Nyrefunksjon i laksefisk – effekt av fotoperiode og salinitet under smoltifisering

Marius Takvam

Institutt for biovitenskap (UiB)/Norwegian Research Center (NORCE)

Nyren har en viktig rolle og er sensitiv for endring i miljø

frontiers in Physiology

REVIEW
published: 20 April 2021
doi: 10.3389/fphys.2021.664588

Check for updates

Ion Transporters and Osmoregulation in the Kidney of Teleost Fishes as a Function of Salinity

Marius Takvam[1,2†], Chris M. Wood[3†], Harald Kryvi[1] and Tom O. Nilsen[1,2†]*

[1] Department of Biological Sciences, University of Bergen, Bergen, Norway, [2] NORCE, Norwegian Research Centre, NORCE Environment, Bergen, Norway, [3] Department of Zoology, University of British Columbia, Vancouver, BC, Canada

Euryhaline teleosts exhibit major changes in renal function as they move between freshwater (FW) and seawater (SW) environments, thus tolerating large fluctuations in salinity. In FW, the kidney excretes large volumes of water through high glomerular filtration rates (GFR) and low tubular reabsorption rates, while actively reabsorbing most ions at high rates. The excreted product has a high urine flow rate (UFR) with a dilute composition. In SW, GFR is greatly reduced, and the tubules reabsorb as much water as possible, while actively secreting divalent ions. The excreted product has a low UFR, and is almost isosmotic to the blood plasma, with Mg^{2+}, SO_4^{2-}, and Cl^- as the major ionic components. Early studies at the organismal level have described these basic patterns, while in the last two decades, studies of regulation at the cell and molecular level have been implemented, though only in a few euryhaline groups (salmonids, eels, tilapias, and fugus). There have been few studies combining the two approaches. The aim of the review is to integrate known aspects of renal physiology (reabsorption and secretion) with more recent advances in molecular water and solute physiology (gene and protein function of transporters). The renal transporters addressed include the subunits of the Na^+, K^+- ATPase (NKA) enzyme, monovalent ion transporters for Na^+, Cl^-, and K^+ (NKCC1, NKCC2, CLC-K, NCC, ROMK2), water transport pathways [aquaporins (AQP), claudins (CLDN)], and divalent ion transporters for SO_4^{2-}, Mg^{2+}, and Ca^{2+} (SLC26A6, SLC26A1, SLC13A1, SLC41A1, CNNM2, CNNM3, NCX1, NCX2, PMCA). For each transport category, we address the current understanding at the molecular level, try to synthesize it with classical knowledge of overall renal function, and highlight knowledge gaps. Future research on the kidney of euryhaline fishes should focus on integrating changes in kidney reabsorption and secretion of ions with changes in transporter function at the cellular and molecular level (gene and protein verification) in different regions of the nephrons. An increased focus on the kidney individually and its functional integration with the other osmoregulatory organs (gills, skin and intestine) in maintaining overall homeostasis will have applied relevance for aquaculture.

Keywords: physiology, renal function, osmoregulation, euryhaline teleosts, salinity, ion transporters

OPEN ACCESS

Edited by:
Ewa Zofia Kulczykowska, Institute of Oceanology, Polish Academy of Sciences, Poland

Reviewed by:
Jason Breves, Skidmore College, United States
Susumu Hyodo, The University of Tokyo, Japan

Correspondence:
Tom O. Nilsen
Tom.nilsen@uib.no

†ORCID:
Marius Takvam
orcid.org/0000-0001-8626-3837
Chris M. Wood
orcid.org/0000-0002-9542-2219
Tom O. Nilsen
orcid.org/0000-0001-7894-9847

Specialty section:
This article was submitted to Aquatic Physiology, a section of the journal Frontiers in Physiology

Received: *05 February 2021*
Accepted: *24 March 2021*
Published: *20 April 2021*

Citation:
Takvam M, Wood CM, Kryvi H and Nilsen TO (2021) Ion Transporters and Osmoregulation in the Kidney of Teleost Fishes as a Function of Salinity. Front. Physiol. 12:664588. doi: 10.3389/fphys.2021.664588

frontiers | Frontiers in Physiology

TYPE Review
PUBLISHED 29 June 2023
DOI 10.3389/fphys.2023.1226068

Check for updates

Role of the kidneys in acid-base regulation and ammonia excretion in freshwater and seawater fish: implications for nephrocalcinosis

Marius Takvam[1]*, Chris M. Wood[2], H. Kryvi[1] and Tom O. Nilsen[1]*

[1]Department of Biological Sciences, University of Bergen, Bergen, Norway, [2]Department of Zoology, University of British Columbia, Vancouver, BC, Canada

