Motueka Catchment Collective sediment event, Tapawera Rugby Club, 21 February 2025

Compound Specific Stable Isotopes

Tools for sediment-source tracing

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Climate, Freshwater & Ocean Science

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Talk overview

- CSSI sediment source tracing – in a nut shell
- Examples from recent catchment to coast studies
- Nelson Bays

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NZ: the “Shaky Isles”

- Geology, steep terrain & high rainfall make NZ naturally susceptible to soil erosion
- Many common land use practices increase soil erosion

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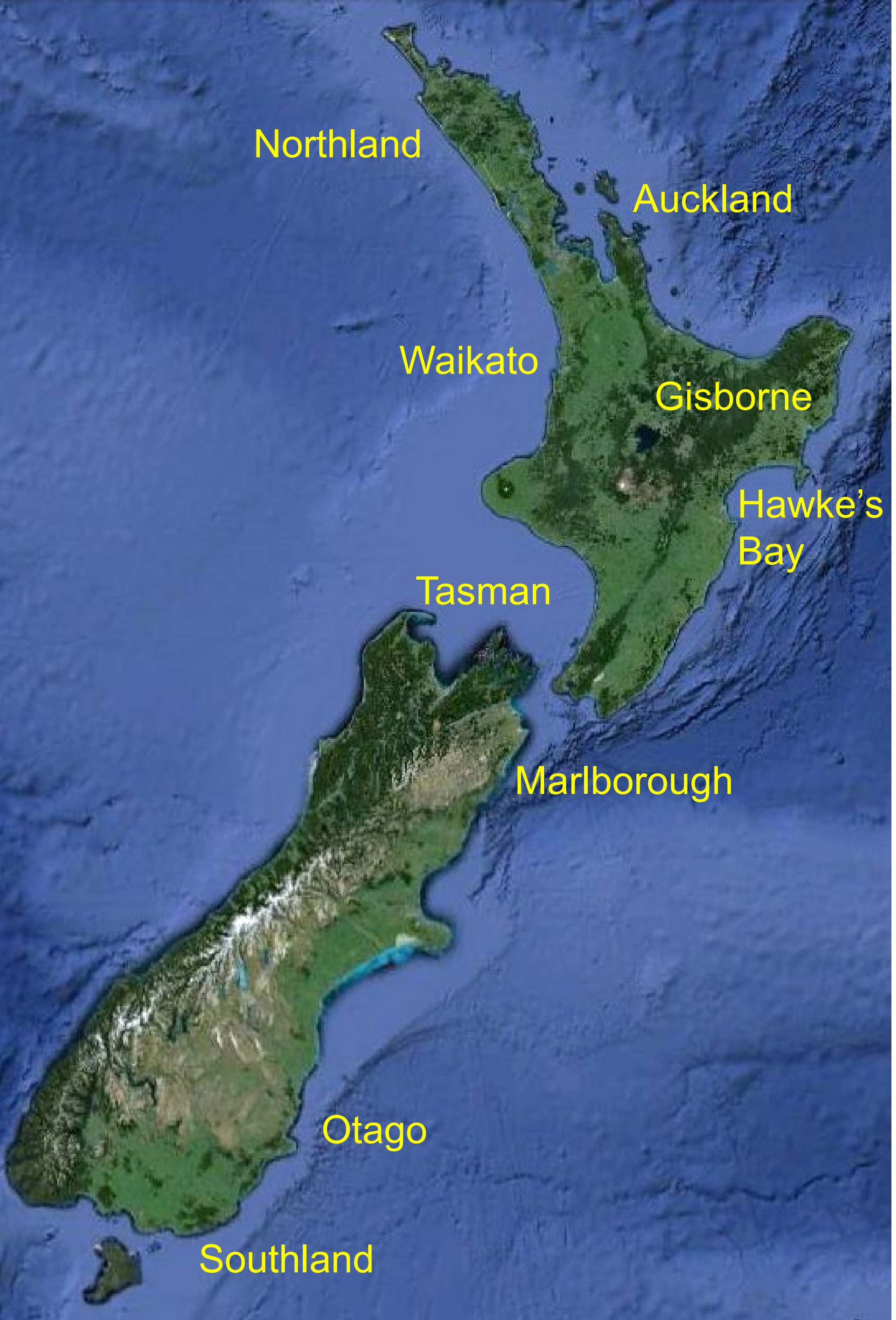

CSSI - background

- Method developed by NIWA to trace sources of eroded soil by land use (Gibbs, 2008)
- ~25 NZ studies since 2009
- CSSI endorsed by UN*, NZ Environment Court
- Scientists from ~40 countries trained
- Ongoing research to enhance CSSI method

Gibbs (2008) *Estuaries & Coasts* 31: 344-359

UN International Atomic Energy Agency/Food & Agriculture Organisation

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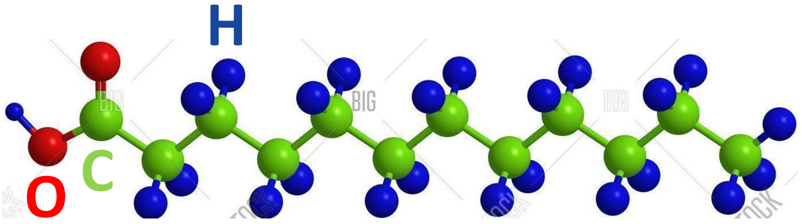
CSSI method

Using Compound-Specific Stable Isotopes (CSSI) to trace soil sources

Concept: land use is defined by the **plant community**

How: plants secrete organic compounds that label the soil (**biomarkers**)

What: Fatty Acids useful & reliable soil tracers



- FA strongly bound to soil particles
- FA persist for 100s – 1000s of years in soil/sediment
- Stable Isotope signature – **$^{13}C/^{12}C$ ratio** of medium to long-chain length FAs
- FA concentrations may reduce over time – but stable isotope signature **does not change**

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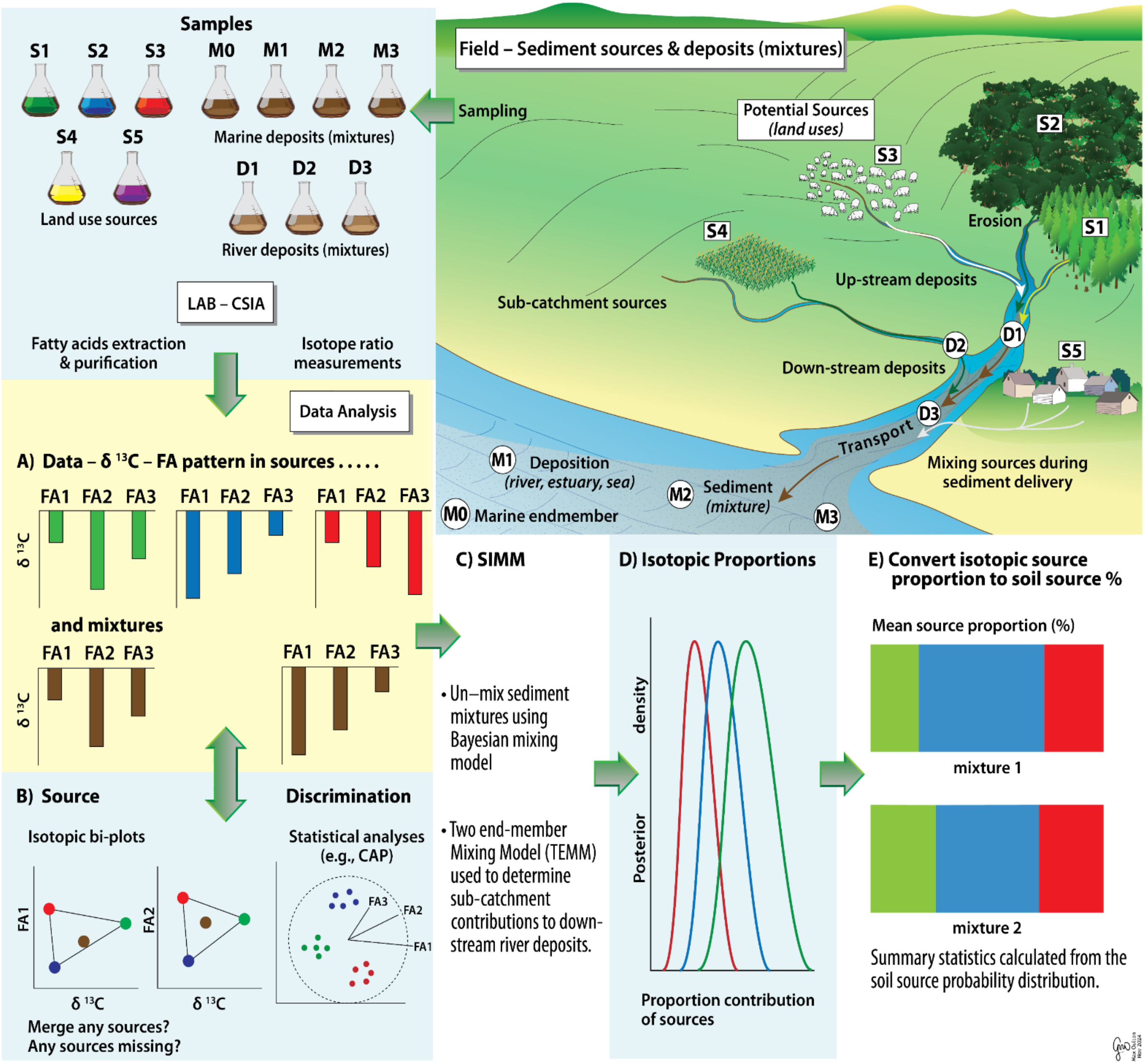
CSSI method - summary



Sample potential soil sources & sediment deposits (i.e., *mixtures*) in receiving environments

Determine suitable FA tracers & test source discrimination

Mixing model used to un-mix *mixtures*:

- Feasible isotopic source proportions (%)
- Convert to soil proportions (%) using organic carbon content

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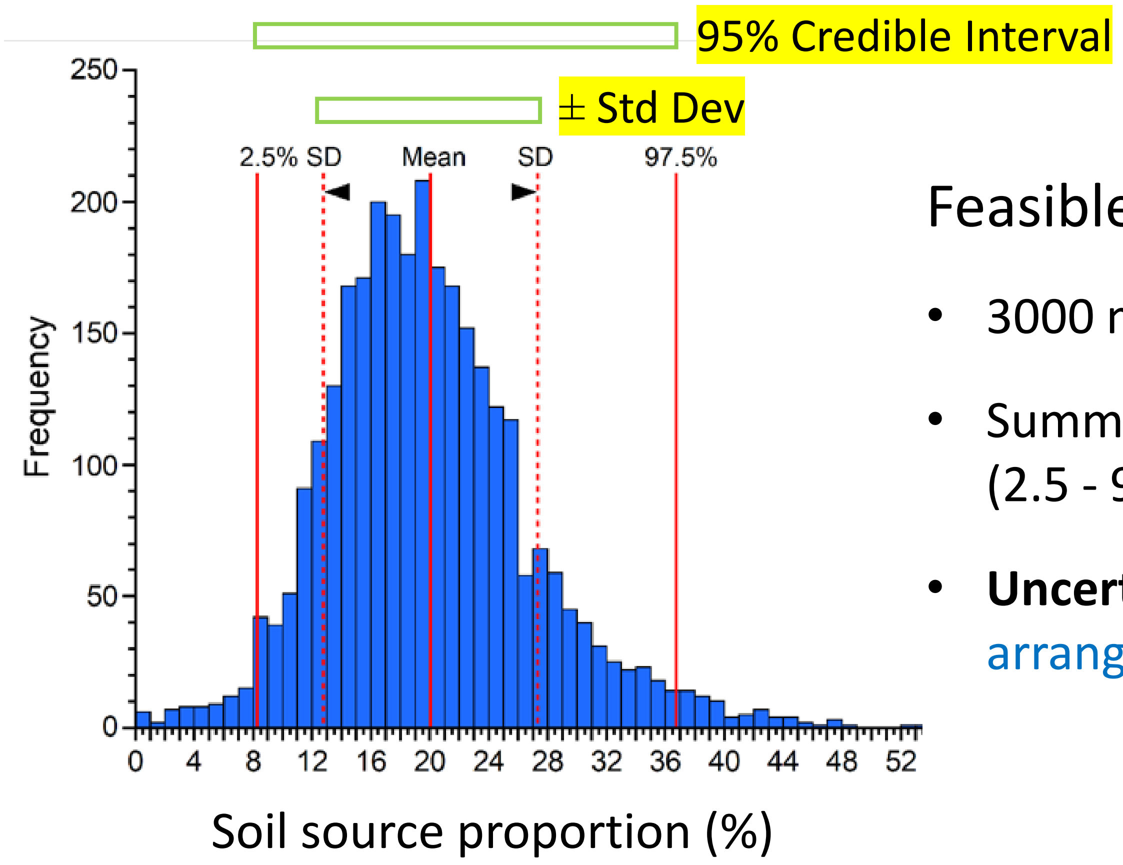
Model output – soil proportions

