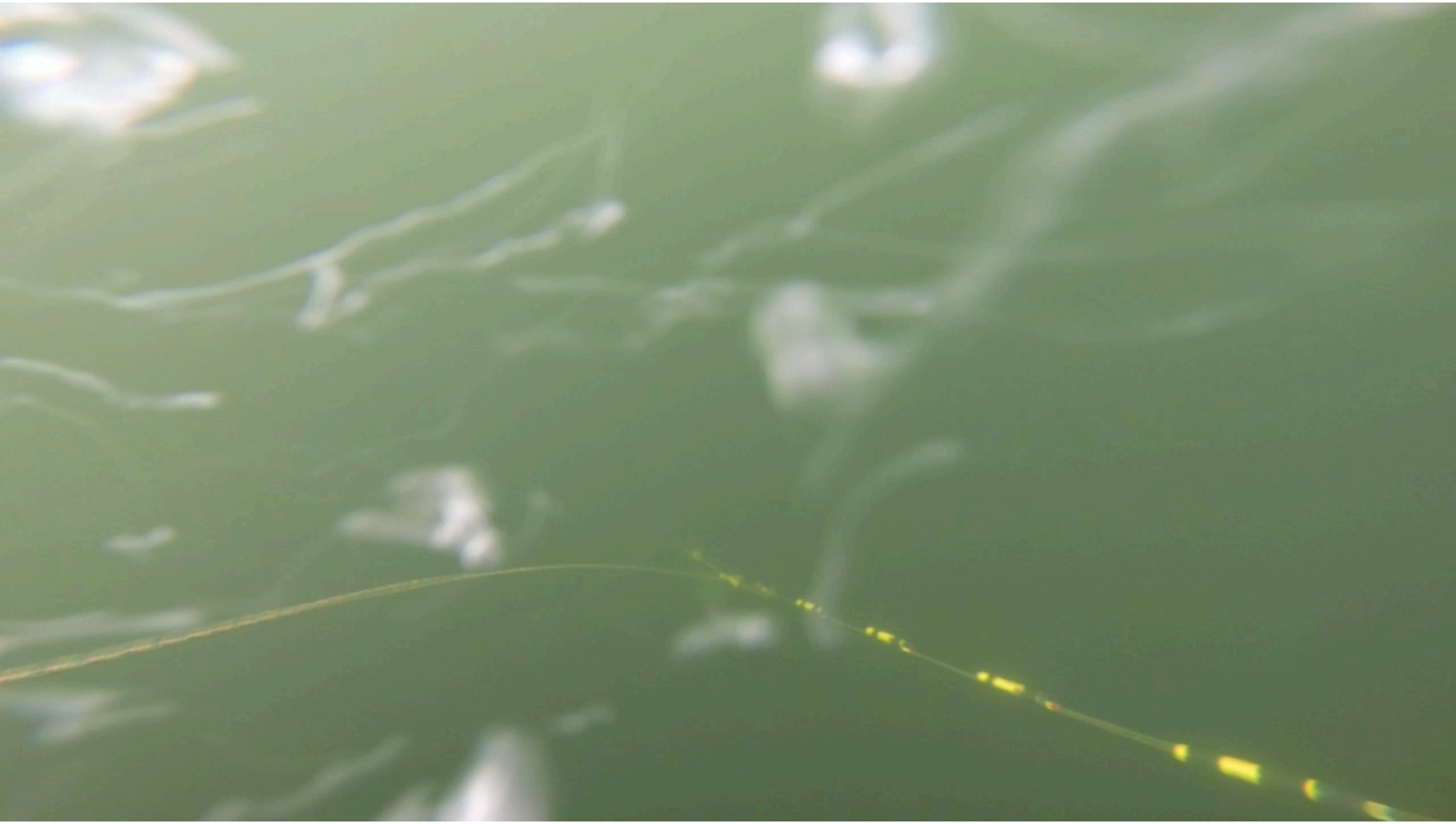
Small boat and kayak profiling:
T, S, oxygen currents, turbulence resolved in **space**

Small boat and kayak profiling:

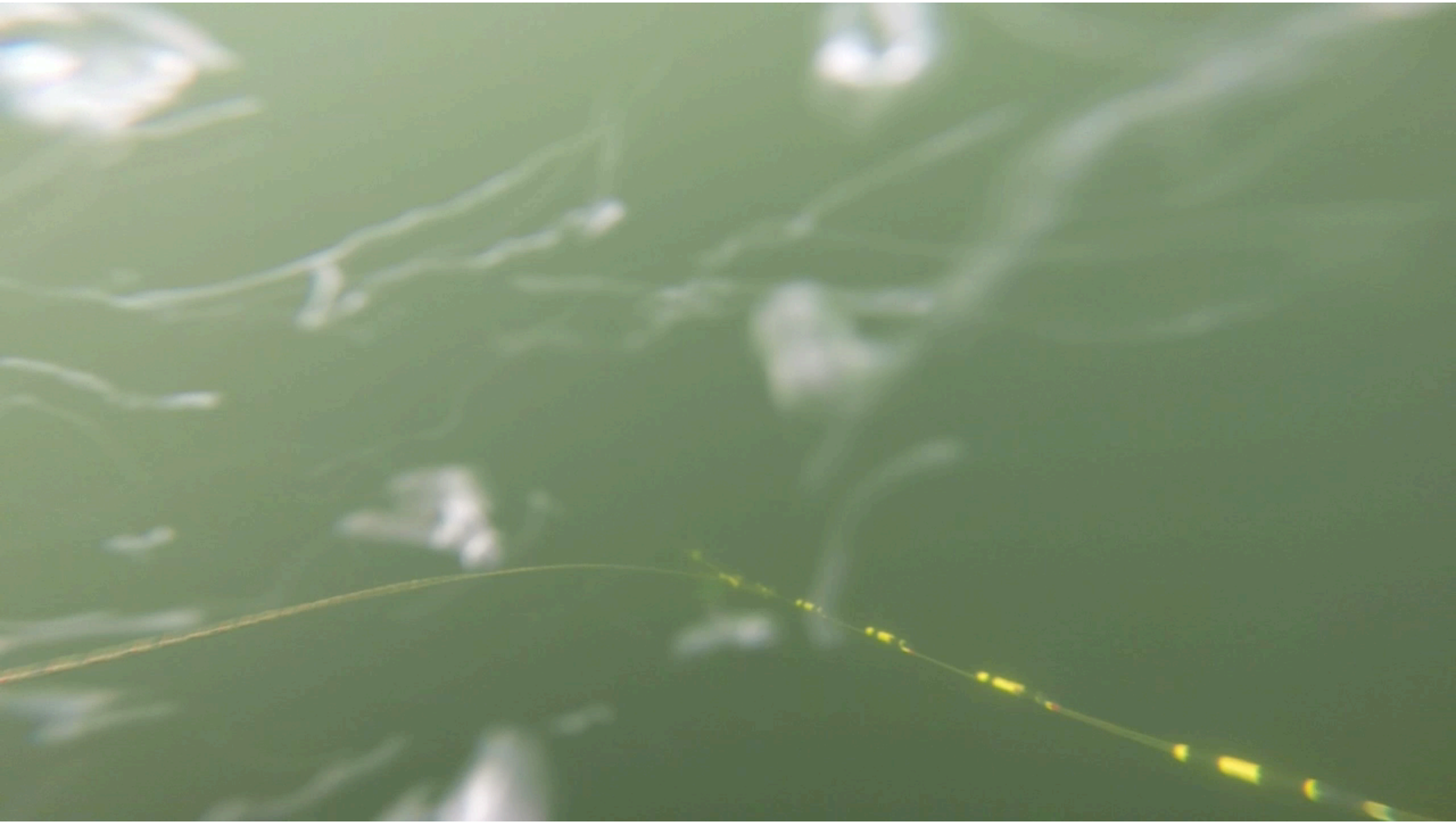
Small boat and kayak profiling:

Small boat and kayak profiling:

Small boat and kayak profiling:



Small boat and kayak profiling:



Small boat and kayak profiling:

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Small boat and kayak profiling:

The Scripps Institution of Oceanography Wirewalker Wave-powered profiler

The Wirewalker system uses energy from ocean surface waves to drive a profiling body vertically.

Rapid profiling at zero energy cost.

Battery power conserved for onboard instrumentation.

Large field-modifiable payload, indefinite profiling, low cost, simple and robust mechanical design.

>400K cycles and ~20,000 km of Wirewalker profiles in the global ocean in the past 10 years.