Maintaining normal pH levels in the body fluids is essential for homeostasis and represents one of the most tightly regulated physiological processes among vertebrates. Fish are generally ammoniotelic and inhabit diverse aquatic environments that present many respiratory, acidifying, alkalinizing, ionic and osmotic stressors to which they are able to adapt. They have evolved flexible strategies for the regulation of acid-base equivalents (H^+, NH_4^+, OH^- and HCO_3^-), ammonia and phosphate to cope with these stressors. The gills are the main regulatory organ, while the kidneys play an important, often overlooked accessory role in acid-base regulation. Here we outline the kidneys role in regulation of acid-base equivalents and two of the key 'urinary buffers', ammonia and phosphate, by integrating known aspects of renal physiology with recent advances in the molecular and cellular physiology of membrane transport systems in the teleost kidneys. The renal transporters (NHE3, NBC1, AE1, SLC26A6) and enzymes (V-type H^+ATPase, CAc, CA IV, ammoniagenic enzymes) involved in H^+ secretion, bicarbonate reabsorption, and the net excretion of acidic and basic equivalents, ammonia, and inorganic phosphate are addressed. The role of sodium-phosphate cotransporter (Slc34a2b) and rhesus (Rh) glycoproteins (ammonia channels) in conjunction with apical V-type H^+ ATPase and NHE3 exchangers in these processes are also explored. Nephrocalcinosis is an inflammation-like disorder due to the precipitation of calcareous material in the kidneys, and is listed as one of the most prevalent pathologies in land-based production of salmonids in recirculating aquaculture systems. The causative links underlying the pathogenesis and etiology of nephrocalcinosis in teleosts is speculative at best, but acid-base perturbation is probably a central pathophysiological cause. Relevant risk factors associated with nephrocalcinosis are hypercapnia and hyperoxia in the culture water. These raise internal CO_2 levels in the fish, triggering complex branchial and renal acid-base compensations which may promote formation of kidney stones. However, increased salt loads through the rearing water and the feed may increase the prevalence of nephrocalcinosis. An increased understanding of the kidneys role in acid-base and ion regulation and how this relates to renal diseases such as nephrocalcinosis will have applied relevance for the biologist and aquaculturist alike.

KEYWORDS
acid-base regulation, kidney stones, patophysiology, transporters and channels, nephron tubule, aquaculture, water quality (WQ), fish

OPEN ACCESS

EDITED BY
Carlo C. Lazado,
Fisheries and Aquaculture Research (Nofima), Norway

REVIEWED BY
Dennis Kolosov,
California State University San Marcos, United States
Edward Mager,
University of North Texas, United States
Janet Genz,
University of West Georgia, United States

*CORRESPONDENCE
Marius Takvam,
m.takvam@uib.no
Tom O. Nilsen,
Tom.nilsen@uib.no

RECEIVED 20 May 2023
ACCEPTED 12 June 2023
PUBLISHED 29 June 2023

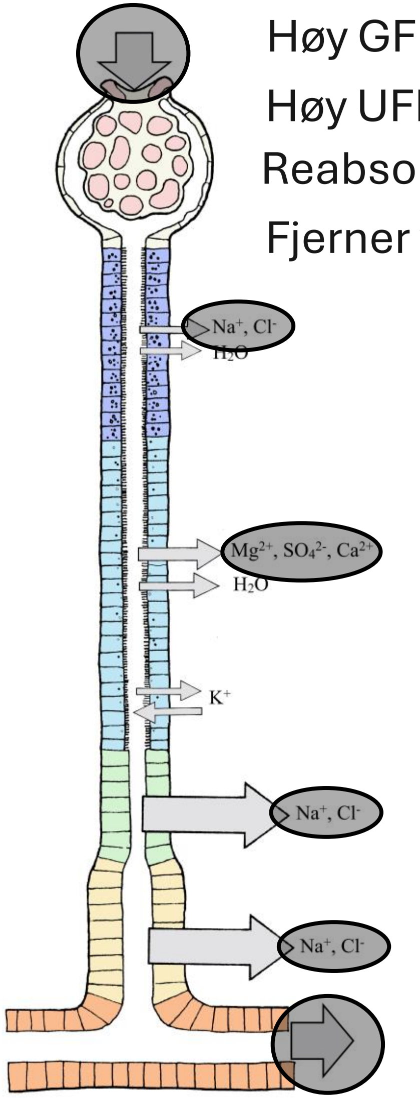
CITATION
Takvam M, Wood CM, Kryvi H and Nilsen TO (2023), Role of the kidneys in acid-base regulation and ammonia excretion in freshwater and seawater fish: implications for nephrocalcinosis.
Front. Physiol. 14:1226068.
doi: 10.3389/fphys.2023.1226068

COPYRIGHT
© 2023 Takvam, Wood, Kryvi and Nilsen. This is an open-access article distributed under the terms of the Creative Commons Attribution License (CC BY). The use, distribution or reproduction in other forums is permitted, provided the original author(s) and the copyright owner(s) are credited and that the original publication in this journal is cited, in accordance with accepted academic practice. No use, distribution or reproduction is permitted which does not comply with these terms.