Example - MixSIAR



Feasible source proportions (%) – probability distribution

- 3000 model runs
- Summary stats: Mean 20%, Median 19%, 95% Credible Interval: (2.5 - 97.5 percentiles, e.g., 8-37%)
- **Uncertainty** reflects variability in source signatures & arrangement of sources in isotopic space

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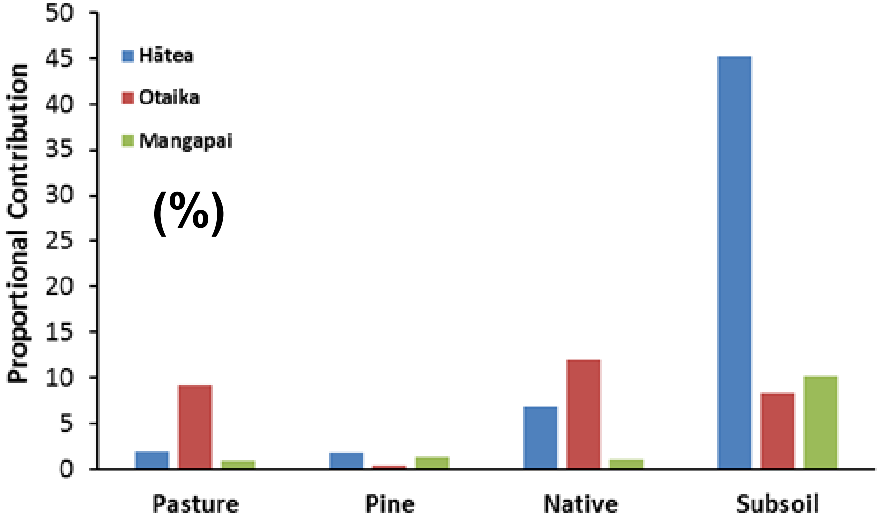
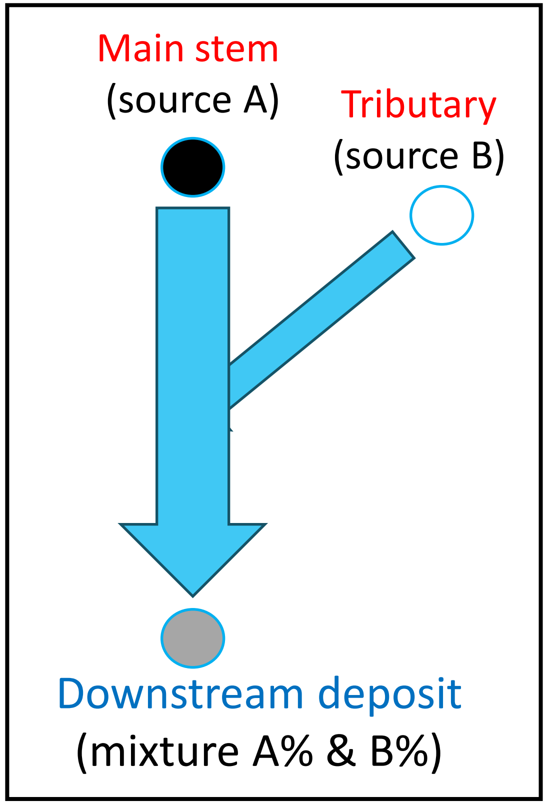
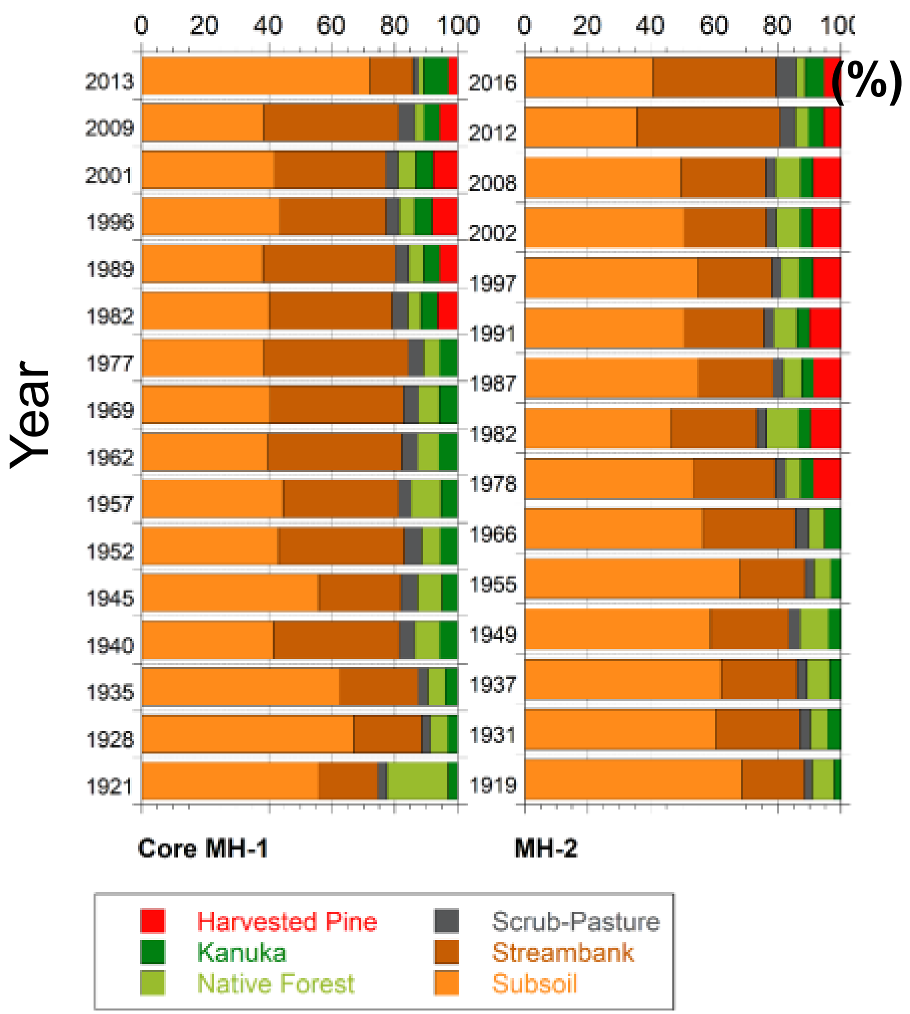
CSSI Applications

Sediment sources by land use & sub-catchment (Whangarei Harbour)





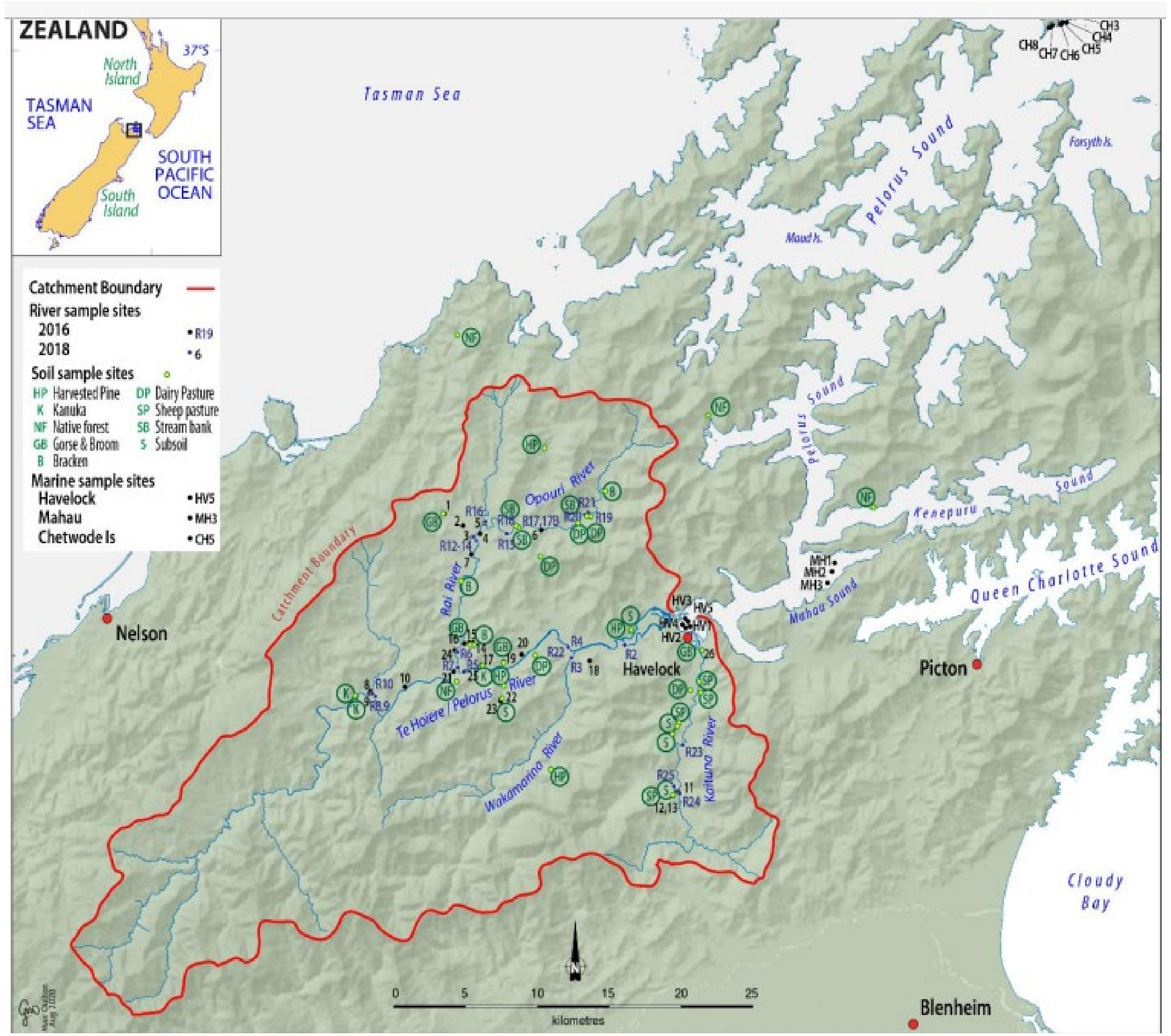
Dated sediment cores: changes in land use sources over **time** (persistence & timing)



Resource-consent monitoring (Whangamarino)

Time scales: storm events to centuries

Example: Pelorus Study 2017 (MDC)