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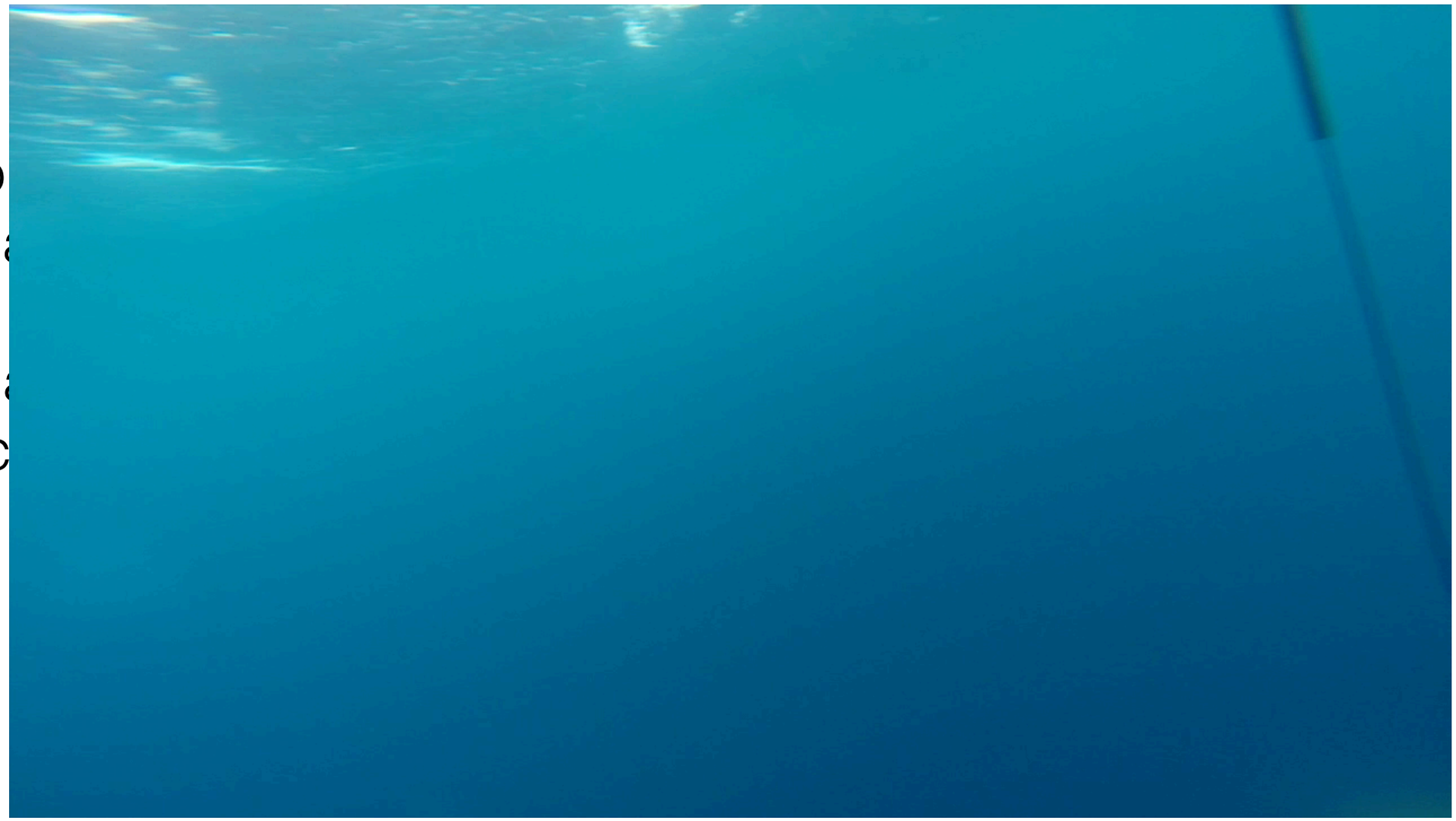