- Store kunnskapshull på nyrefunksjon i laks
- De siste årene har vi sett på biomarkører for å kunne evaluere nyrefunksjon i laksefisk
- Dysfunksjonell regulering av disse markørene er direkte knyttet opp mot nyresykdom, blant annet nefrokalsinose
- Mulig verktøy for evaluering av nyrefunksjon under produksjon

Ferskvann vs Sjøvann

FV

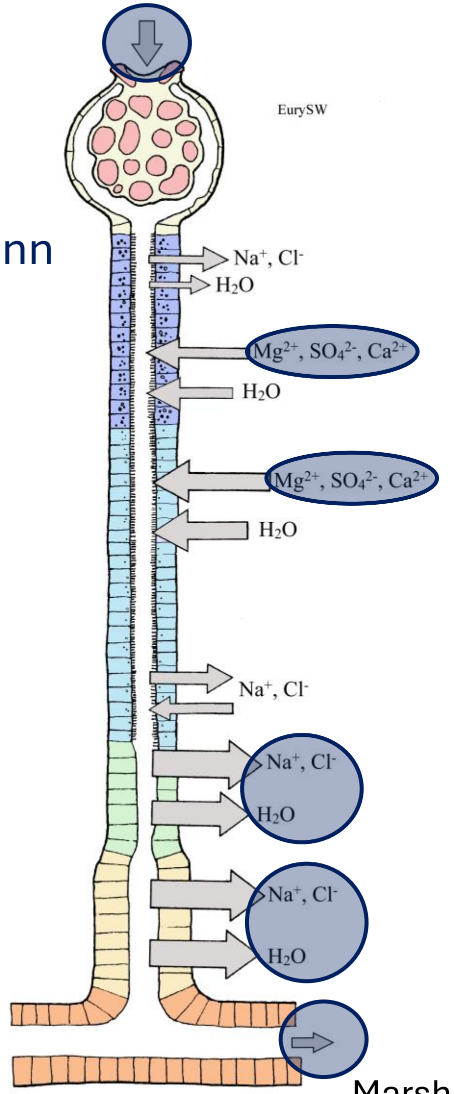


- Høy GFR
- Høy UFR