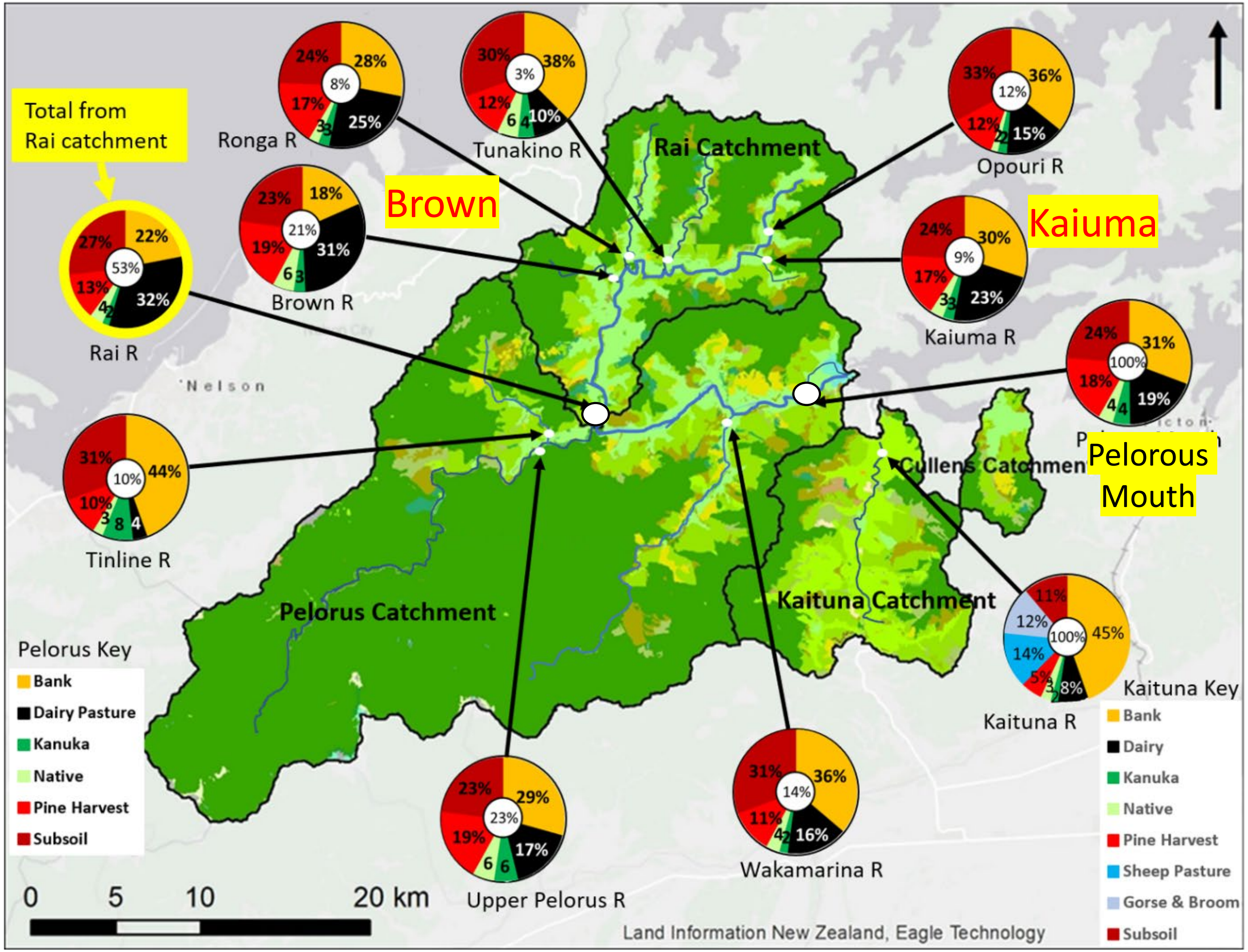


Objectives

Identify sources of:

- River sediment deposits that are **over-represented** as a proportion of land area.
- Sediment accumulating in Pelorus Sound & changes over time.

Sediment sources by land use & sub-catchment



Sediment source classes

- Bank
- Dairy
- Gorse & broom
- Native
- Kanuka
- Pine harvest
- Sheep
- Subsoil

10% Normalised % contribution to Pelorus-Rai (100% at outlet)

Erosion hotspots

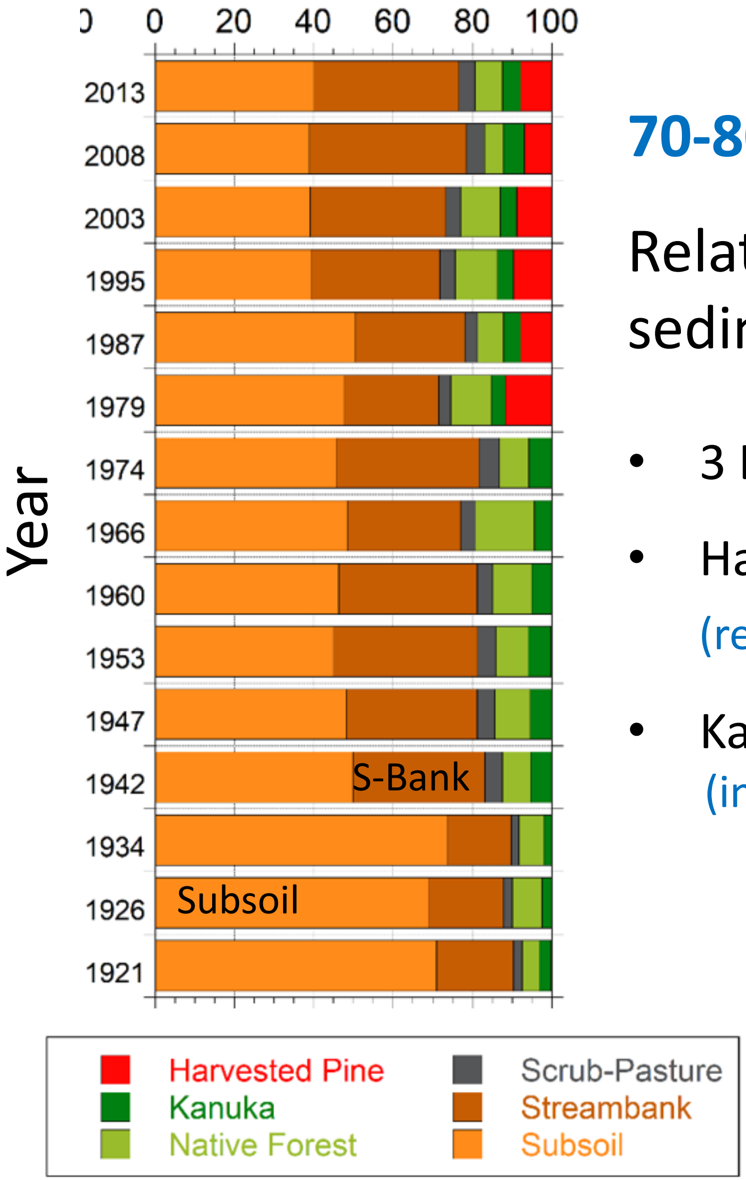
Sediment yields in **Brown** and **Kaiuma** sub-catchments 23 & 17 x higher than reference values*.

Harvested Pine & Gorse/Broom sources yield ratios 6-7x higher than expected based on land area

*Annual average yields NZ River Map

Soil erosion - comparison with native forest

Mean soil proportions (%) - Inner Pelorus Sound - 3 core sites (1920-2013)



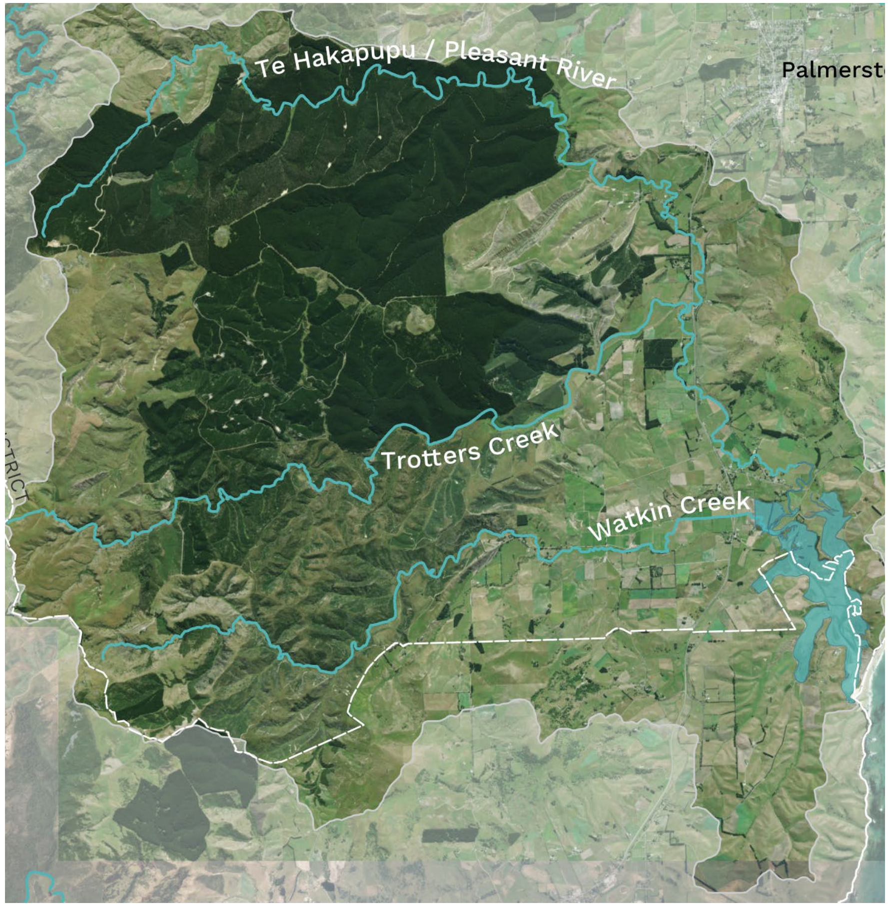
70-80 % of eroded soil = **subsoils** & **streambank erosion**

Relative contribution of **Harvested Pine** & **Kanuka Scrub** to sedimentation: compare sediment yields (% km^{-2}) with Native Forest

- 3 LCDB landcover snapshots spanning a ~**decade** (2001 – 2013)
- Harvested Pine yield: **99-51 x** Native forest
  (reducing over time period)
- Kanuka Scrub yield: **5-17 x** Native Forest
  (increasing)

LCDB = Land Cover Data Base

Example: Pleasant River Catchment (ORC, 2023)



Objectives

- Contemporary sources of **river sediment** deposits (by sub-catchment and land use).
- Sources of sediment depositing in estuary

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Streambanks & Subsoil

Streambank & subsoil erosion > 80% of sediment deposited in river network:

- Streambank erosion more prevalent in lower catchment – increased stream power & stock?

- Subsoil erosion from steepland and unsealed roads (forestry & farms)

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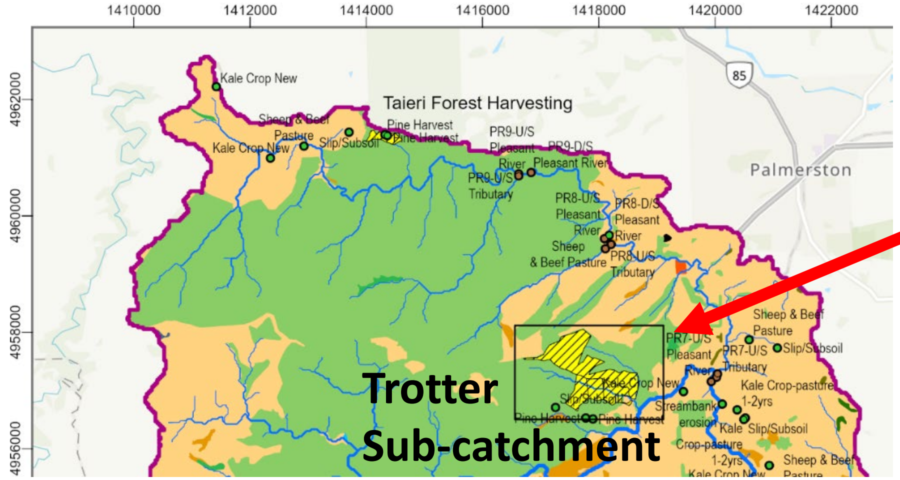
Production forestry



Relative contribution of harvesting to topsoil erosion?