The Scripps Institution of Oceanography Wirewalker Wave-powered profiler

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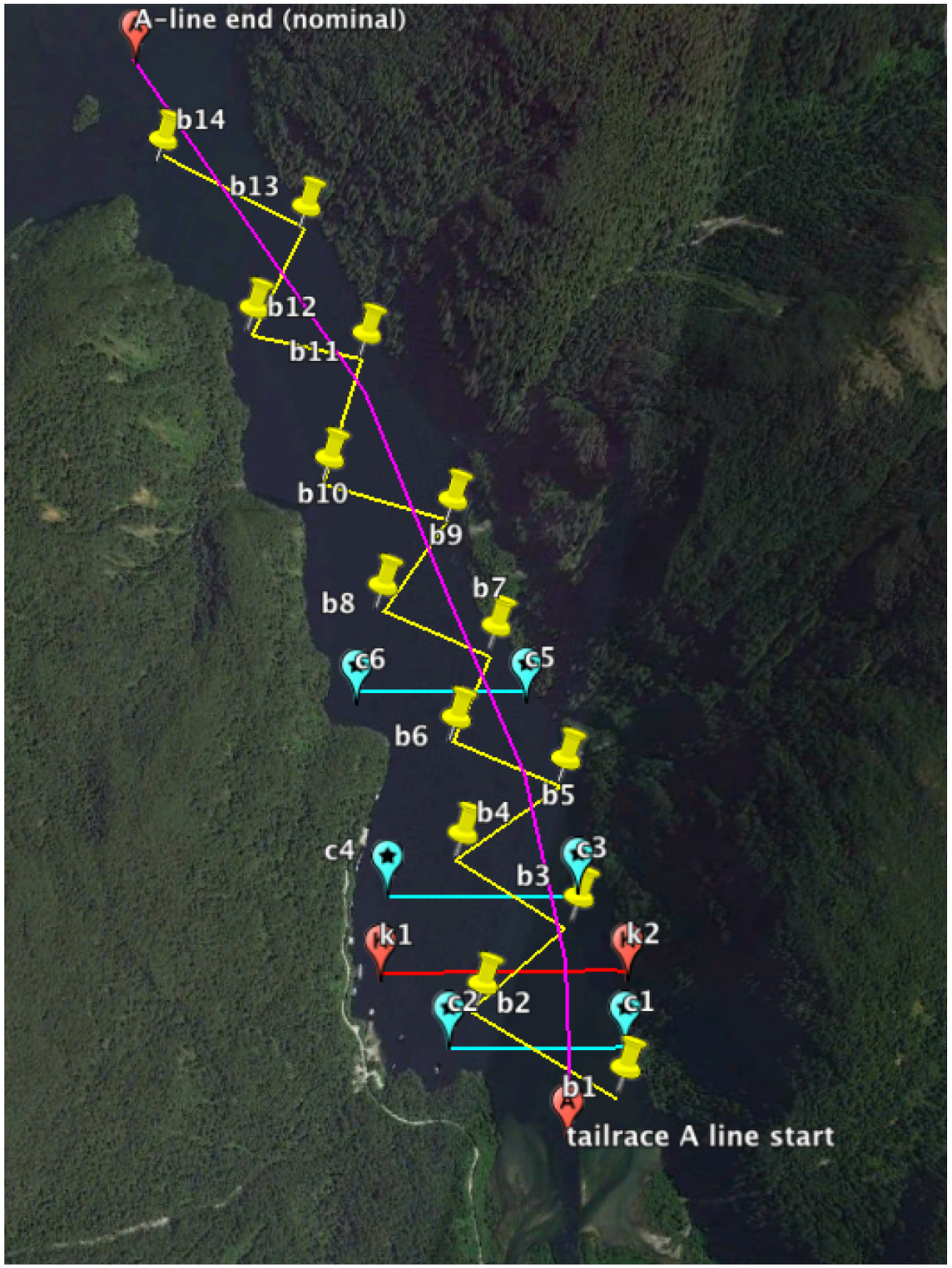
The Scripps Institution of Oceanography Wirewalker Wave-powered profiler

Sampling an estuary: How?