- Reabsorbering
- Fjerner vann

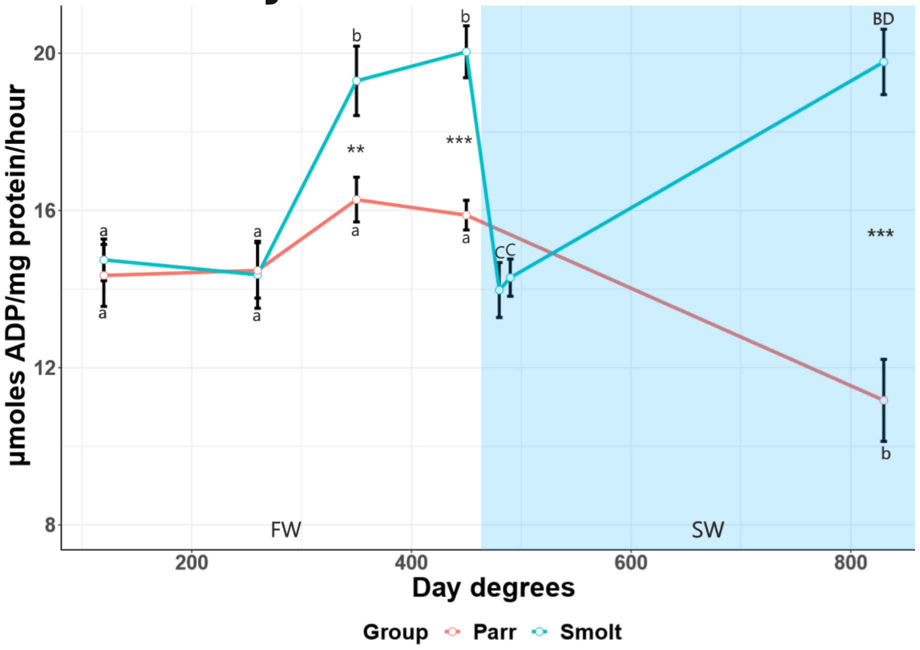
SV

- Lav GFR
- Lav UFR
- Fjerner ioner
- Holder på vann

Overføring

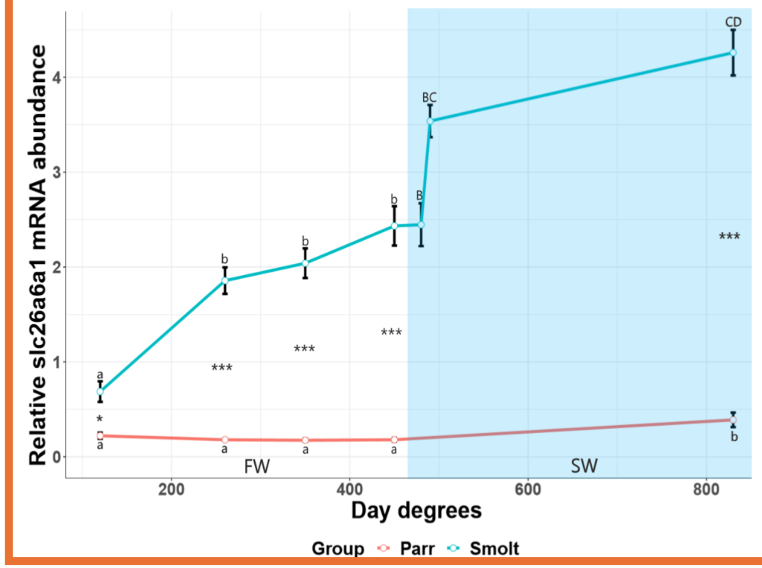


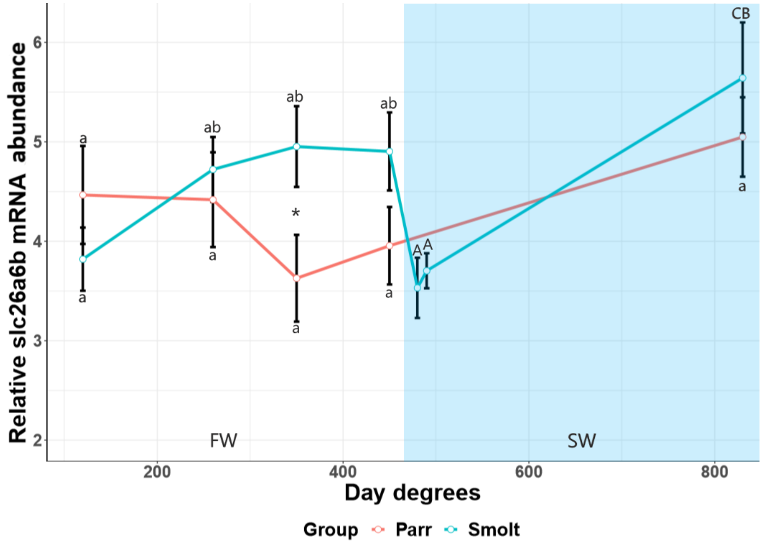
NKA enzymaktivitet

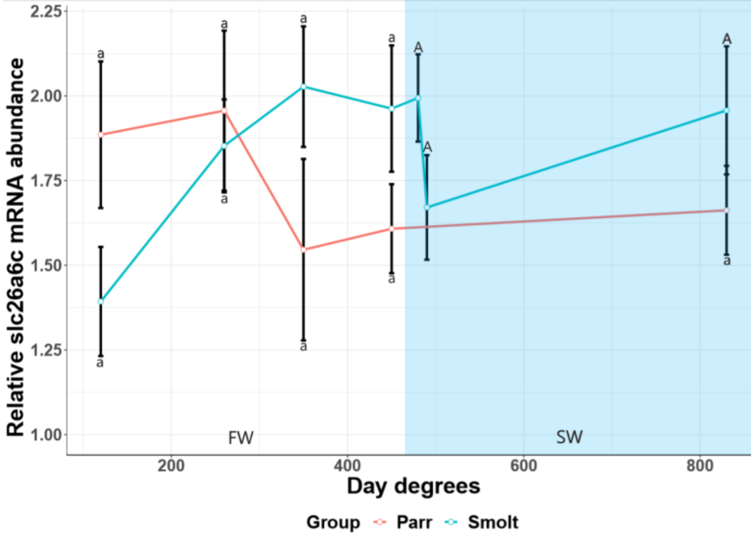


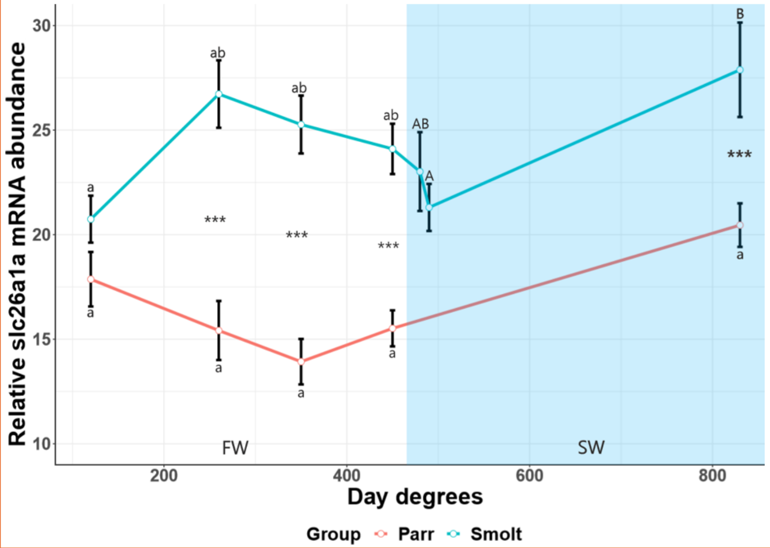
Marshall and Grosell, 2005; Takvam *et al.*, 2021a; Takvam et al., 2021b