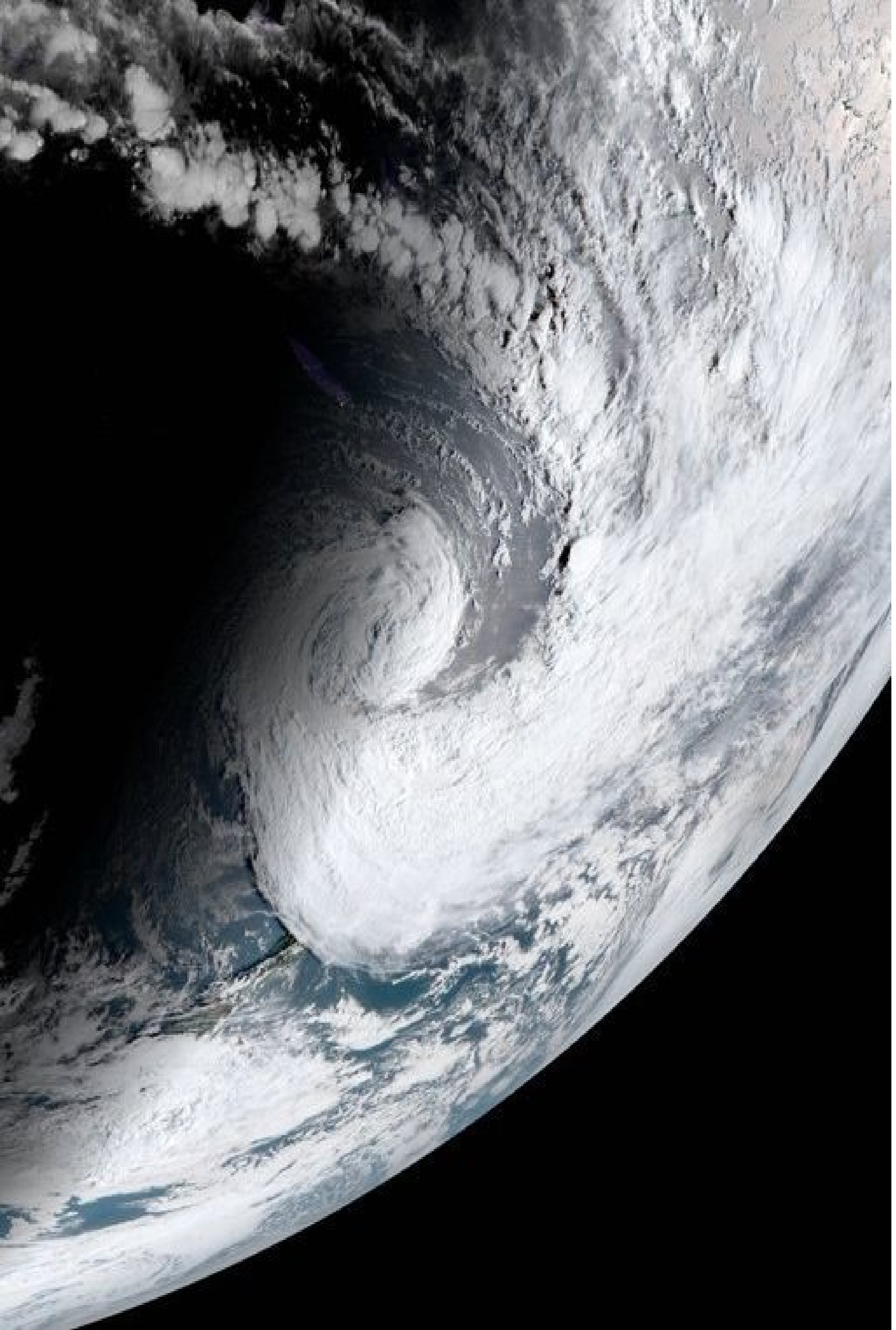
Mean sediment source proportions – **estuary deposits**

- Harvested 1.1 km^2 area – over 2 yr prior to sampling (May 2022)
  (i.e., 0.9% of 128 km^2 catchment area)
- Dry stock pasture & fodder crops: 74 km^2
  (i.e., 58% of catchment).

Specific topsoil yields (per km^2)

- Pine harvest 6.9% km^2
- Pasture & Fodder: 0.1% km^2

Topsoil yield from pine harvest: ~69 x pasture & fodder crops.



Example: Cyclone Gabrielle (MPI)

Event sedimentation

Objective*: determine contribution of river sediment sources to marine sedimentation* (during cyclone)*. Inform future management*

Example: demonstrate far-field dispersal of sediment plumes

2024-2025: HBRC & GDC phase 2 study - contribution of land use to **river and marine deposition** in Hawke's Bay & Tairawhiti

Swales et al. (2024)., AEBR 343 *Cyclone Gabrielle: tracing river-sediment source contributions to marine sedimentation*.
https://fs.fish.govt.nz/Page.aspx?pk=113&dk=25800

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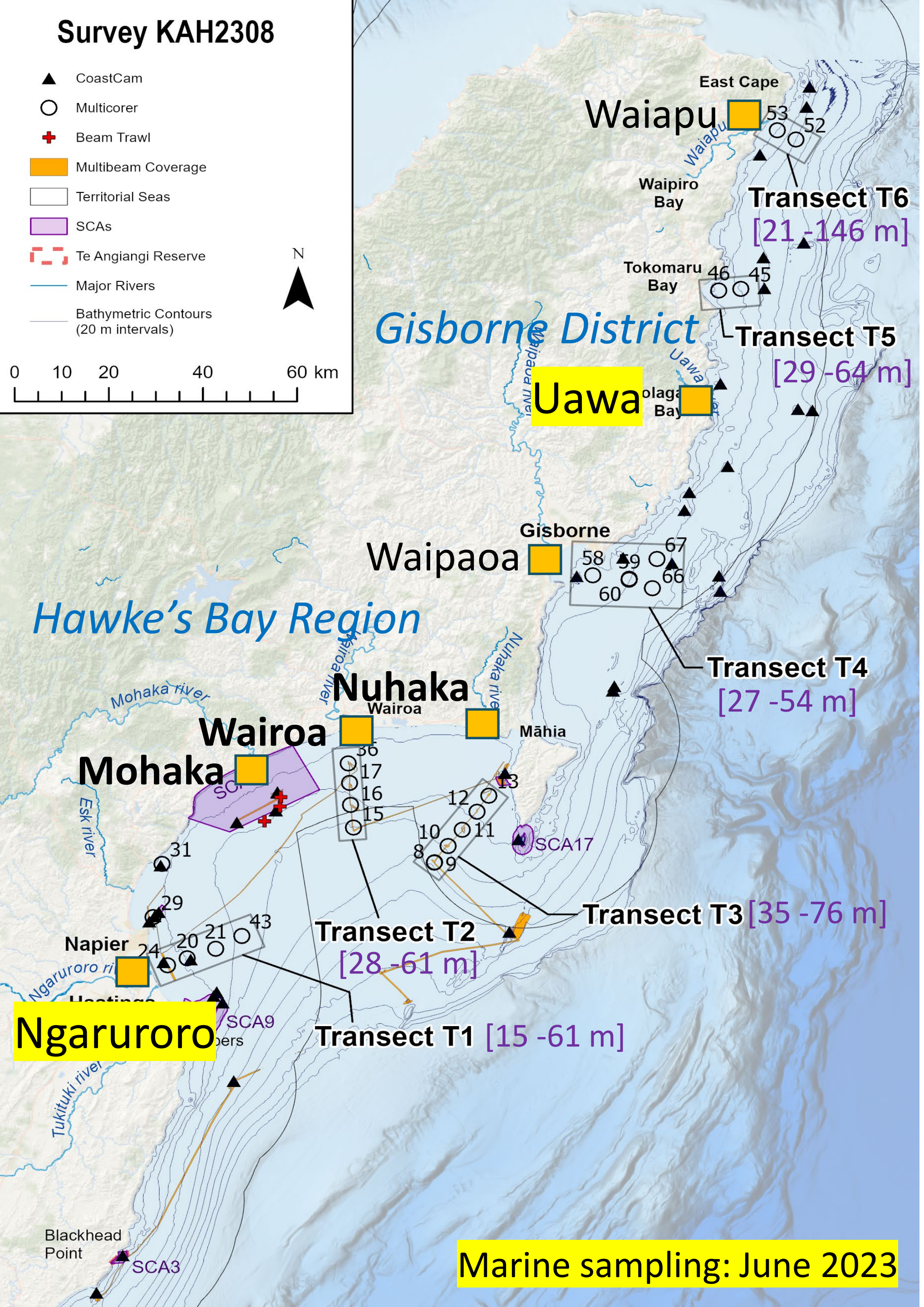

Soil & sediment sampling

Event scale erosion & sedimentation

- **Sampled** river mouths (7/13 analysed) & marine sediment deposits
- Marine sediment deposits - 6 transects to ~140 m water depth.
- **Ngaruroro** & **Uawa catchments** – intensive sampling of soils (land use), streambanks & river sediment deposits (GDC & HBRC 2025 study) .

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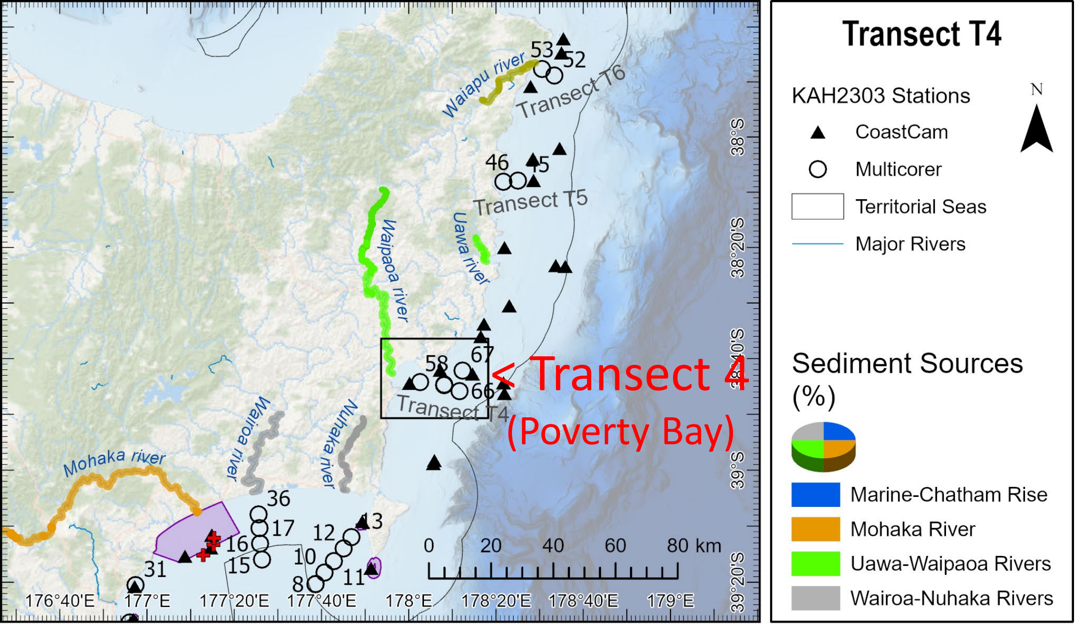
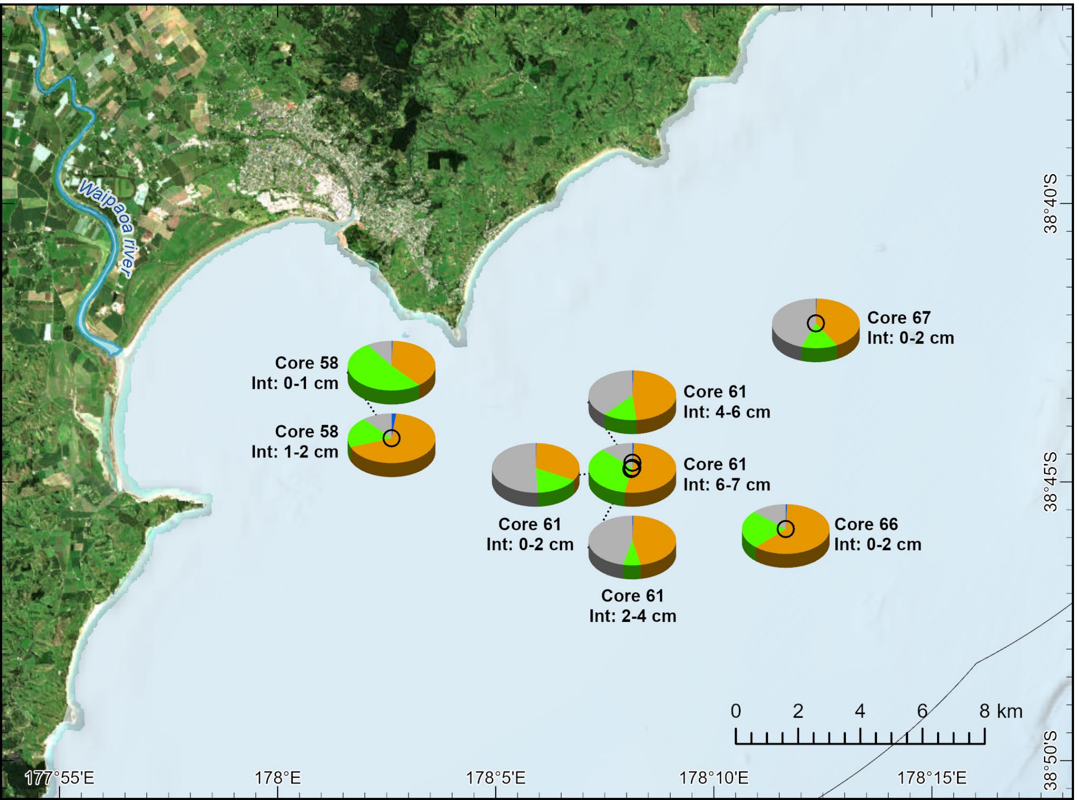
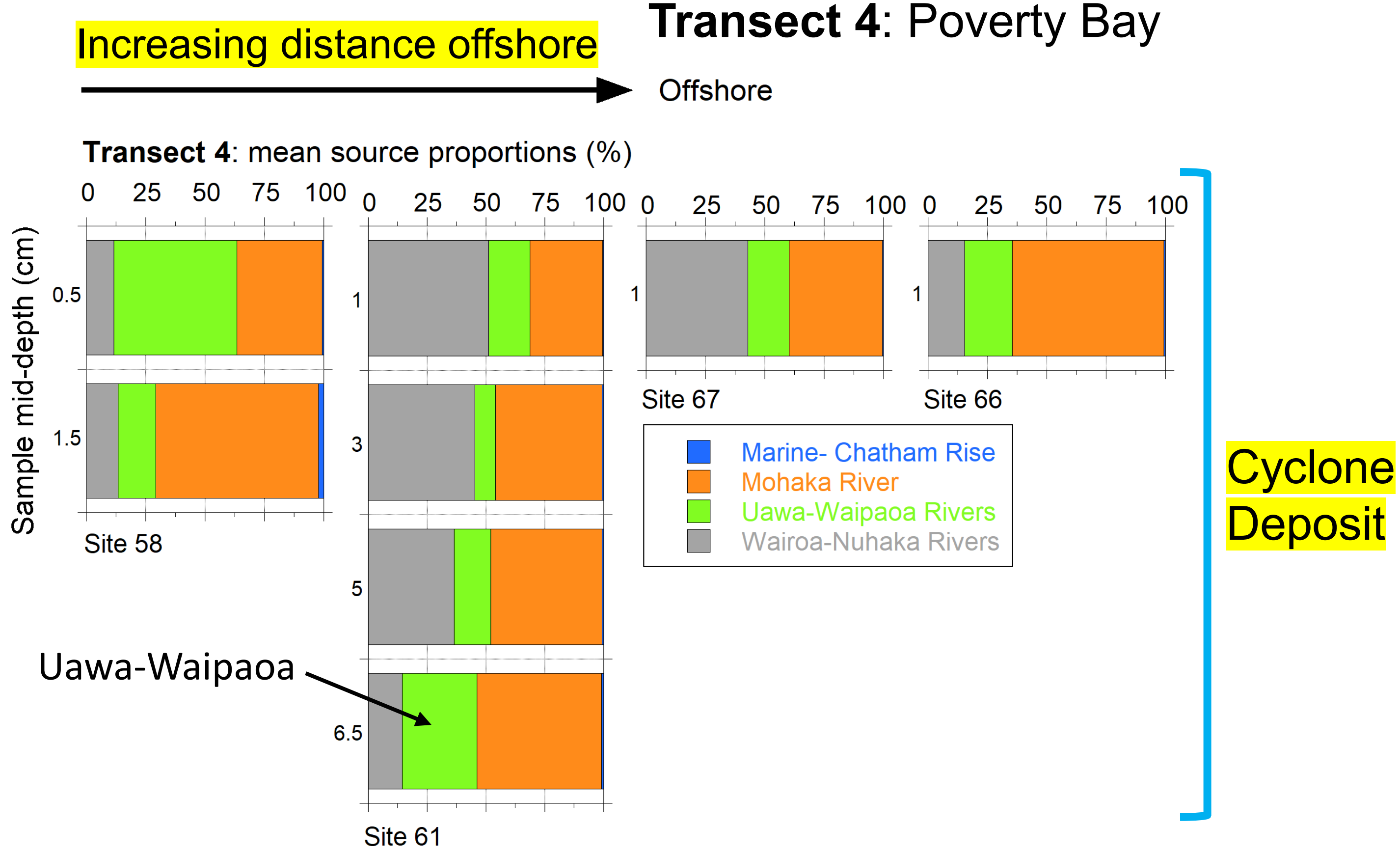
Sediment sources

Transcect 4: Poverty Bay

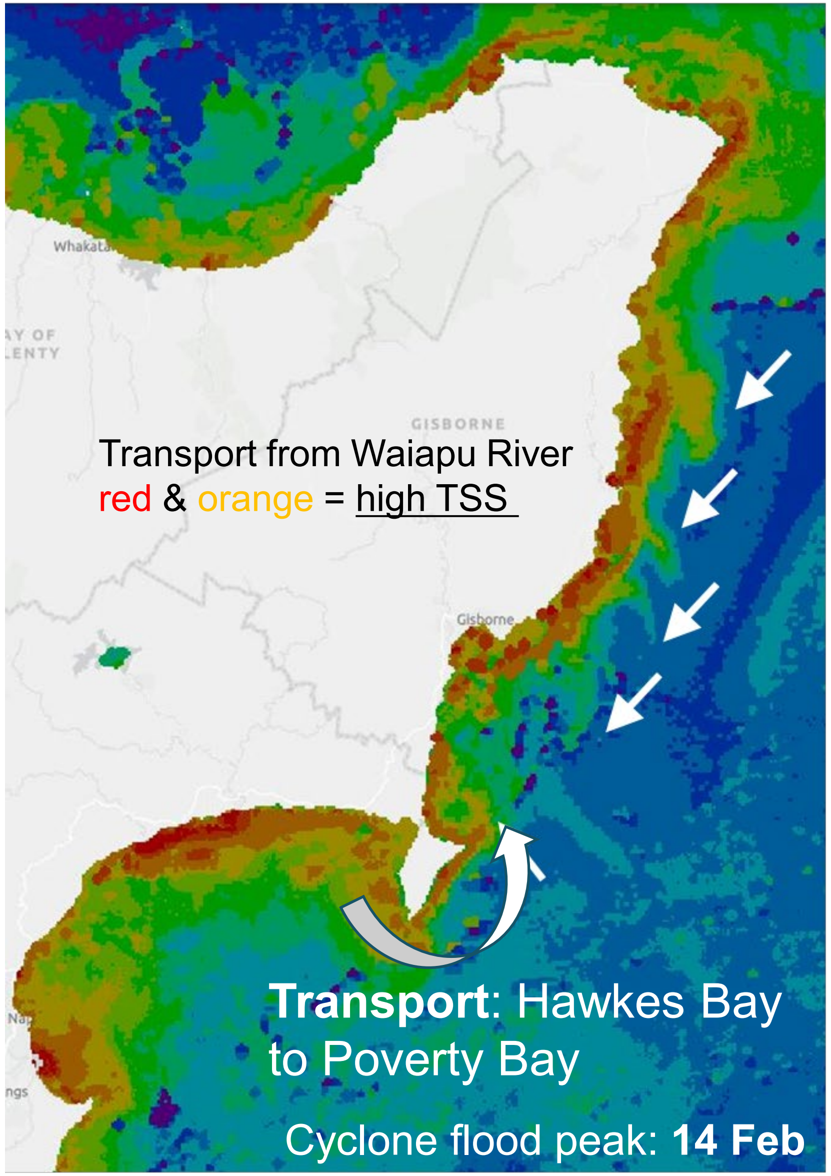






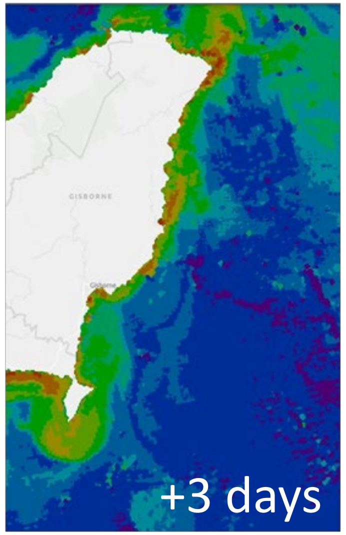
- Poverty Bay sedimentation dominated by **Hawke's Bay Rivers**
- **Mohaka** contribution **decreases** & **Wairoa-Nuhaka increases** towards top of deposit (tail end of cyclone?).
- FAR-FIELD effects of river plumes

River plumes

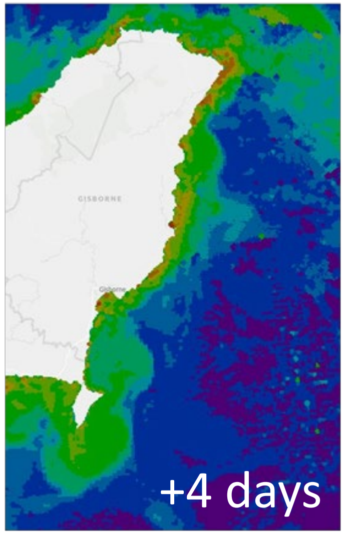


TSS g/m³, 13:00 NZST 14 Feb 2023

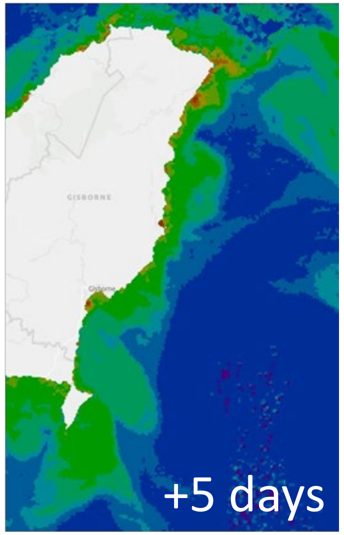
source: NIWAhttps://bucolic-smakager-081edc.netlify.app/.