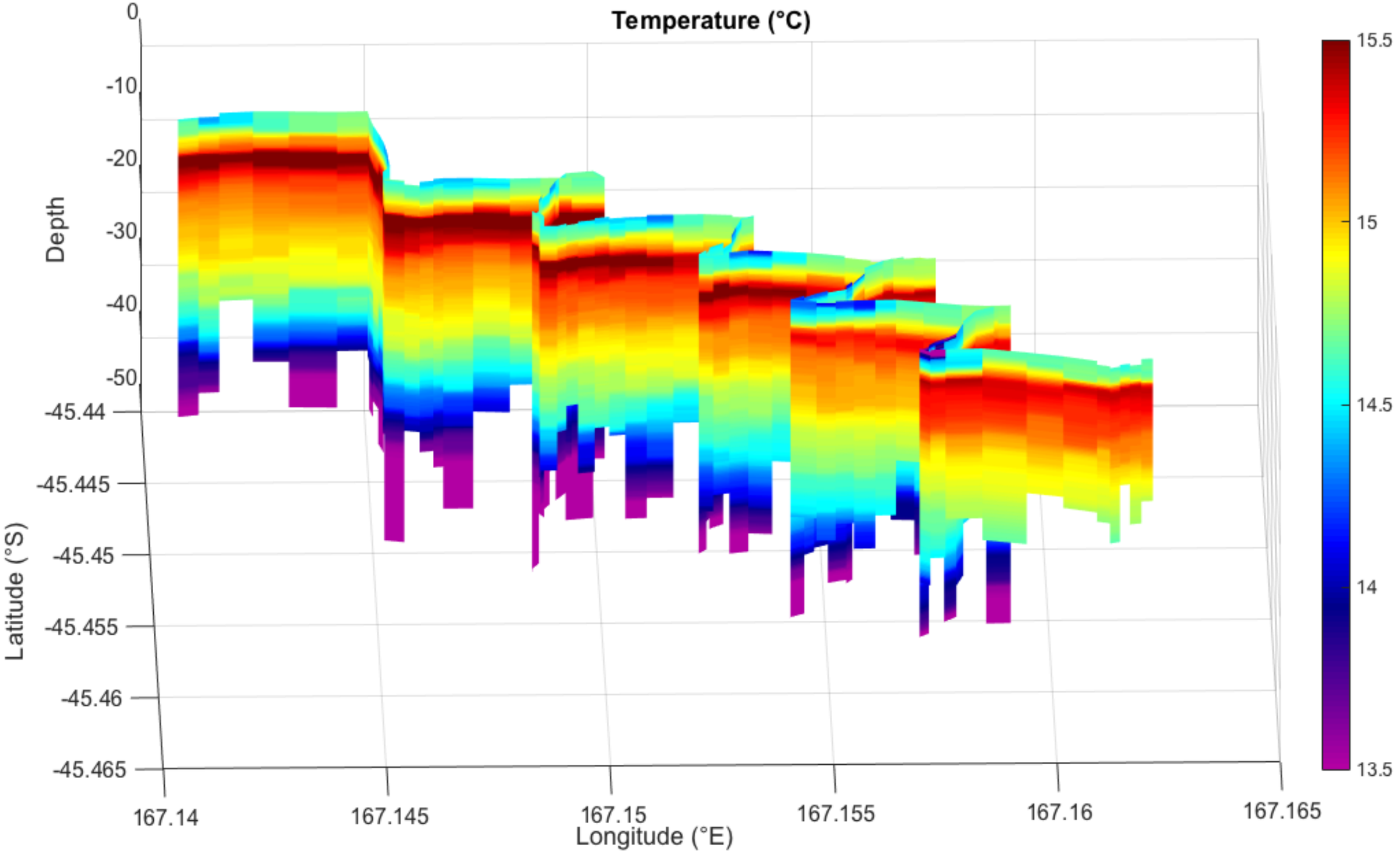


Get a toolkit appropriate to the problem.

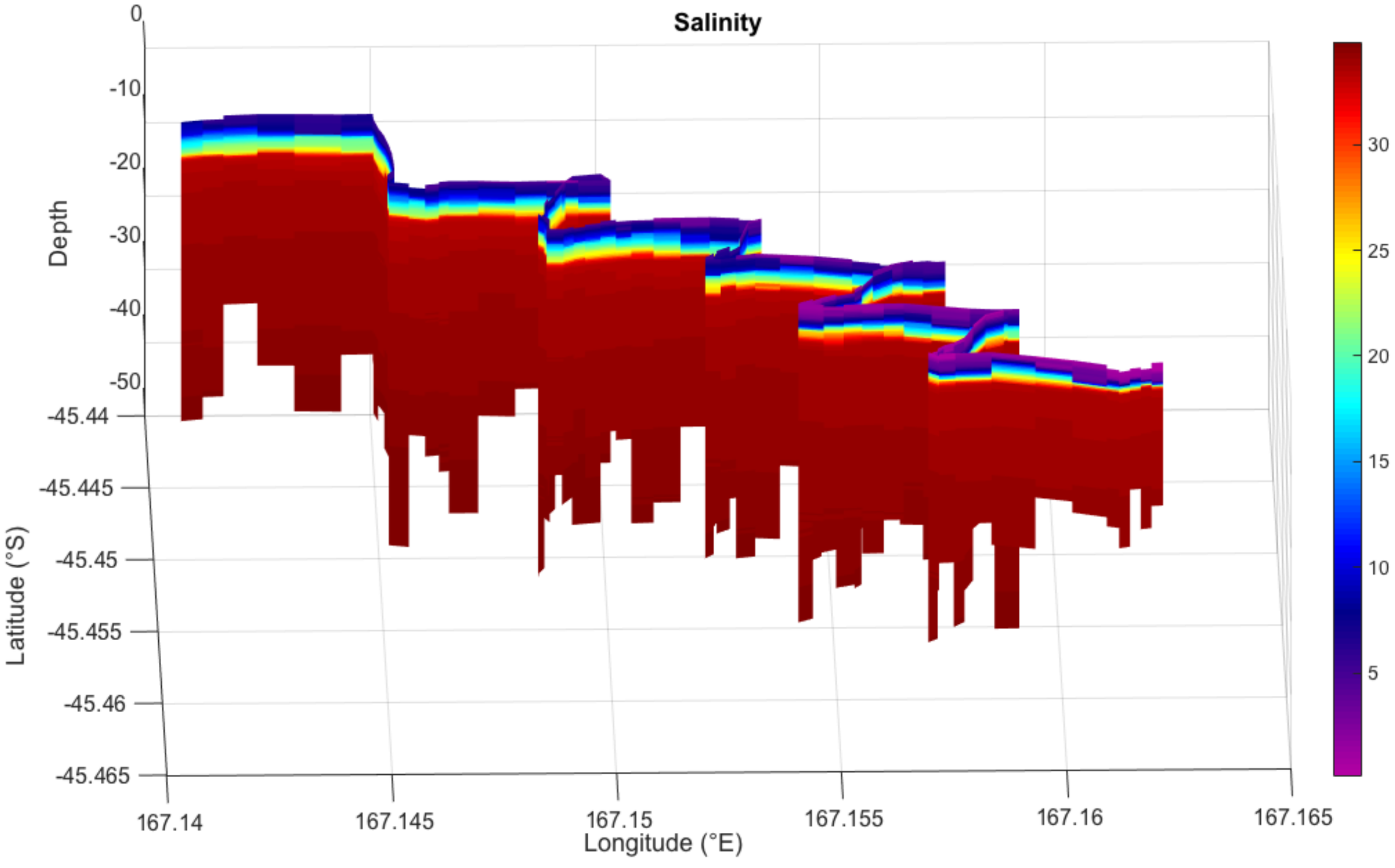
Choose the simplest possible sampling scheme that gives the sampling characteristics you require.