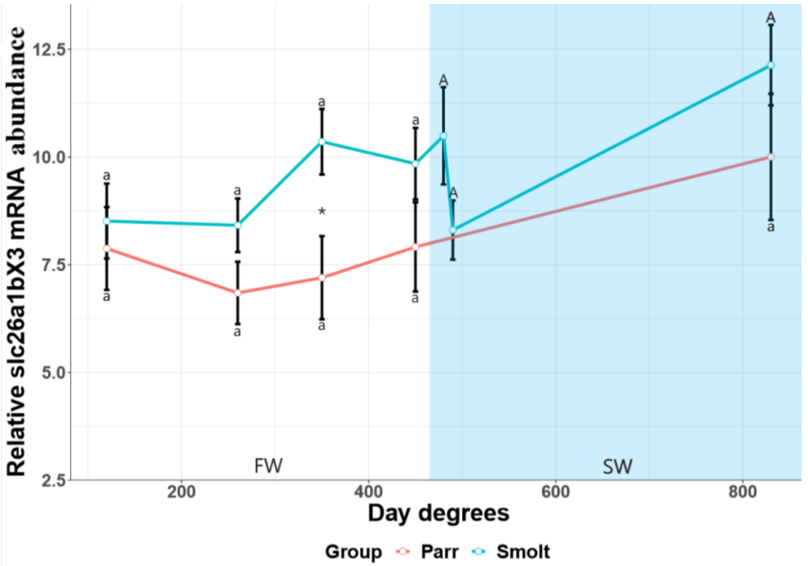
Sulfate/bikarbonat transportere











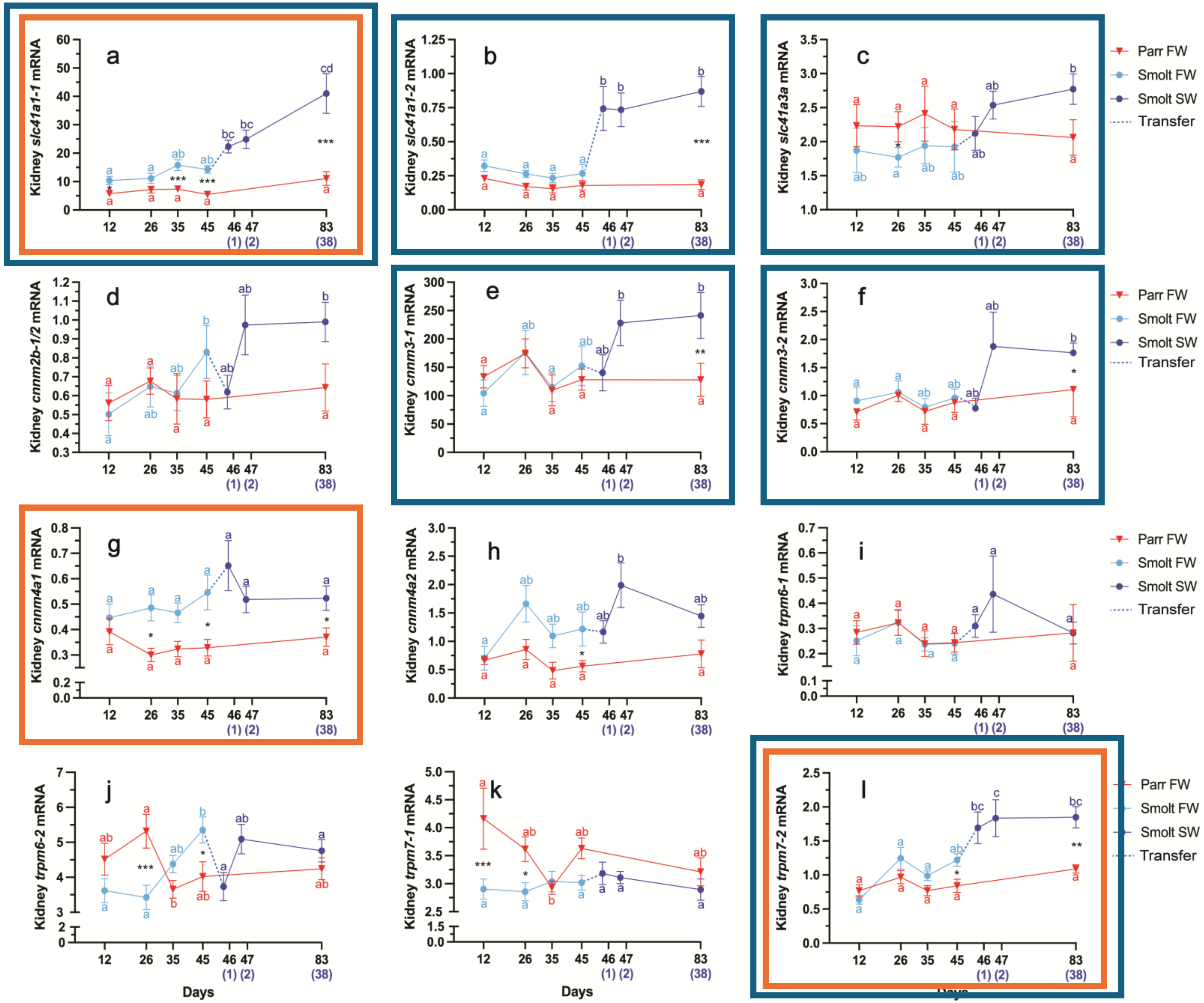
The *Slc26a6a1* og Slc26a1a responderer på fotoperiode

The *Slc26a6a1* og Slc26a1a responderer også på sjøvann

* Noen av disse er også uttrykt i gjeller og tarm