17 Feb 2023



18 Feb 2023



19 Feb 2023

SCENZ product**:** 14-19 Feb 2023

Near surface TSS (g/m³)

- **River plume transport** - Hawke's Bay to Poverty Bay
- **Cyclone** +5 days - sediment dispersed & deposited

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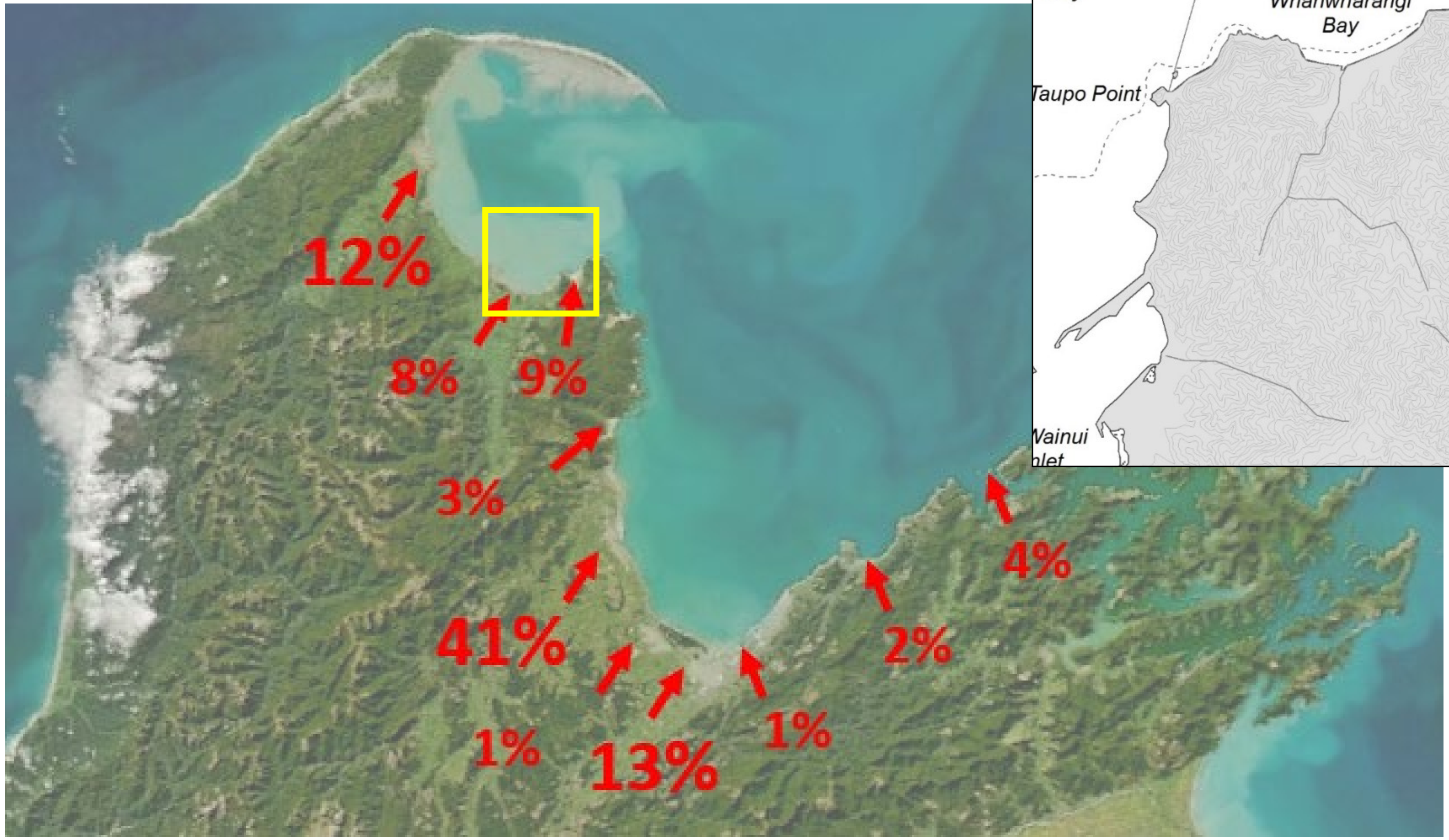
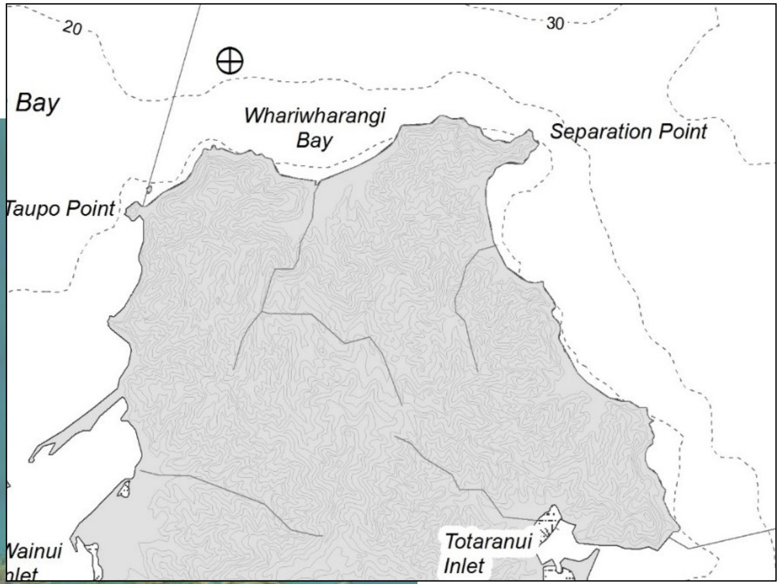
SCENZ: Seas, Coasts & Estuaries NZ

Have humans changed Nelson Bays sedimentation?





- Yes - sedimentation rates increased > 11x pre-human levels (Handley et al. 2020)
- Motueka catchment is a major sediment source (41%, Basher & Hicks, 2012)

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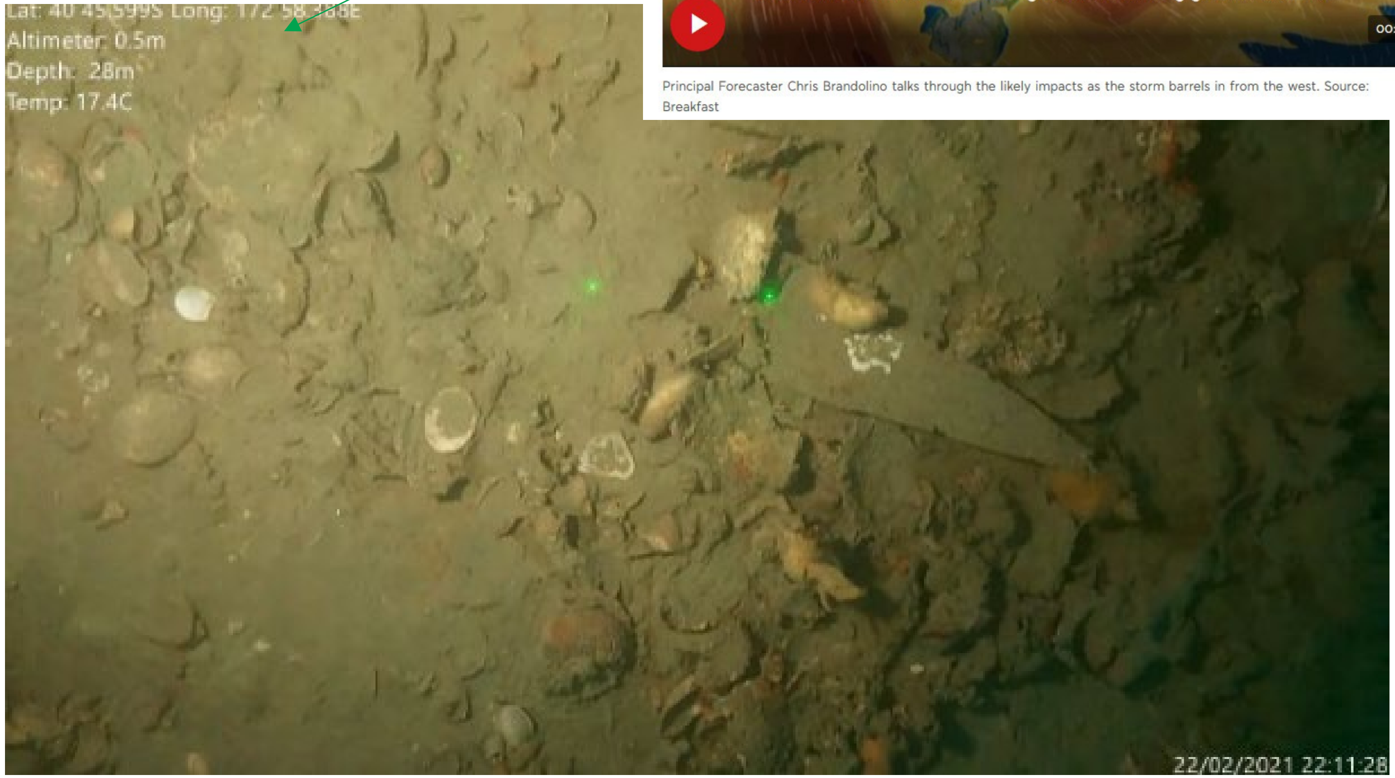
Sedimentation

- Impacts of extreme storm events
- Climate change – increased freq. & intensity of storms



Tasman Bay Coral (Bryozoans, Separation Point, 2017, left) and following cyclones Fehi & Gita (Jan & Feb, 2018).

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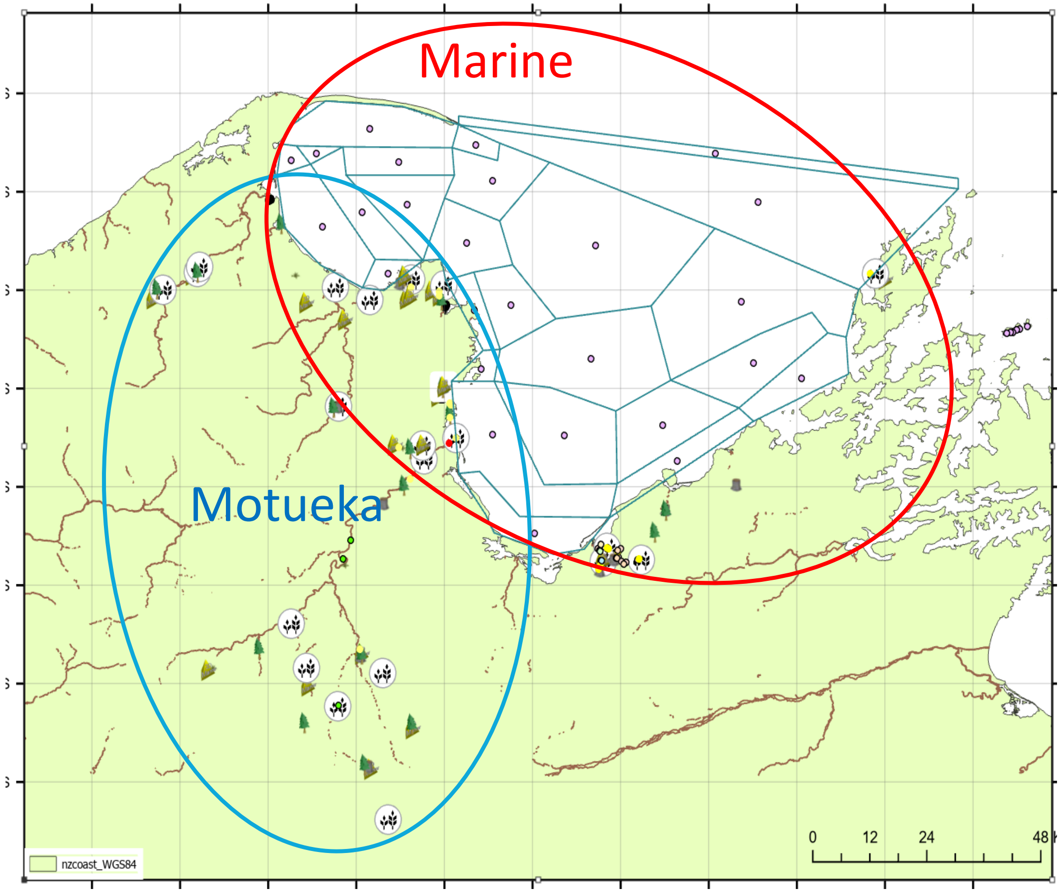
Research – Nelson Bays



Sustainable Seas NSC

- CSSI (land use) & sediment coring study (2017)
- Includes Motueka catchment (*analysis incomplete*)
- Sediment 10-15% more silty (last ~60 years)

MBIE Smart Idea project 2024-2026

- Regional-scale mapping of sediment sources for Atlantis Ecosystem Model
- Marine samples - *analyses underway*
- Preliminary CSSI results*: bank erosion & subsoils (53%) harvested pine (38%), pasture (5%), native forest (4%)

*mean source proportions at one site

Summary - CSSI

- Unique capability to identify eroded soil by land use & apportion contributions to sedimentation
- Contemporary & long-term changes in sources (decades – centuries)
- Uncertainties quantified & reflect underlying data (e.g., source signatures)
- Soil erosion – far-field effects in marine receiving environment
- Motueka Catchment - potential to identify soil erosion hot spots & fate

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Fatty Acids

A fatty acid is a **carboxylic acid with an aliphatic chain, which is either saturated or unsaturated**. It is a subunit of fats, oils, and waxes. Most naturally occurring fatty acids have an unbranched chain of an even number of carbon atoms, from 4 to 28. Fatty acids are produced by the breakdown of fats (usually triglycerides or phospholipids) through a process called hydrolysis. Fatty acids and their associated derivatives are the primary components of lipids

Carboxylic acid | Aliphatic chain

Saturated fatty acid

Carboxylic acid: organic compound containing a carboxyl group (-COOH).

Aliphatic chain: organic compound containing a carboxyl group (-COOH).

Plant derived FAs: **even-chain length saturated** fatty acids most commonly used for CSSI sediment source tracing (e.g., C14:0 to C:32)

List of saturated fatty acids

From Wikipedia, the free encyclopedia

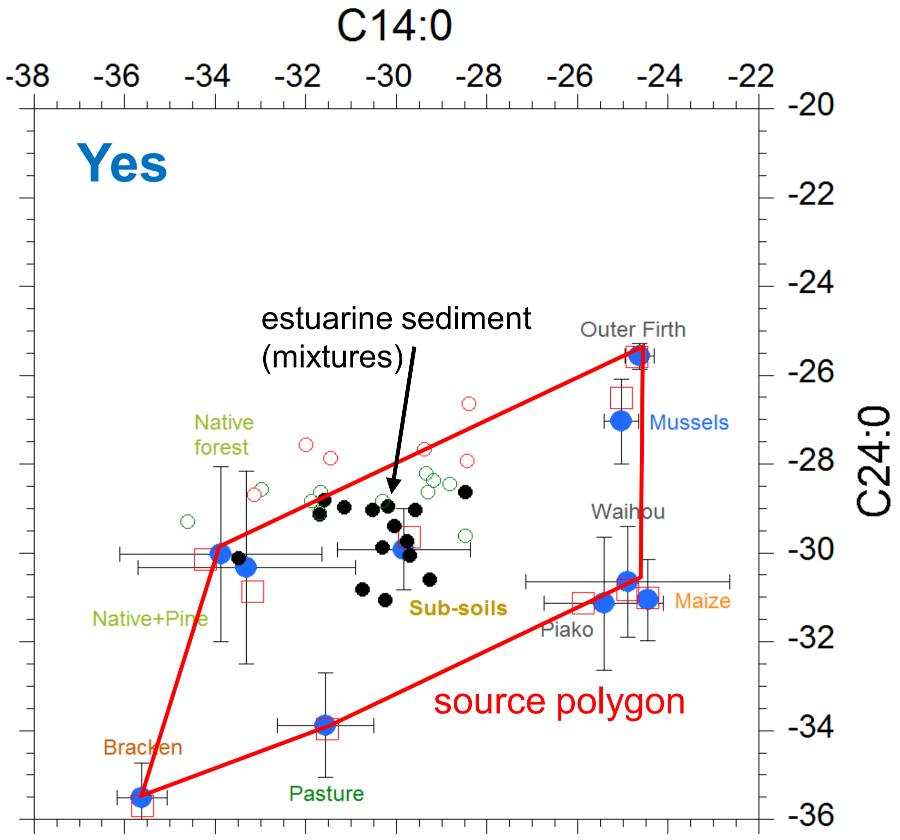
Main article: Saturated fat

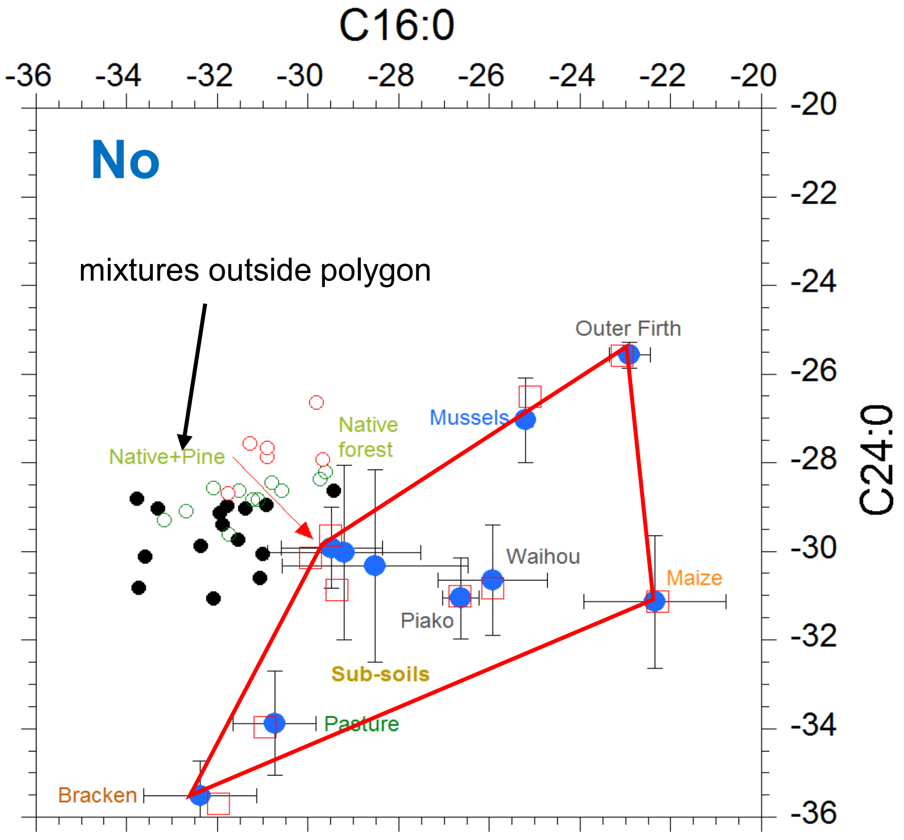
Common Name	Systematic Name	Structural Formula	Lipid Numbers
Propionic acid	Propanoic acid	CH_3CH_2COOH	C3:0
Butyric acid	Butanoic acid	$CH_3(CH_2)_2COOH$	C4:0
Valeric acid	Pentanoic acid	$CH_3(CH_2)_3COOH$	C5:0
Caproic acid	Hexanoic acid	$CH_3(CH_2)_4COOH$	C6:0
Enanthic acid	Heptanoic acid	$CH_3(CH_2)_5COOH$	C7:0
Caprylic acid	Octanoic acid	$CH_3(CH_2)_6COOH$	C8:0
Pelargonic acid	Nonanoic acid	$CH_3(CH_2)_7COOH$	C9:0
Capric acid	Decanoic acid	$CH_3(CH_2)_8COOH$	C10:0
Undecylic acid	Undecanoic acid	$CH_3(CH_2)_9COOH$	C11:0
Lauric acid	Dodecanoic acid	$CH_3(CH_2)_{10}COOH$	C12:0
Tridecylic acid	Tridecanoic acid	$CH_3(CH_2)_{11}COOH$	C13:0
Myristic acid	Tetradecanoic acid	$CH_3(CH_2)_{12}COOH$	C14:0
Pentadecylic acid	Pentadecanoic acid	$CH_3(CH_2)_{13}COOH$	C15:0
Palmitic acid	Hexadecanoic acid	$CH_3(CH_2)_{14}COOH$	C16:0
Margaric acid	Heptadecanoic acid	$CH_3(CH_2)_{15}COOH$	C17:0
Stearic acid	Octadecanoic acid	$CH_3(CH_2)_{16}COOH$	C18:0
Nonadecylic acid	Nonadecanoic acid	$CH_3(CH_2)_{17}COOH$	C19:0
Arachidic acid	Eicosanoic acid	$CH_3(CH_2)_{18}COOH$	C20:0
Heneicosylic acid	Heneicosanoic acid	$CH_3(CH_2)_{19}COOH$	C21:0
Behenic acid	Docosanoic acid	$CH_3(CH_2)_{20}COOH$	C22:0
Tricosylic acid	Tricosanoic acid	$CH_3(CH_2)_{21}COOH$	C23:0
Lignoceric acid	Tetracosanoic acid	$CH_3(CH_2)_{22}COOH$	C24:0
Pentacosylic acid	Pentacosanoic acid	$CH_3(CH_2)_{23}COOH$	C25:0
Cerotic acid	Hexacosanoic acid	$CH_3(CH_2)_{24}COOH$	C26:0

Data

Key requirement: to apply mixing models to tracers – sediment mixtures must be constrained within source polygons/hyper-volumes (i.e, typically 4+ tracers).

[example: Firth of Thames study – dated sediment cores]





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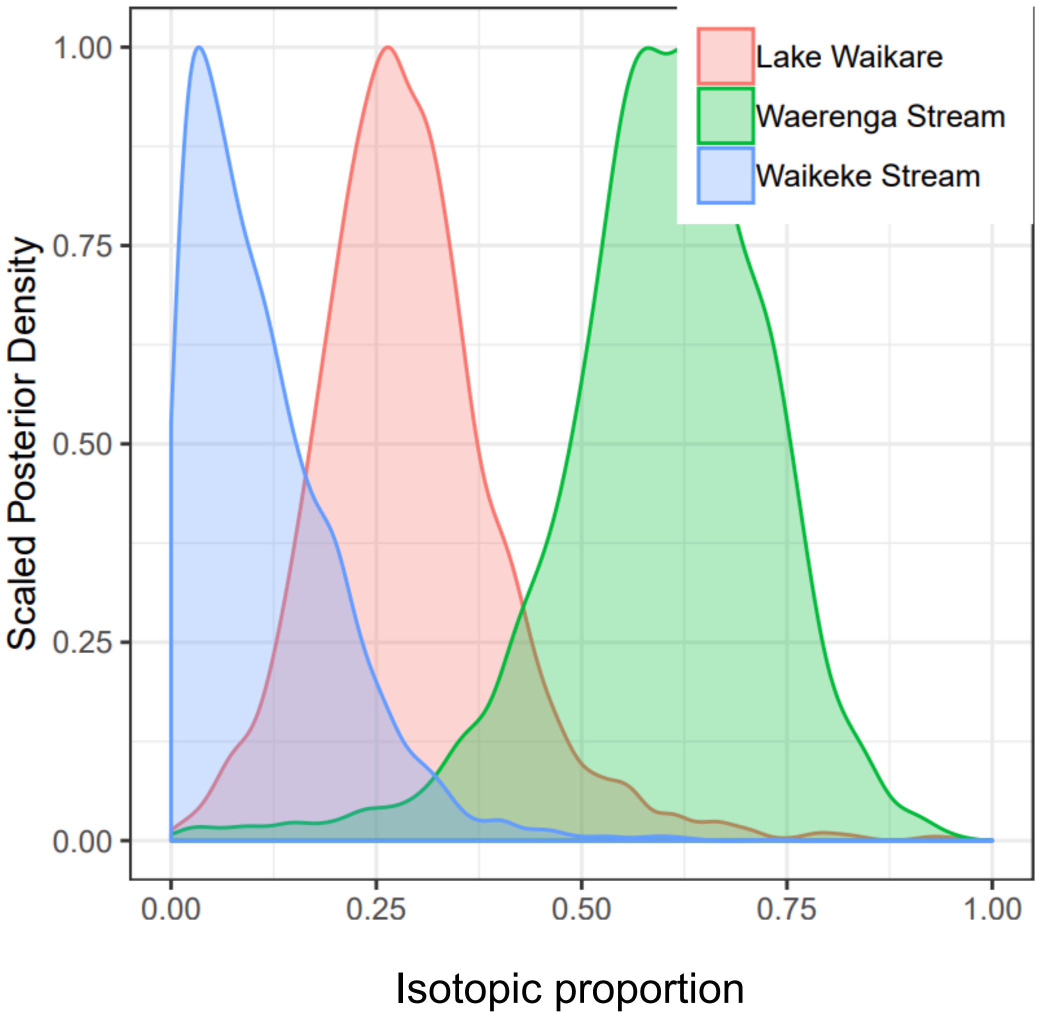
Model output

MixSIAR

Average proportions (of *n* = 3000 PDF estimates)



Example: model output

- Use **mixing model** to determine feasible proportions of soil sources in a sediment mixture
- **Output**: Probability distributions >> calculate statistics (e.g., mean, standard deviation etc)*
- **Uncertainty** in source proportions quantified

*Convert isotopic proportions to soil proportions using **%C** in source soils

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A B S T R A C T

The effects of climate warming on soil erosion in upland ecosystems will be disproportionately higher than for lowlands due to steeper topography and higher predicted rainfall. Soil erosion may be enhanced by climate warming and upslope shifts in agriculture as conditions for plant growth improve. Identification of eroded-soil sources will inform land management practices that mitigate soil loss and impacts on aquatic receiving environments. Isotopic signatures of plant-derived fatty acid (FA) soil biomarkers can discriminate sediment sources and will detect shifts in land use and natural vegetation toposequences. Accounting for these isotopic shifts requires knowledge of the magnitude and time scale for transition in biomarker signatures. We examined a 30-year chronosequence to quantify the transition in isotopic values of bulk nitrogen, carbon and FA biomarkers following a change from pine forestry to pastoral agriculture in the central North Island of New Zealand. We found the transition in soil biomarker isotopic values was complete within 6 years, with substantial increases in both organic carbon (1% yr^{-1}) and total N (0.13% yr^{-1}) of top soils. Subsequent changes were negligible (i.e., <0.04% yr^{-1}), indicative of a new steady state. Similar patterns were observed in the isotopic signatures of bulk $\delta^{13}C$ and $\delta^{15}N$ values and FA $\delta^{13}C$ values (i.e., $\pm$0.5–0.6‰ yr^{-1}). Bulk C and N properties and the FAs C14:0, C16:0, C18:2, C24:0 and C26:0 displayed clear transitions from harvested pine to mature pasture. We found evidence that mycorrhizal fungi could disperse and influence soil FA isotopic signatures. This highlights the need to consider both harvested and mature forests in source-tracing studies. Finally, our study shows that near-instantaneous changes in land use associated with agriculture can alter the isotopic signatures of plant biomarkers in soils. This produces a step change that can be readily detected in sedimentary records.

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Transition in the isotopic signatures of fatty-acid soil biomarkers under changing land use: Insights from a multi-decadal chronosequence

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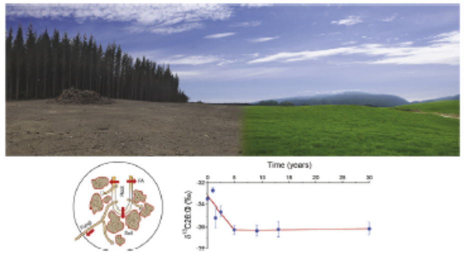
H I G H L I G H T S

- Soil biomarker changes for a pine forest to pasture chronosequence are quantified.
- Transition in soil carbon and fatty acid isotopic values complete after 6 years.
- Mycorrhizal fungi influence on isotopic values of soil short-chain fatty acids
- Step-change in soil biomarker values under land use change readily detected
- Findings aid discrimination between natural and anthropogenic climate warming effects

G R A P H I C A L A B S T R A C T



H I G H L I G H T S

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Post-harvest: isotopic enrichment: short-chain length FAs

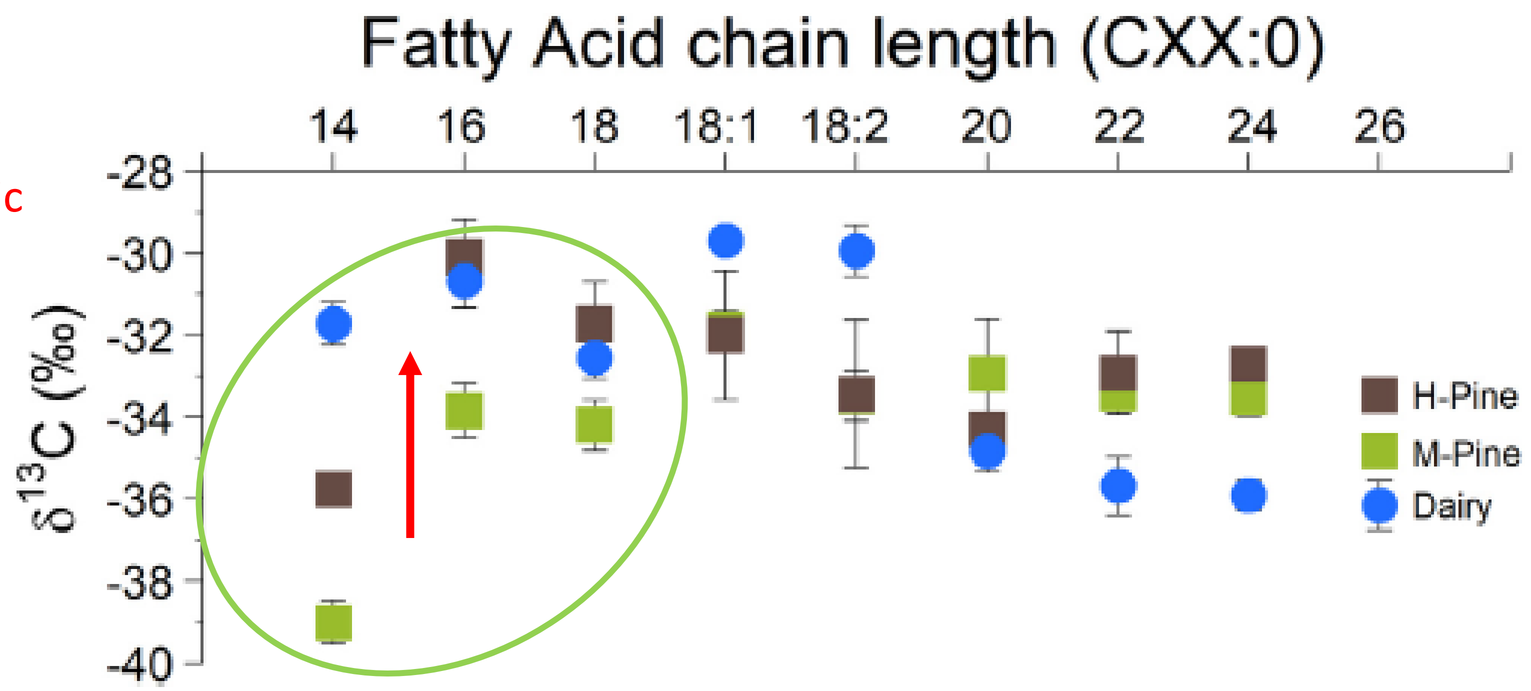

Fig. 8. Isotopic values of saturated FAs C14:0 to C26:0 and unsaturated FAs C18:1 and C18:2, extracted from top soils for mature pine (M-Pine), recently harvested pine prepared for sowing of pasture seed (H-Pine) and mature dairy pasture (Dairy, T + 30 yr). Data are mean values (±1 std. deviation) of 10 replicate composite samples.

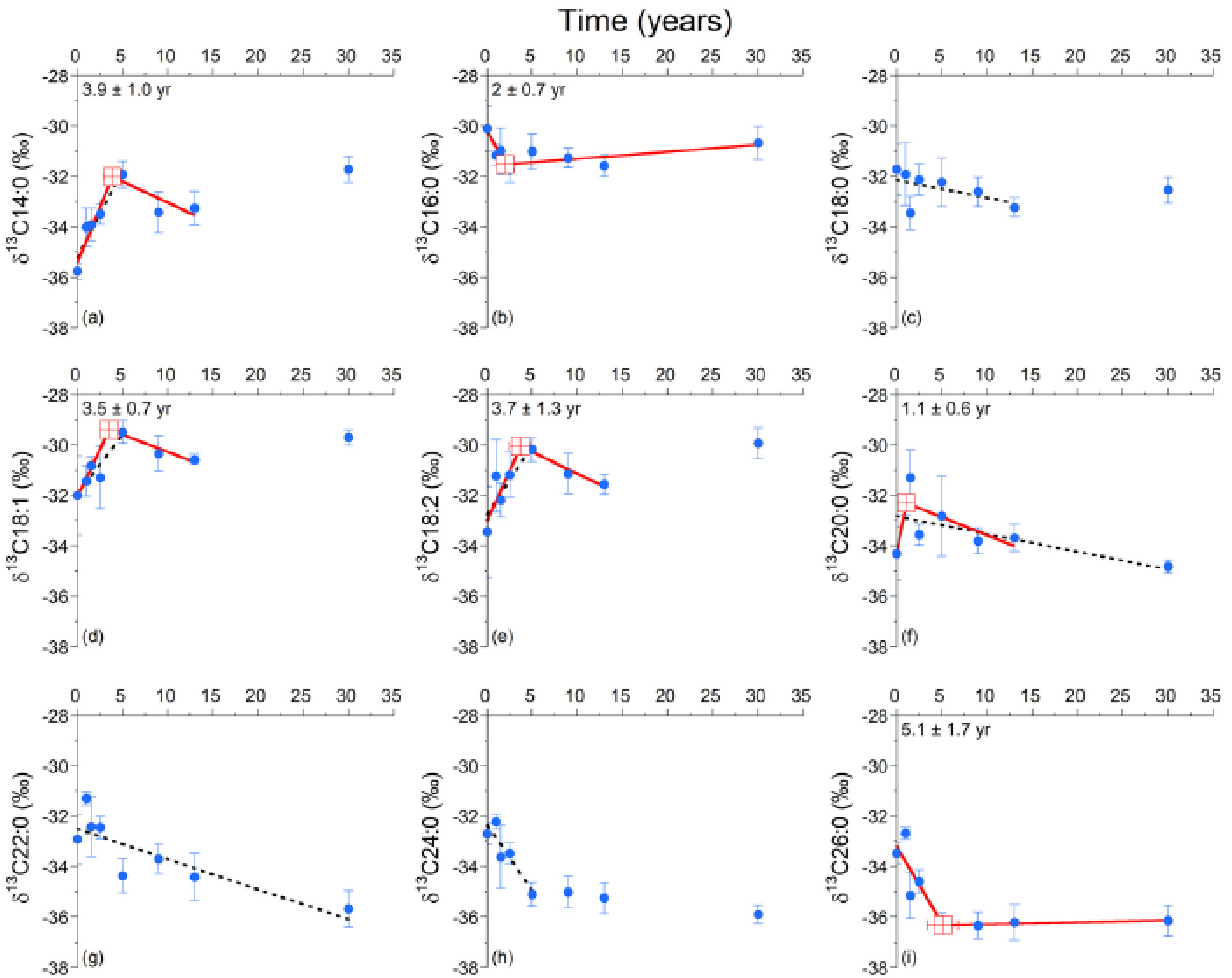

Fig. 9. Temporal changes in the mean isotopic values of FA biomarkers (C14:0 to C26:0). Data based on 10 replicate composite samples at each time step. Error bars are one standard deviation about the mean. Simple linear regression fits (black dashed line) and segmented regression fits (red line) to estimate the breakpoint (red square) are shown. The elapsed time (years) ±1 standard error to the breakpoint is shown. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

CSSI method

Compound-Specific Stable Isotopes

Number crunching Use **Fatty Acid biotracers** & **mixing model** to determine proportions of soil-erosion source contributions to river, estuary & marine sedimentation.