Repeat until you can't stand it. And then repeat some more.

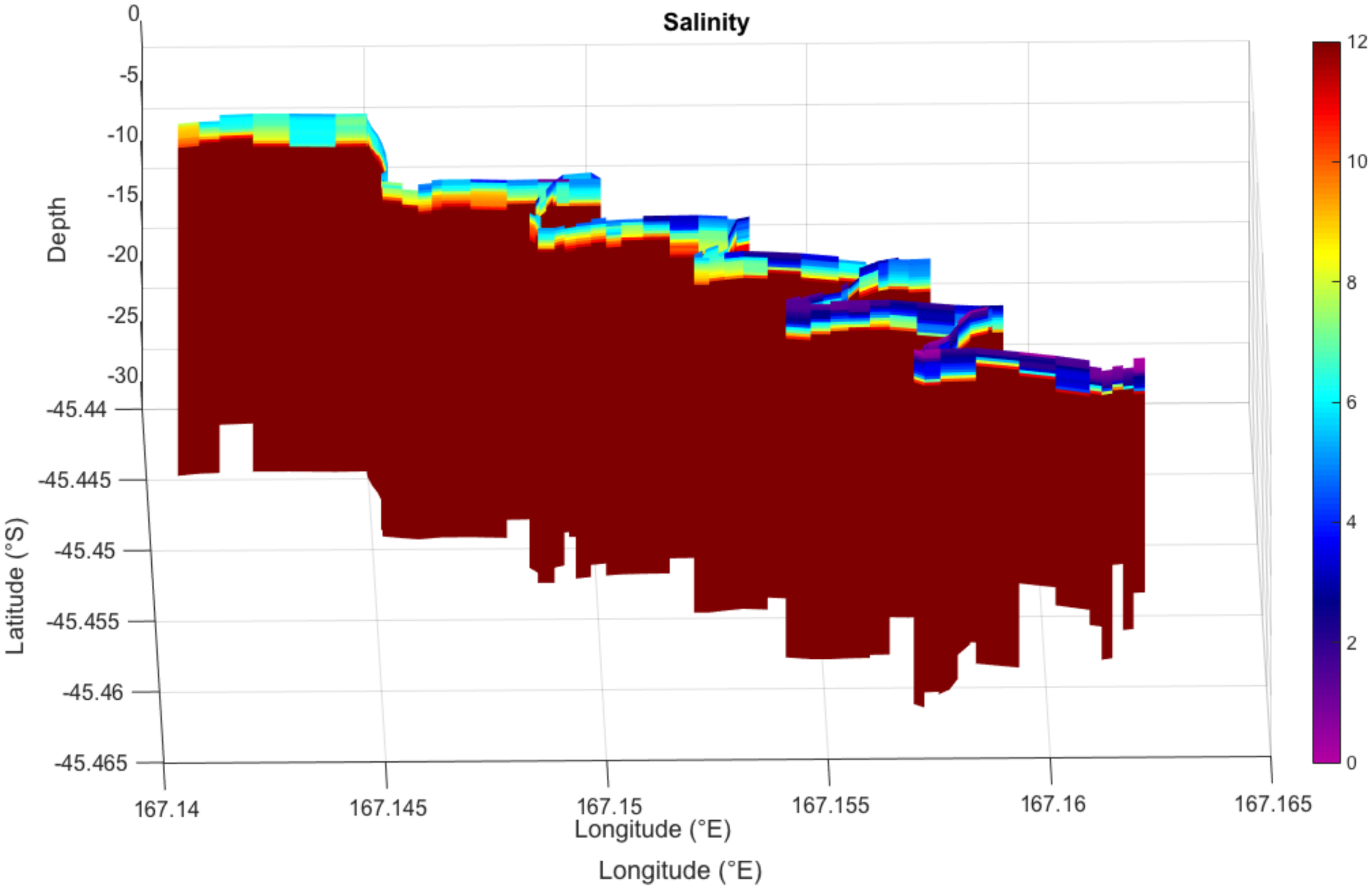
Sampling an estuary: boat



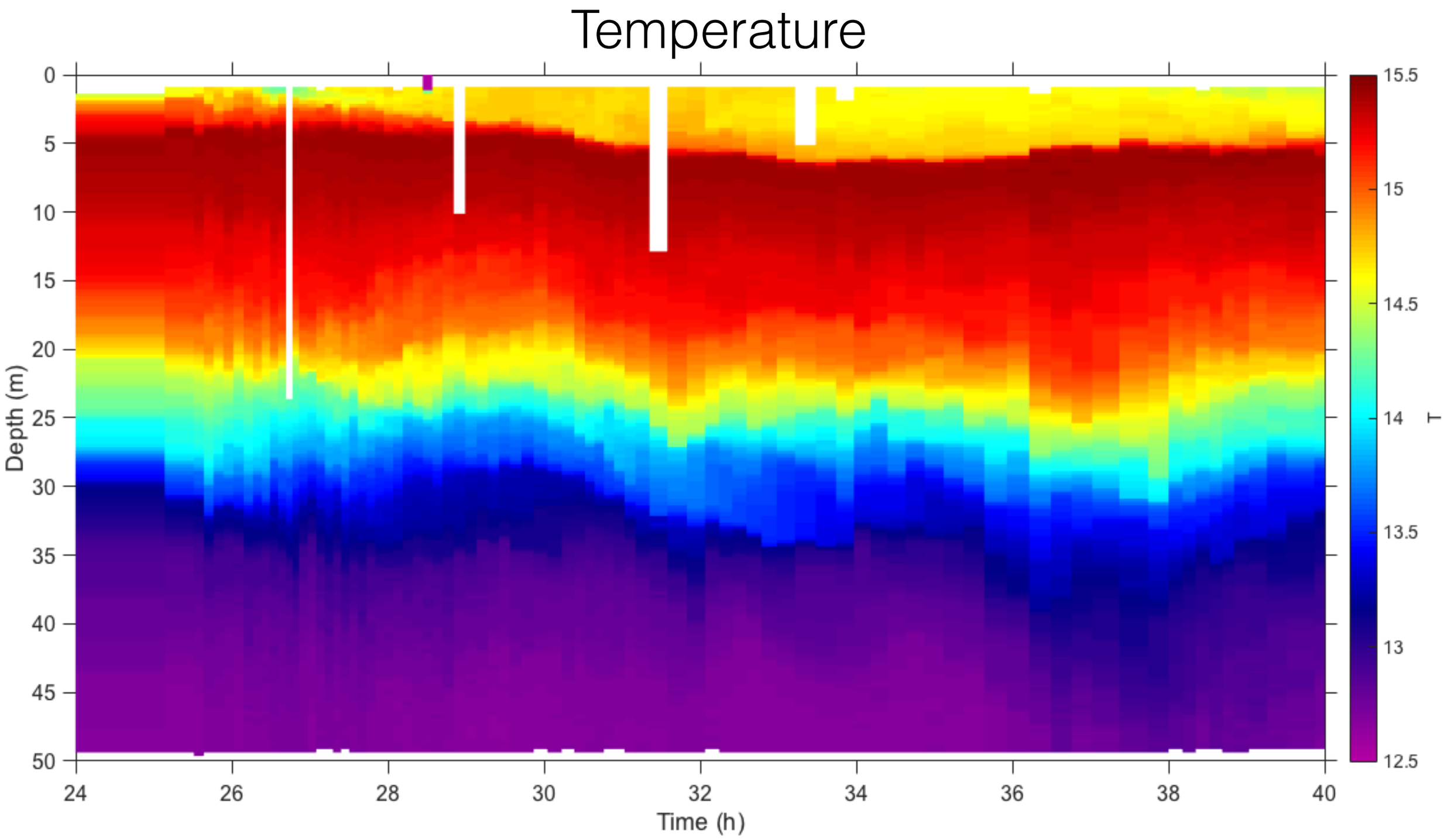
Sampling an estuary: boat



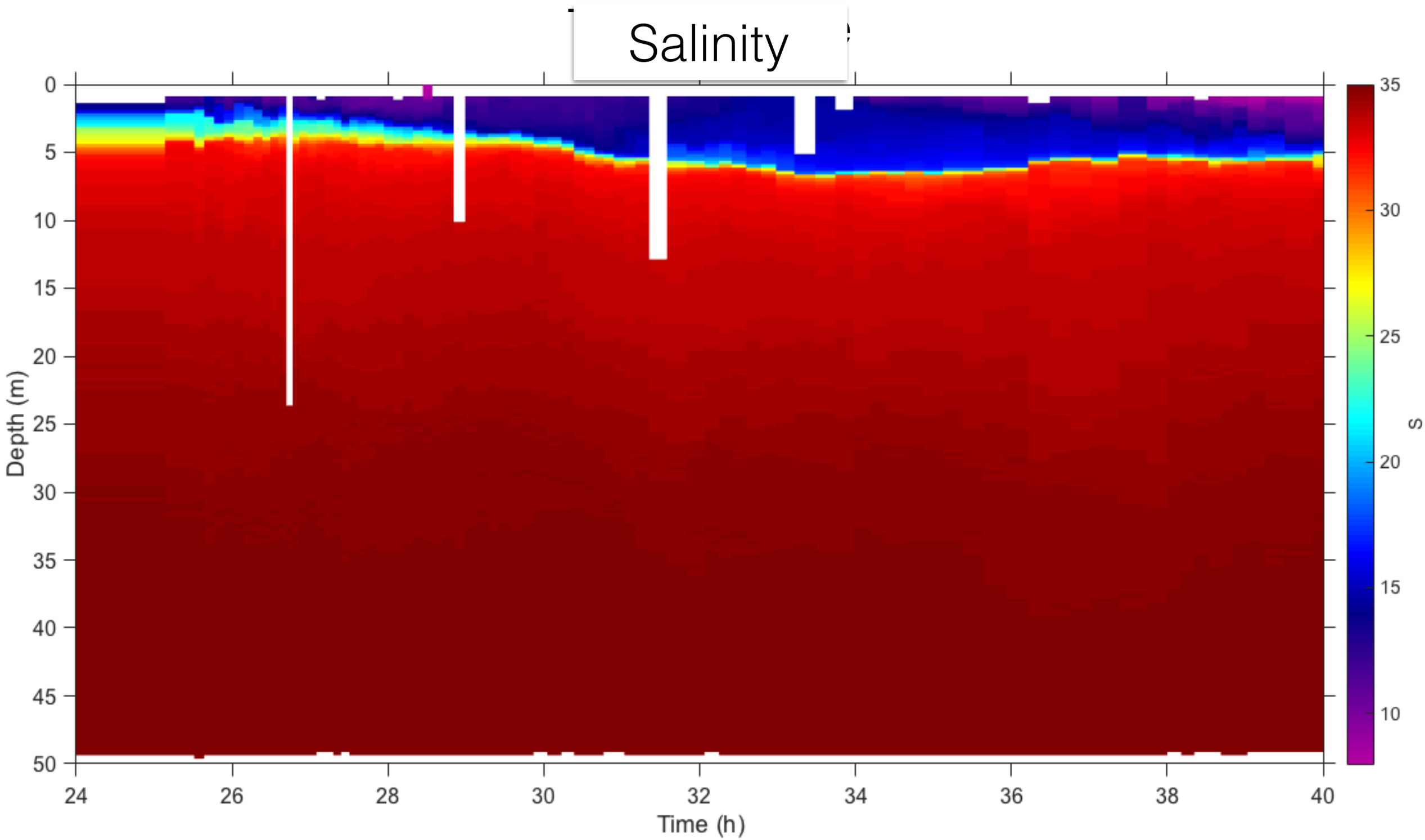
Sampling an estuary: boat



Sampling an estuary: Wirewalker



Sampling an estuary: Wirewalker



The End

Estuary categorization:

Geological:

- Coastal plain
- Bar-built
- Delta system
- Tectonic
- Fjords

Hydrodynamical:

- Salt-wedge
- Fjord
- Slightly Stratified
- Vertically Mixed
- Freshwater