Takvam et al., 2021b

Magnesium transportere



slc41a1-1, *cnnm4a1* og *trpm7-2* responderer på endringer i fotoperiode

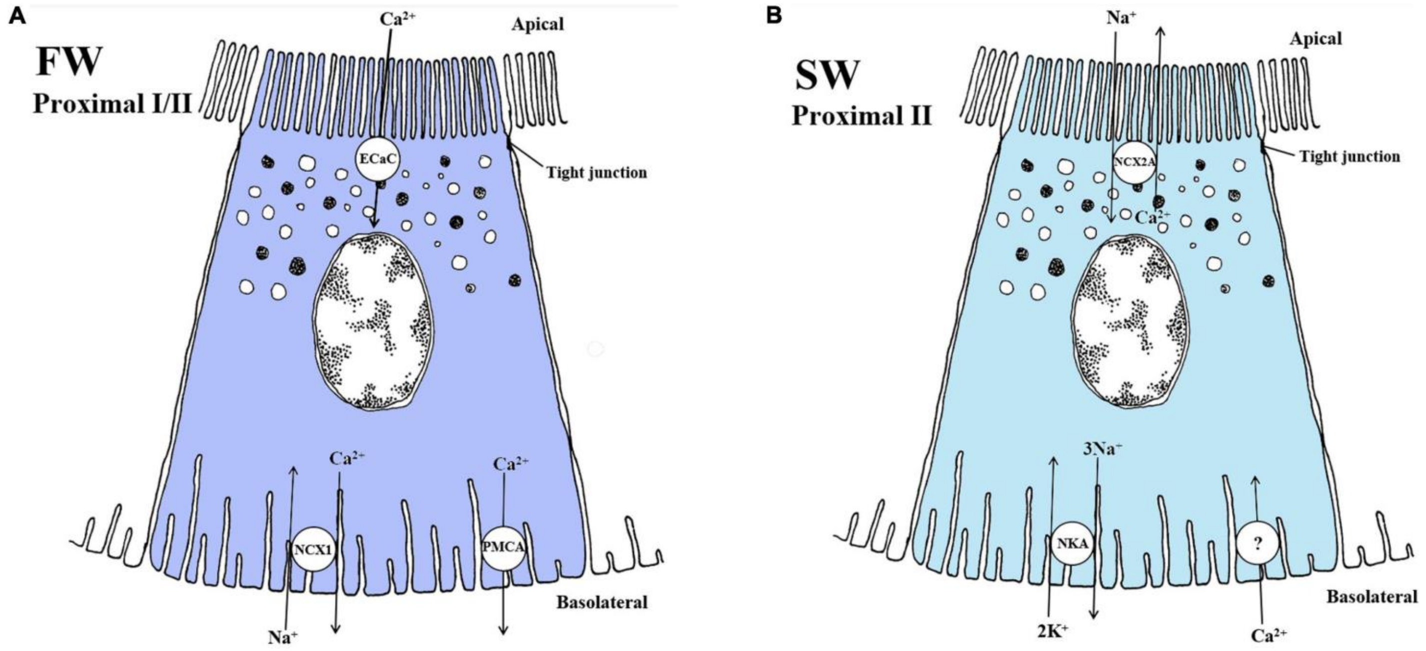
slc41a1-1, *slc41a1-2*, *slc41a3*, *cnnm3-1*, *cnnm3-2*, *cnnm4a1* and *trpm7-2* responderer på sjøvann

* Flere også uttrykt i gjeller og tarm

Takvam et al., 2024 (in review)

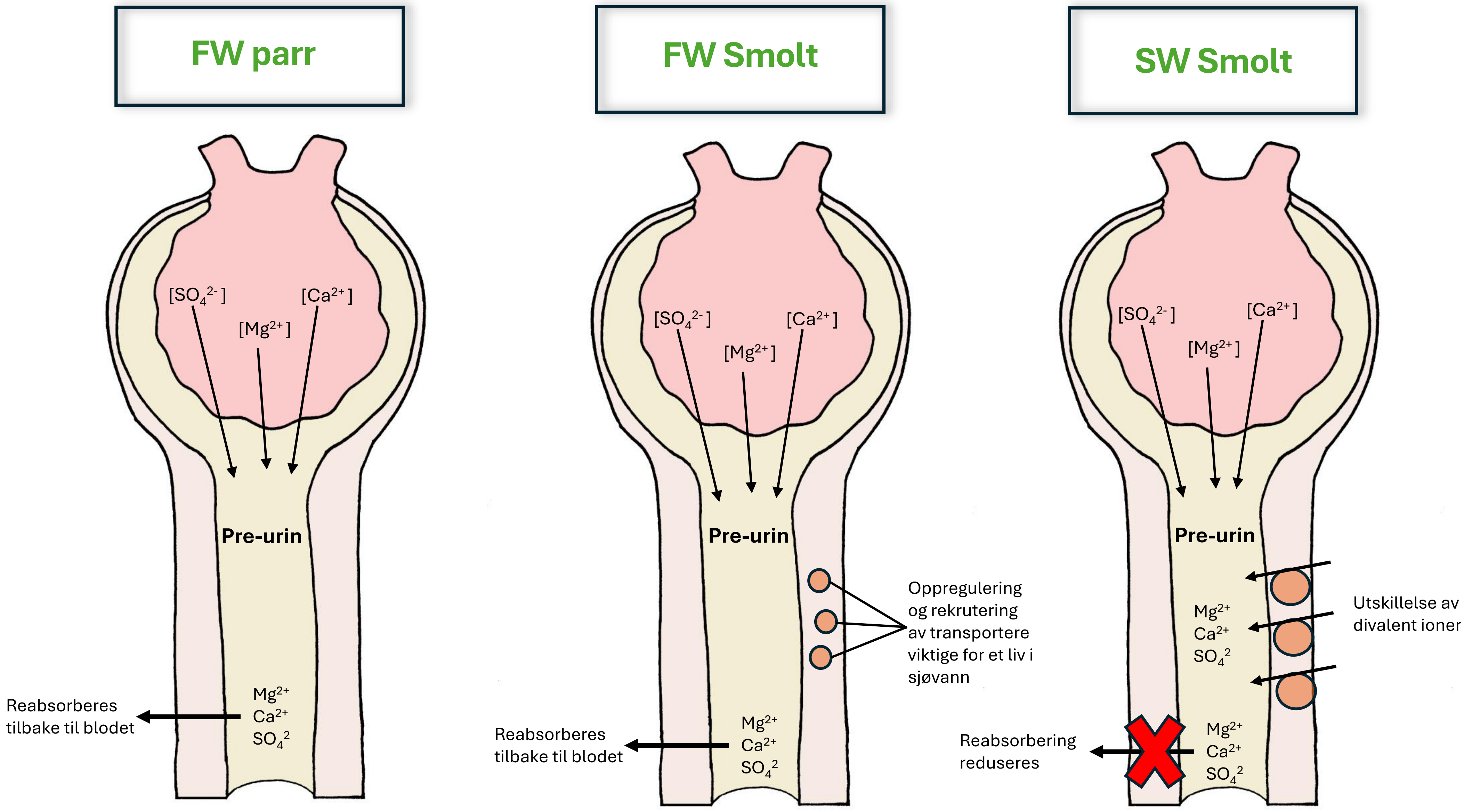
Kalsium transportere

- Kalsium transportere (NCX og PMCA) responderer også på fotoperiode og salinitet
- I likhet med sulfat og magnesium transportere er også flere av disse uttrykt i gjeller og tarm
- Kunnskap på regulering av disse gir håp om bedre forståelse om kalsium regulering i fisk



Takvam et al., 2021a; Takvam et al., 2025 (in prep)

Nyrefunksjon – modell i laks

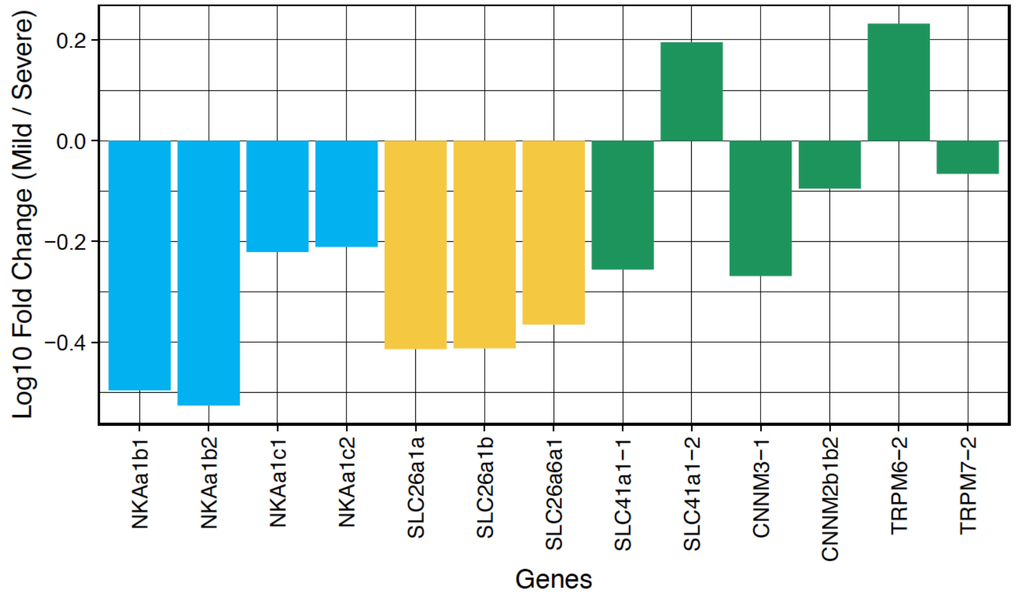


Hickman and Trump, 1969; Marshall and Grosell, 2005; Takvam et al 2021a

Oppsummering

- Første beskrivelse av laksespesifikke transportører i nyren til laks
- Disse ser ut til å reguleres av flere **ulike faktorer**:
  - **Fotoperiode** (smoltifisering)
  - **Salinitet** (brakkvann og sjøvann)
  - **Ionespesifisitet** (data ikke inkludert i prestasjon)
- Fisken trenger **riktige signaler** for unngå forstyrrelser (nyren utsatt) hva gjelder fotoperiode og salinitet
- Mange av de regulerte transportørene er direkte knyttet til **nyresykdom**
- Potensielle **biomarkører** for nyrefunksjon
- Det er nødvendig å forstå de underliggende **mekanismene** i nyrene – gir mulighet for **forebyggende behandlinger**
- Flere av transportørene er også uttrykt i **gjeller** og **tarm** som gir mulighet for mer holistisk tilnærming når vi undersøker påvirkning fra diett og vannmiljø

Barstad, 2024 (Masteroppgave)



Takk for oppmerksomheten! Spørsmål?

Marius Takvam:
m.takvam@uib.no

Tom Ole Nilsen

Elsa Denker

Stor takk til samarbeidspartnere: