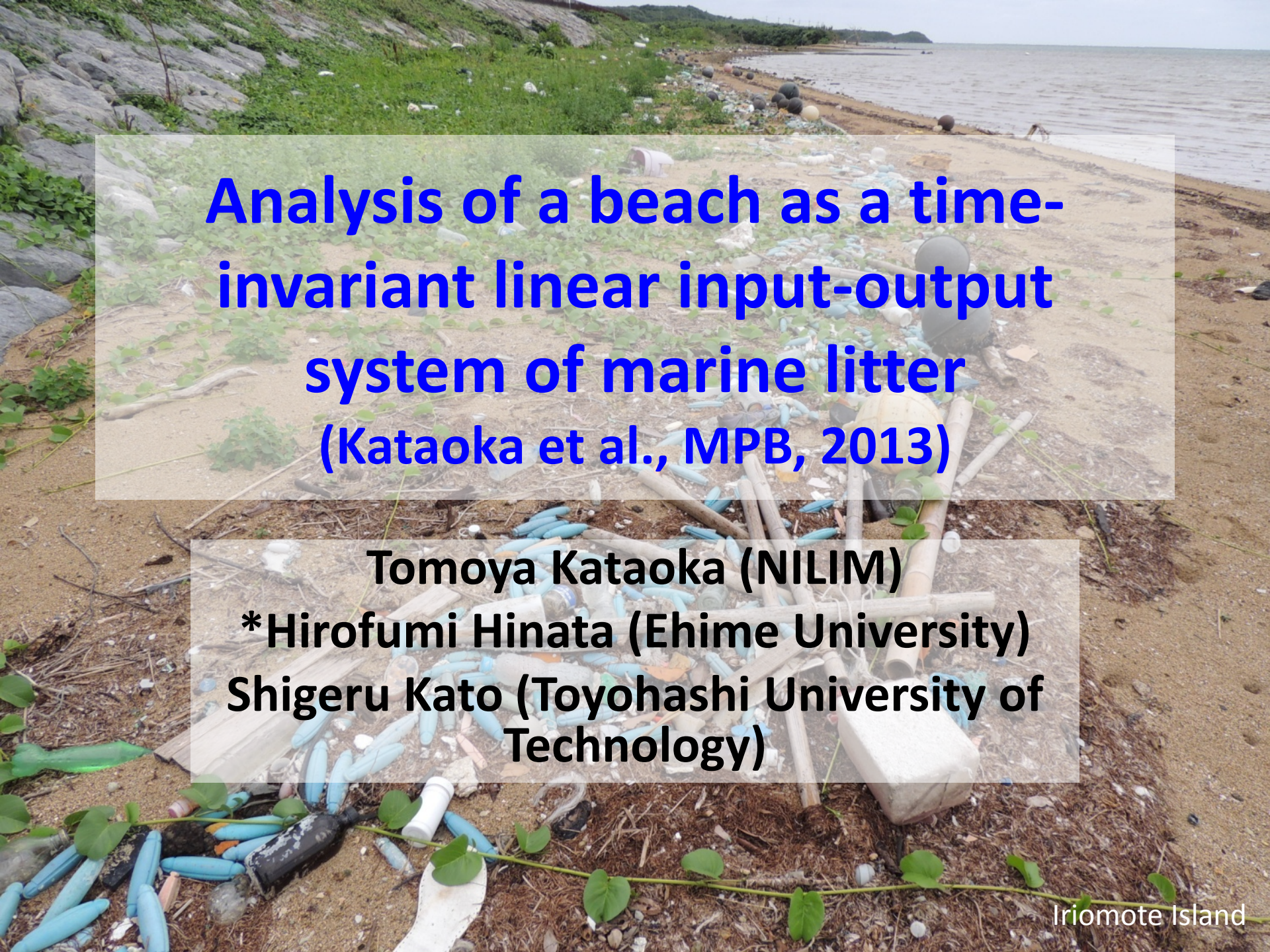


Analysis of a beach as a time-invariant linear input-output system of marine litter

(Kataoka et al., MPB, 2013)

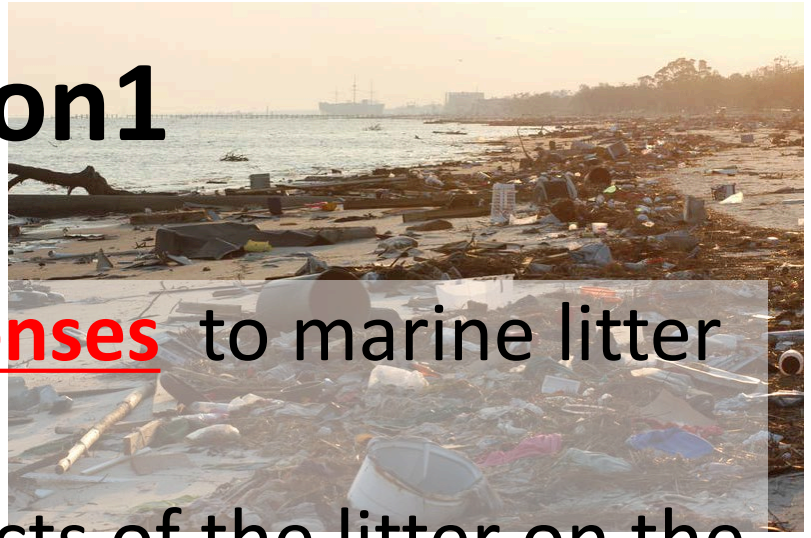
Tomoya Kataoka (NILIM)

*Hirofumi Hinata (Ehime University)

Shigeru Kato (Toyohashi University of Technology)

Iriomote Island

2005 Hurricane Katrina



Motivation1

To understand **beach responses** to marine litter inputs from offshore

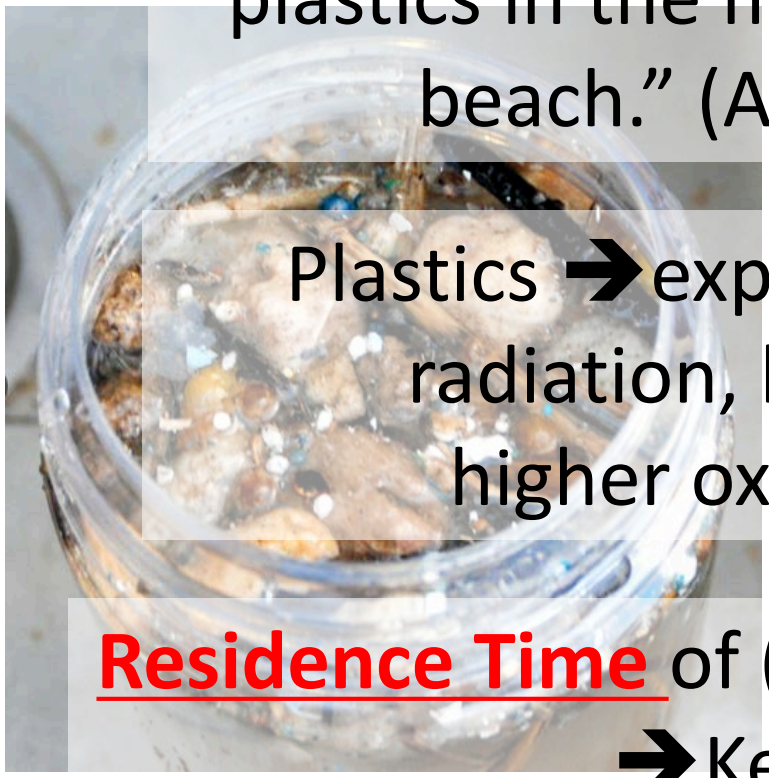
🡸 In order to access impacts of the litter on the beach environment and/or take measures for scenarios of natural disasters or run-off accidents

2011 Tohoku-oki Earthquake

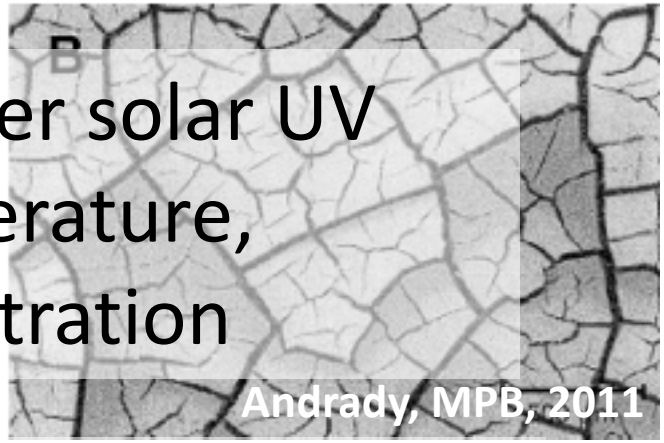
Motivation 2

Beach➔Hot spot of microplastic generation

"The most likely site for generation of micro plastics in the marine environment is the beach." (Andrady, MPB, 2011)



Plastics ➔exposed to higher solar UV radiation, higher temperature, higher oxygen concentration



Residence Time of (Macro) Plastics on Beaches ➔Key Parameter

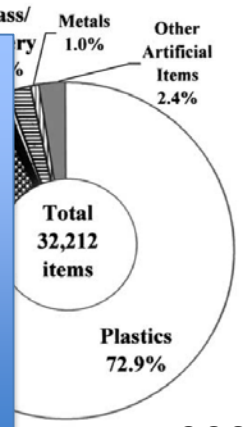
Previous Studies on Beached Macro Plastics

Abundance and categorization of beached litter

e.g., Walker et al., 1997;
Kusui and Noda, 2003;
Ivar do Sul and Costa, 2007;
Ryan et al., 2009;
Ribic et al., 2012.

Present Beach Environment,
Its variability Trend,
Its origin

Residence time
Beach Response



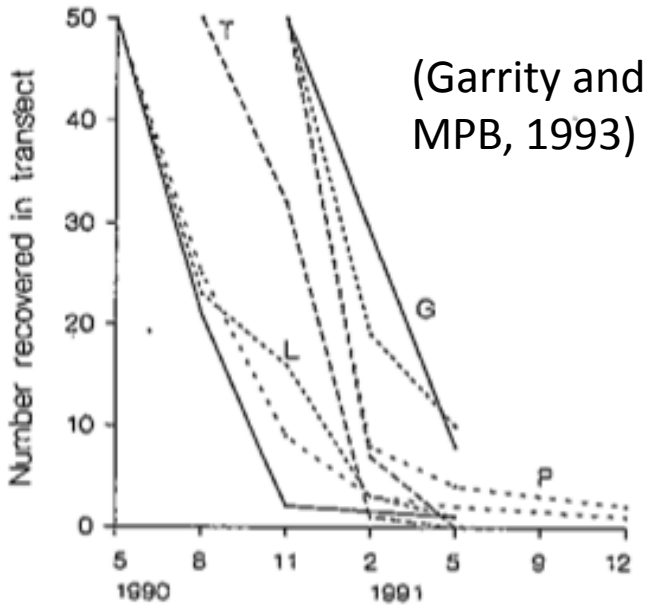
a, MPB, 2003)

Residence Time

e.g., Garrity and Levings (1993);
Williams and Tudor, 2001;
Bowman et al., (1998)

Mark-recapture (MR) Experiment

G&L➔50 target items in 1*50m transect were sprayed with the same color



(Garrity and Levings, MPB, 1993)

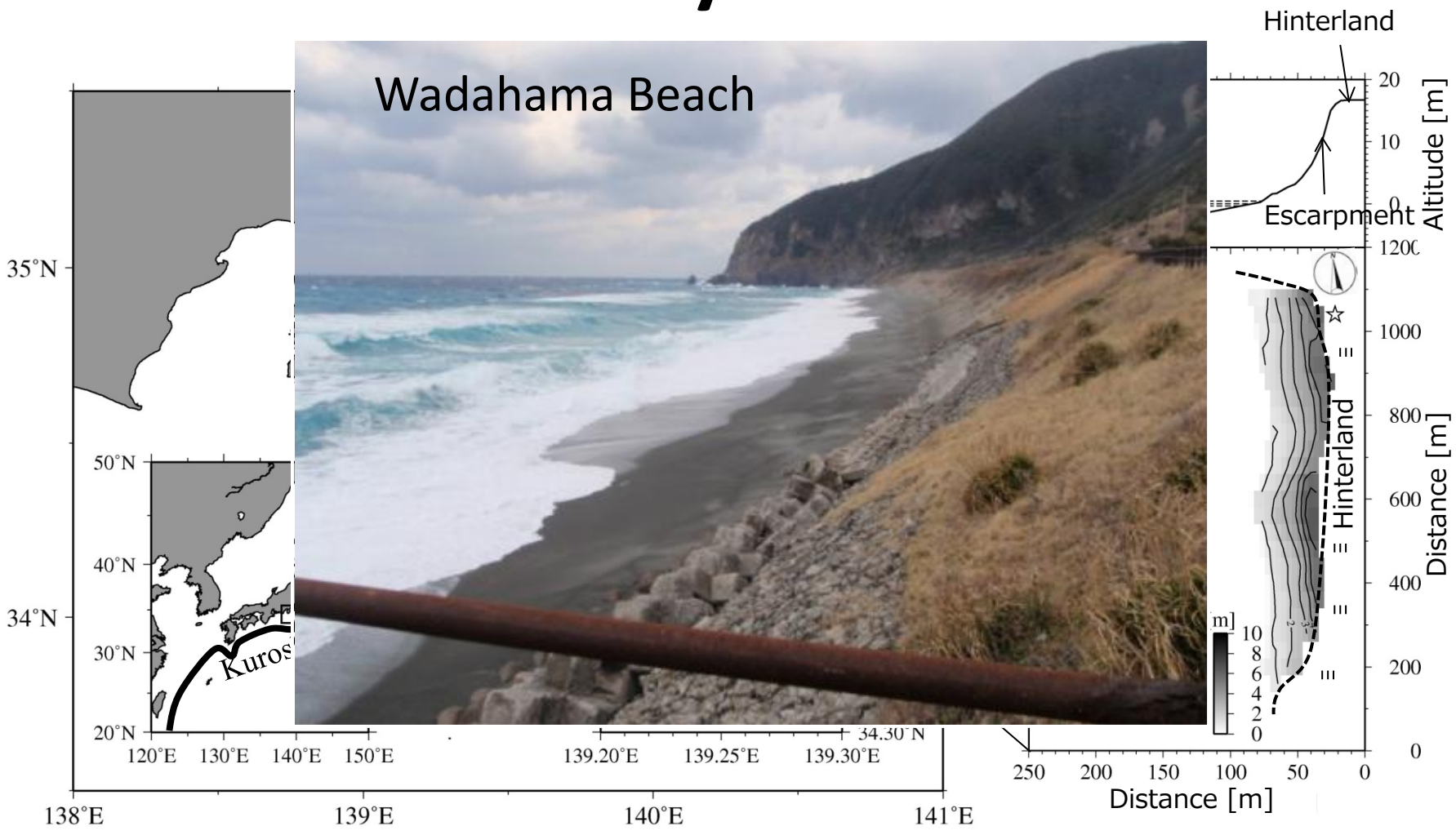
Objective

Time decay of population ← Linear System Analysis

Unit impulse response of the beach to litter input

We consider a beach as a linear black box and measure the residence time by the MR experiment, and investigate the system characteristics and beach response to idealized litter inputs by applying linear system analysis.

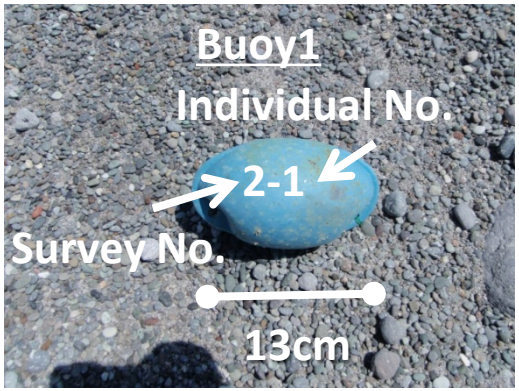
MR Experiment
Study Field

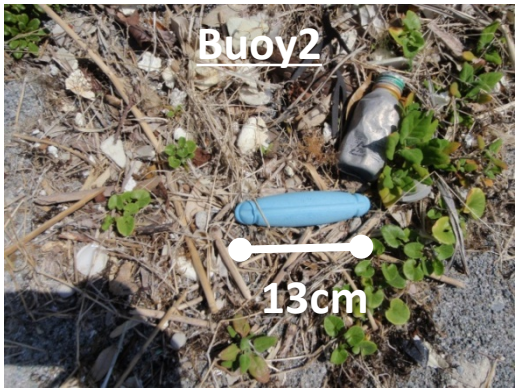


MR Experiment
Date and Target Items

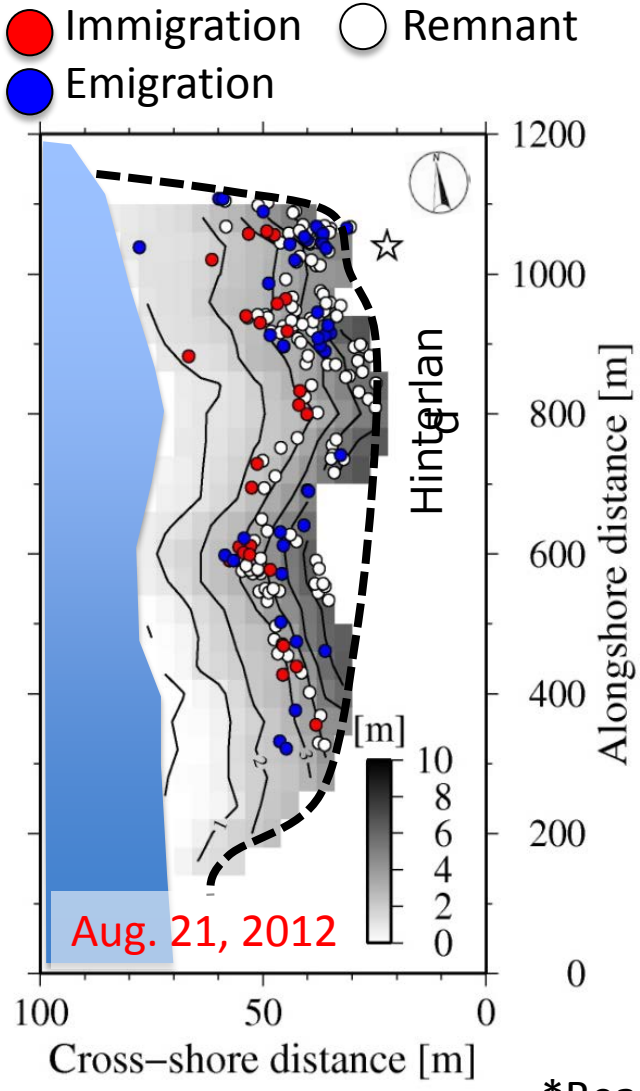
- **Date:** 2011/09/30 ~ (@ 2-3 months)
  2011: 09/30, 10/27, 11/24, 11/26
  2012: 01/26, 03/23, 06/29, 08/21, 11/08, 12/27
  2013: 02/27, 05/08, 06/27, 08/31, …

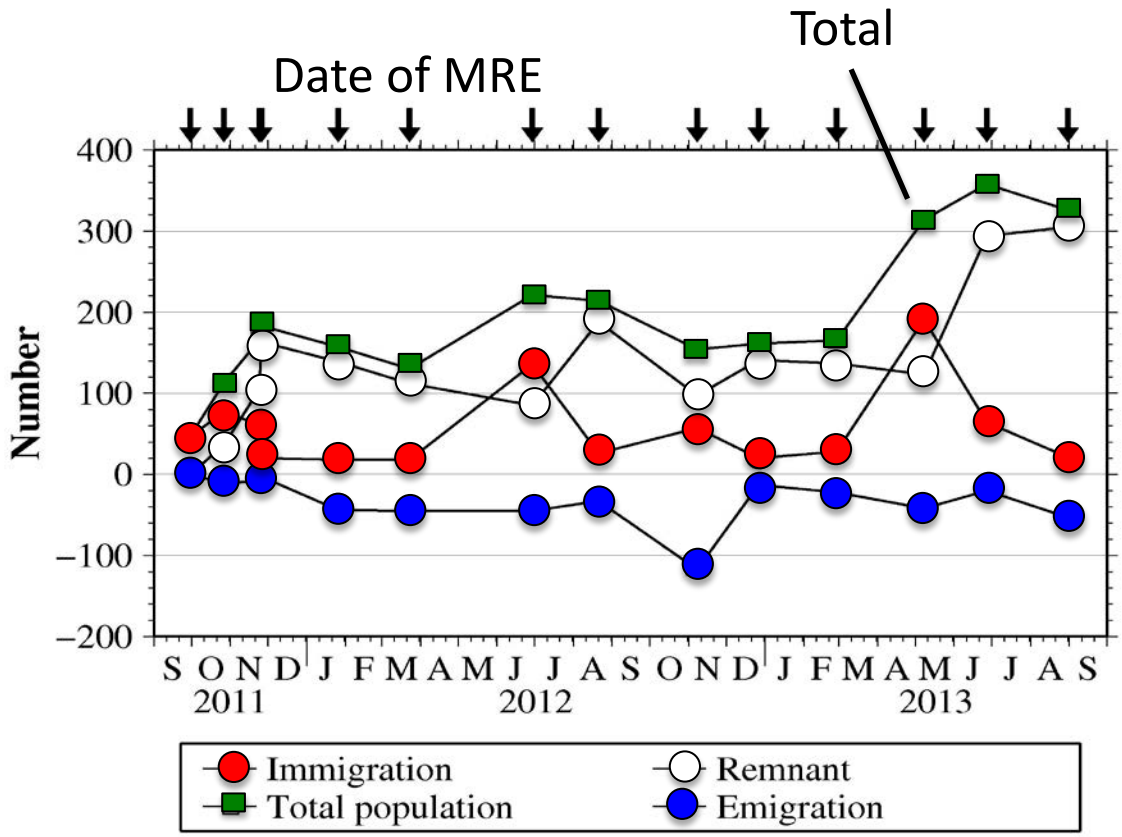
- **Target Items:**
  Plastic Fishing Floats (**H**ardly moved by wind, **F**ound on many Japanese beach,
  Buoy2 containing a high concentration of Pb (Nakashima et al., EST, 2012))
  Putting ID number and Measuring Position by Handy GPS Receiver
  (measurement error: 3m)





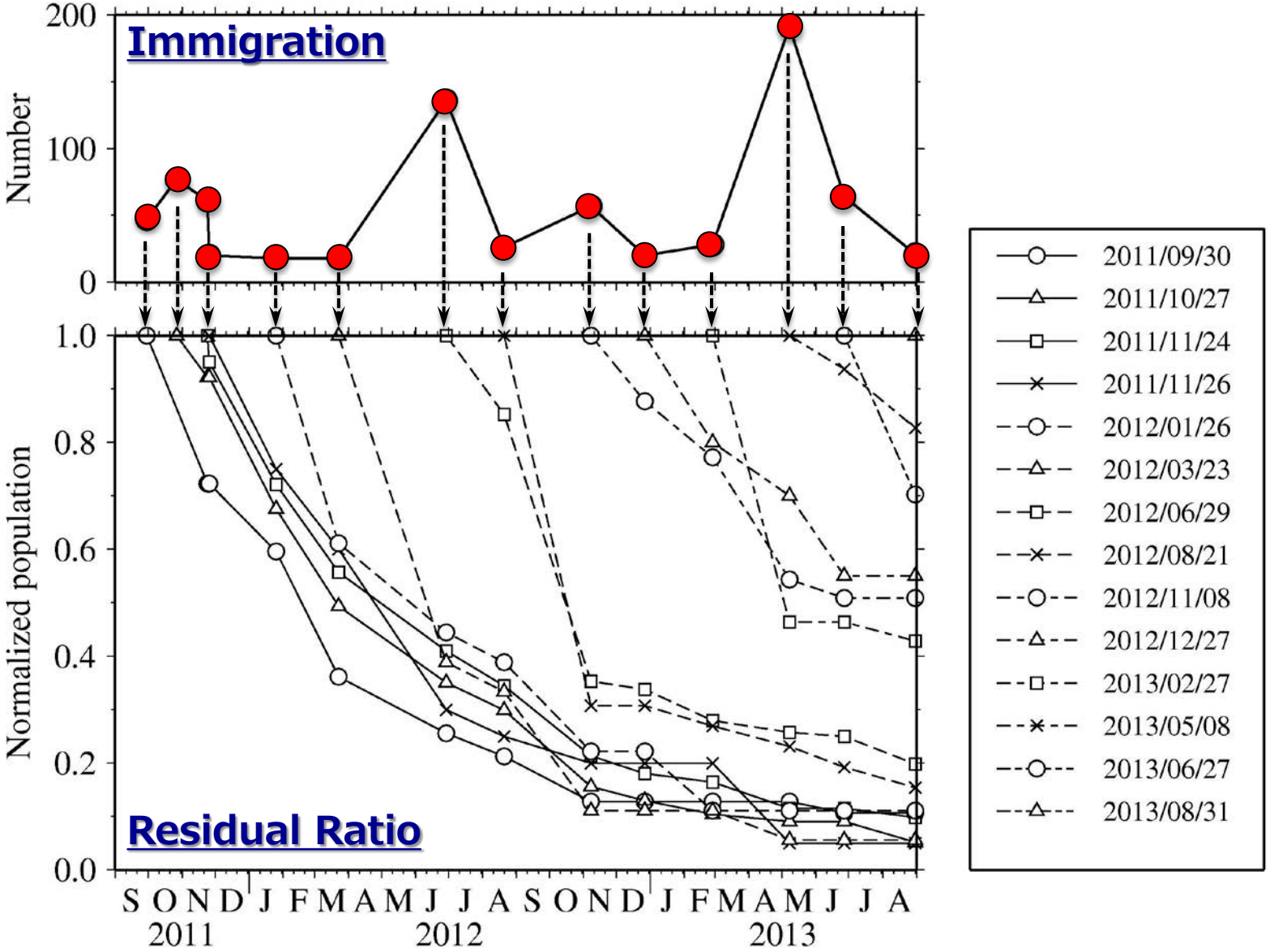
Time series of Immigration, Remnant Emigration and Total



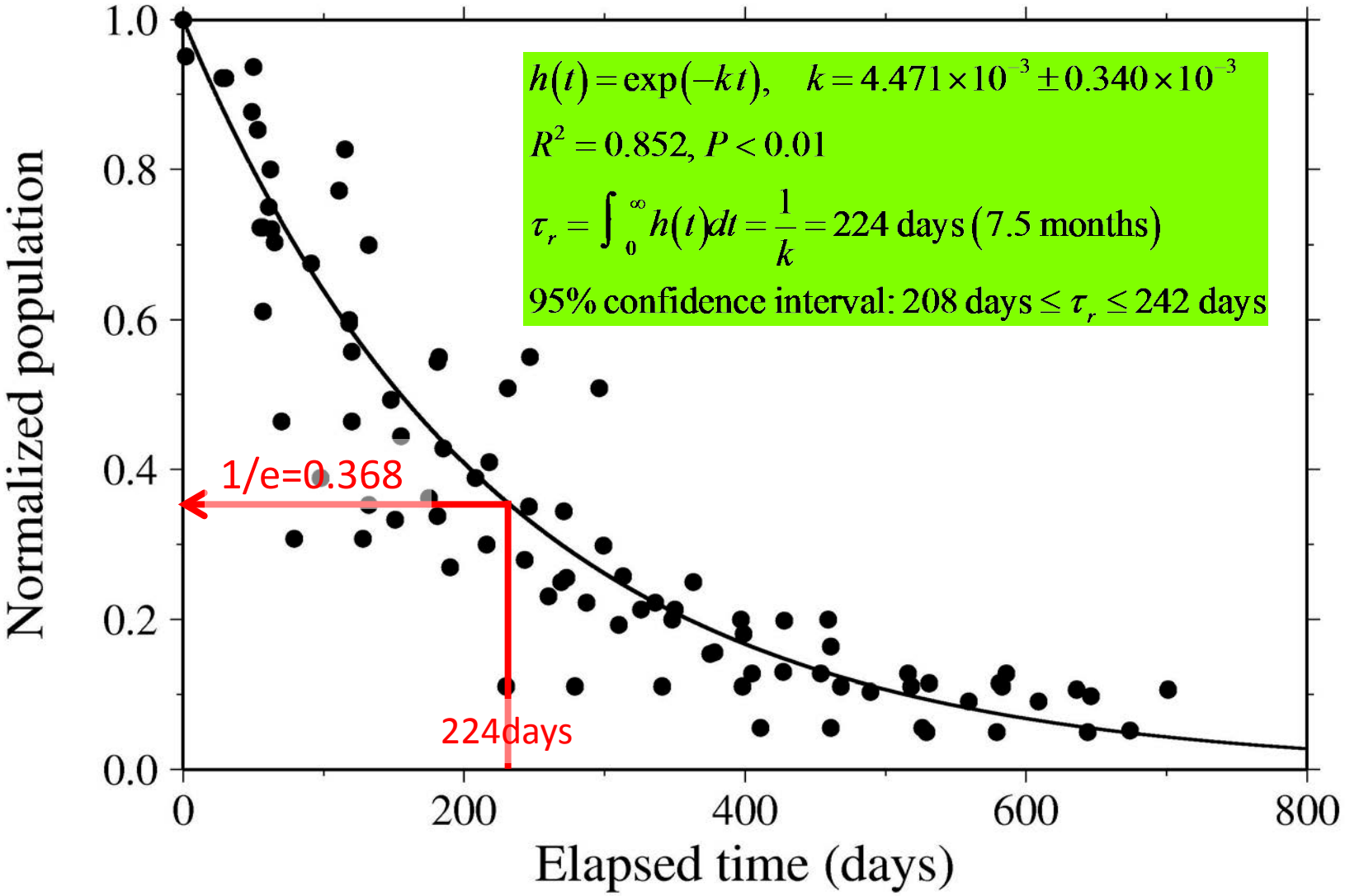


*Beach surveys measure the total population, not the immigration.

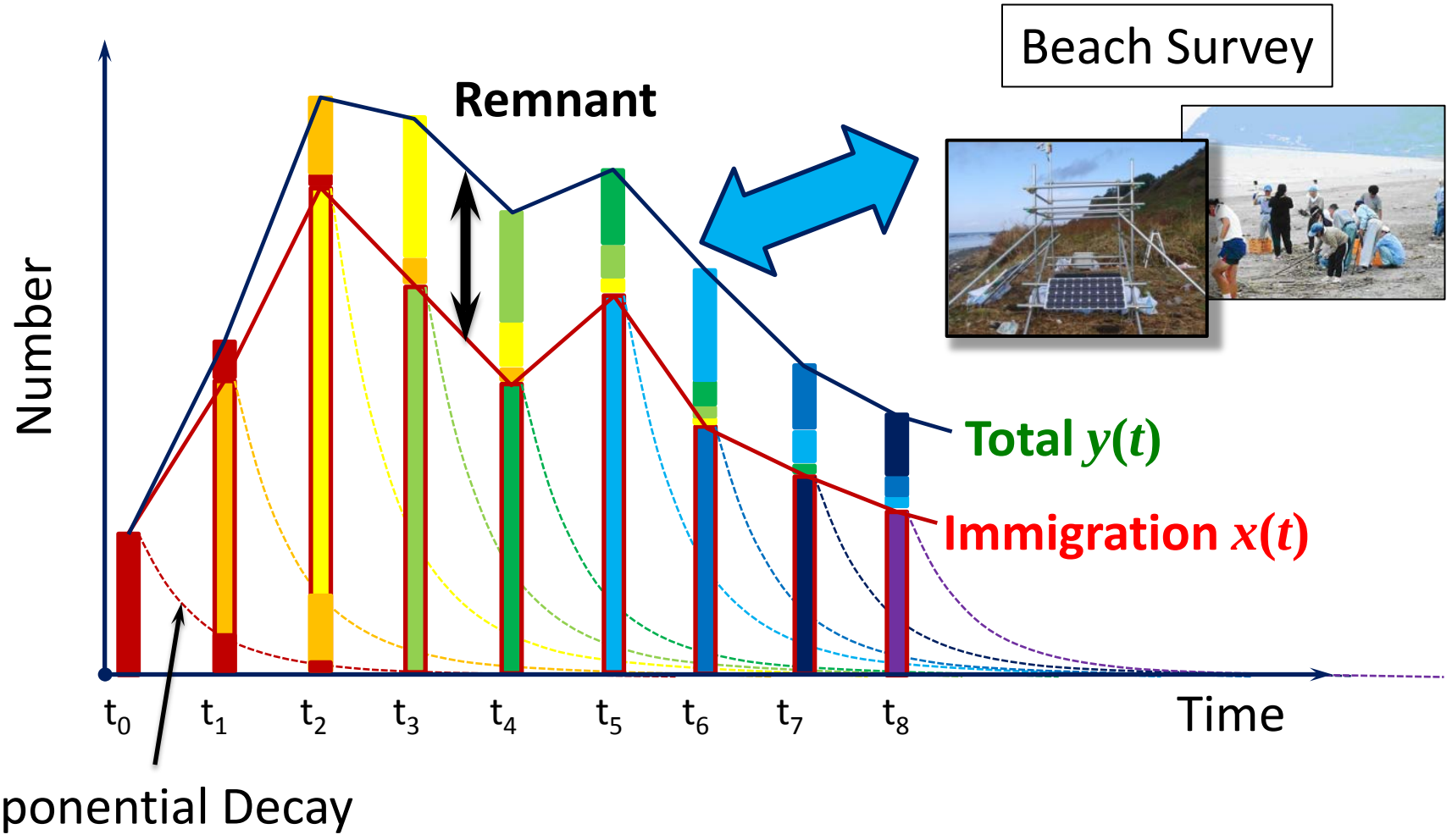
Cohort Population Decay



Residence Time of Wadahama Beach



Relation between Immigration, Remnant and Total



Wadahama Beach as a time-invariant liner system

Output (Total)

$$y(t) = \int_0^t x(\tau) h(t-\tau)\, d\tau$$

Input (Immigration)

Unit Impulse Response (UIR)

$$h(t) = exp(-kt) = \exp\left(-\frac{t}{224}\right)$$

residence time

Wadahama Beach as a time-invariant liner system

Output (Total)

$$y(t) = \int_0^t x(\tau) h(t-\tau)\, d\tau$$

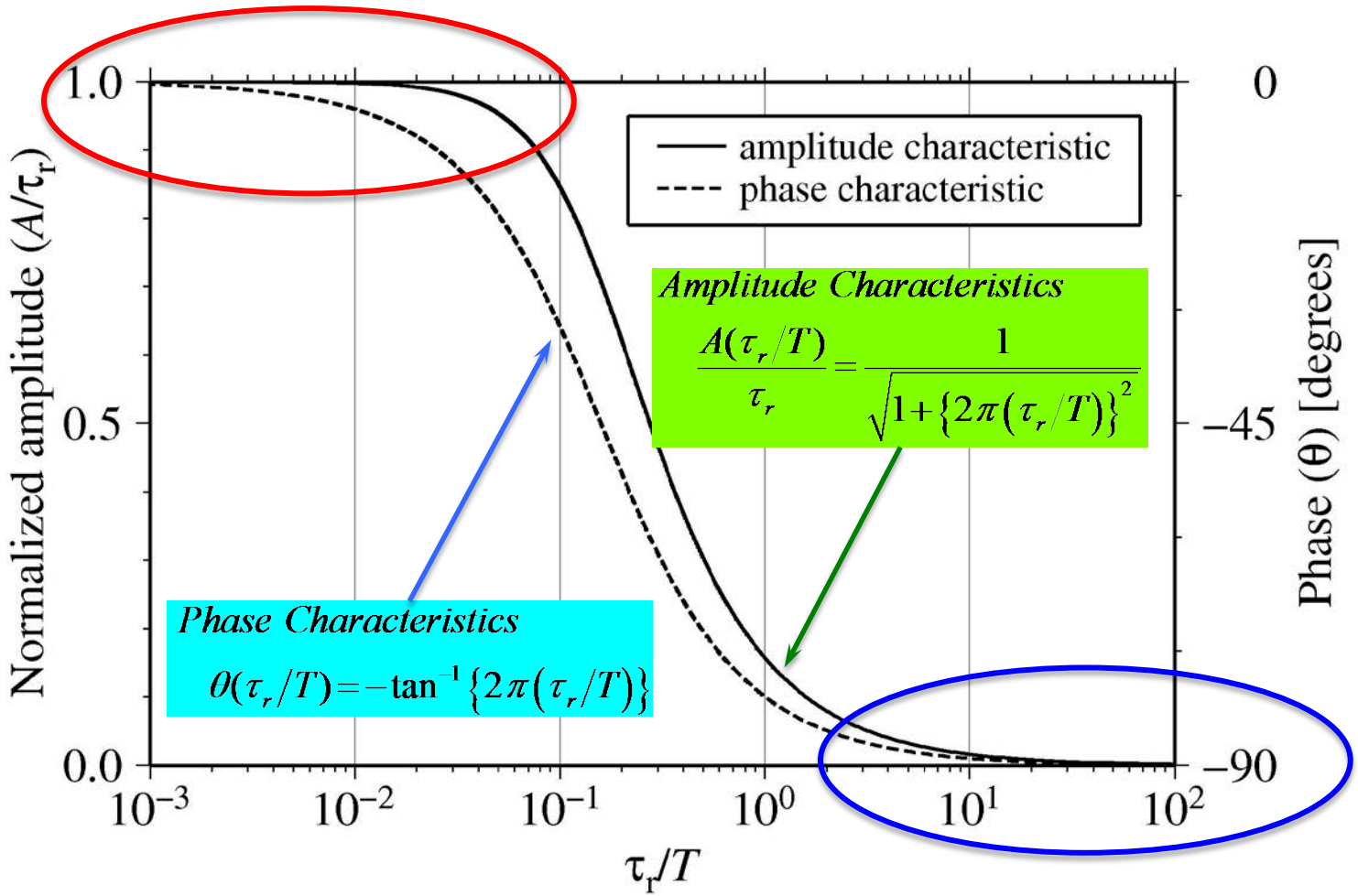
Input (Immigration)

Unit Impulse Response (UIR)

$$h(t) = exp\left(-\frac{1}{\tau_r}\right) = \exp\left(-\frac{t}{224}\right)$$

Residence time

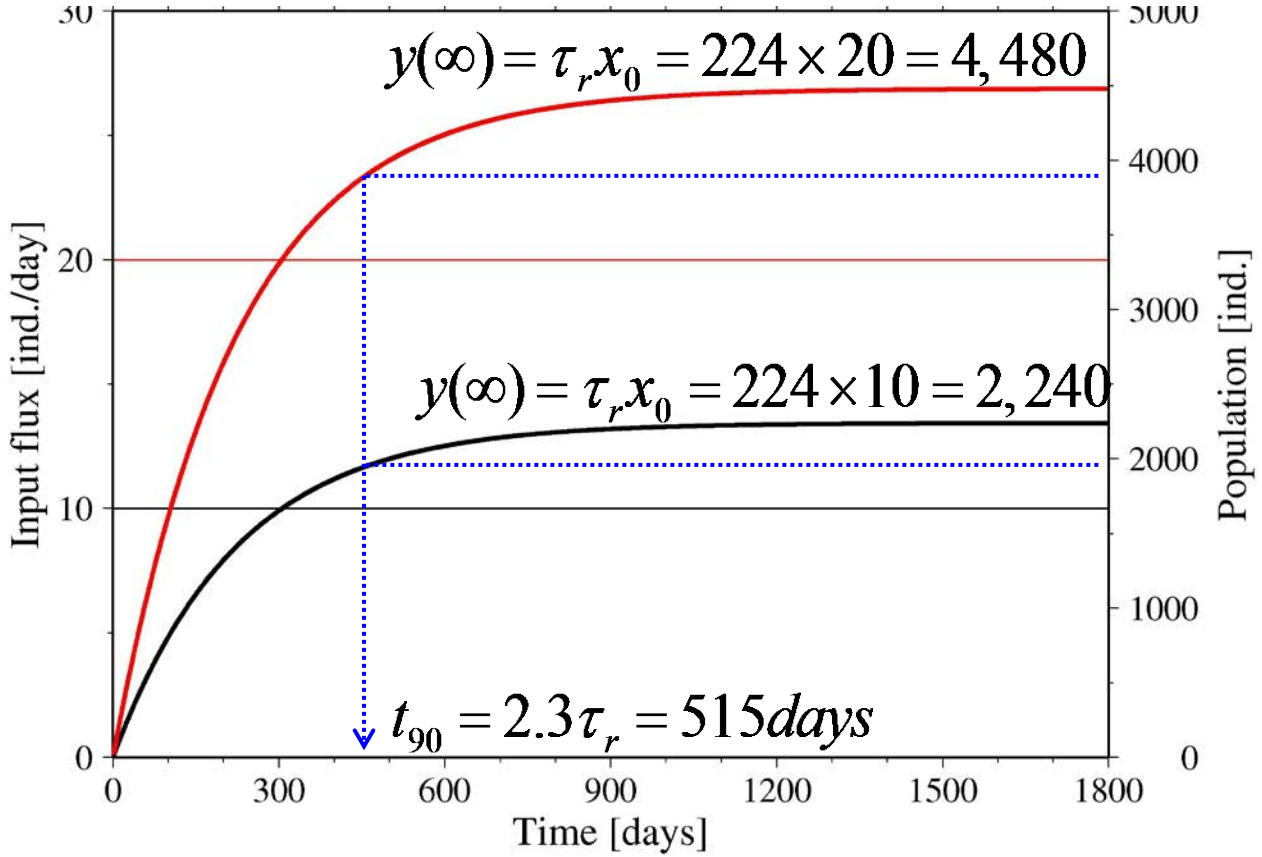
Amplitude and Phase Characteristics



(Residence time/Input period)

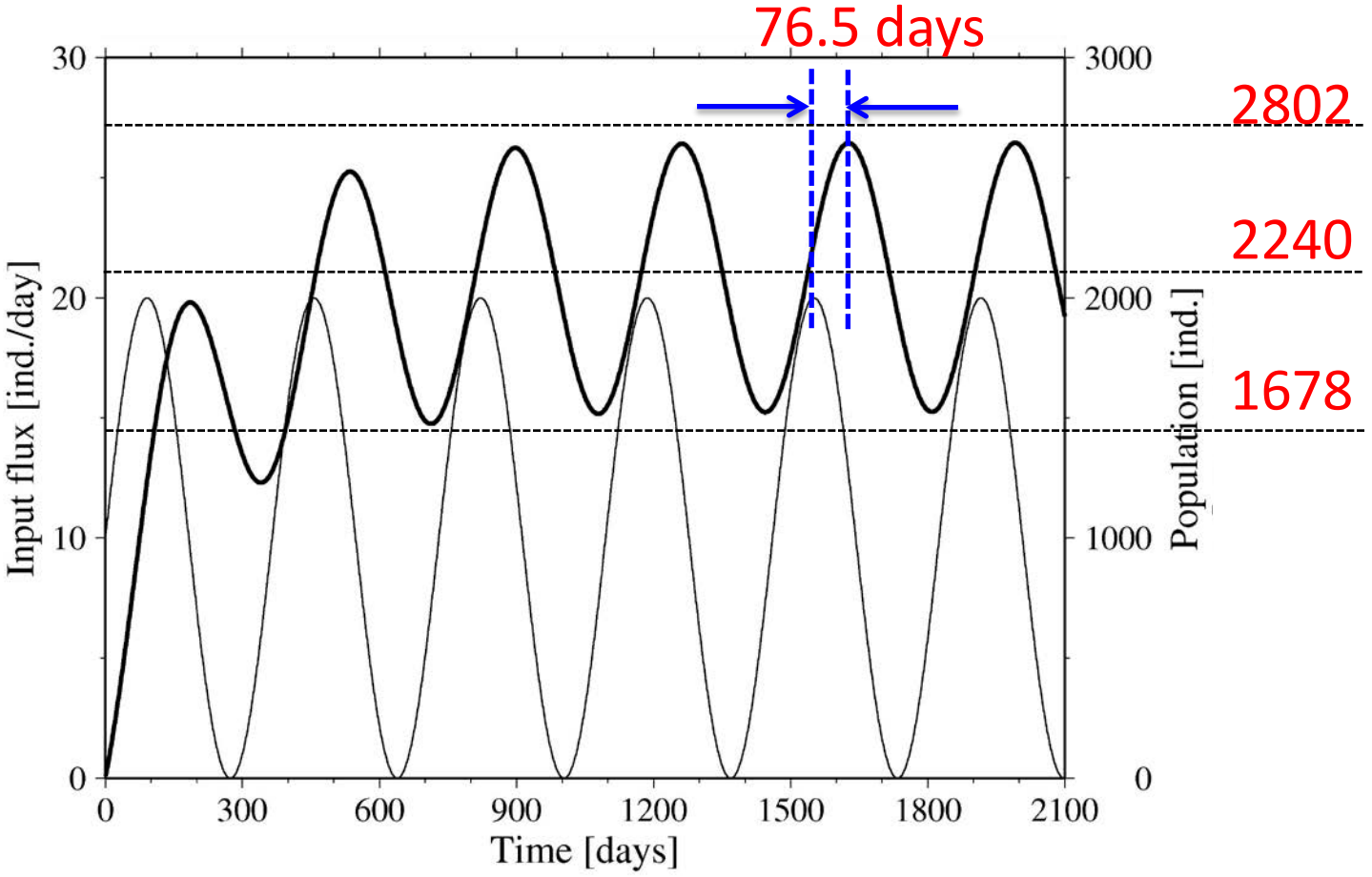
Wadahama Beach Response to Constant Input

$$y(t) = \int_0^t x_0 e^{-(t-\tau)/\tau_r} d\tau = \tau_r x_0 \left[1 - \exp\left(-\frac{t}{\tau_r} \right) \right] \Rightarrow y(t) = \tau_r x_0$$



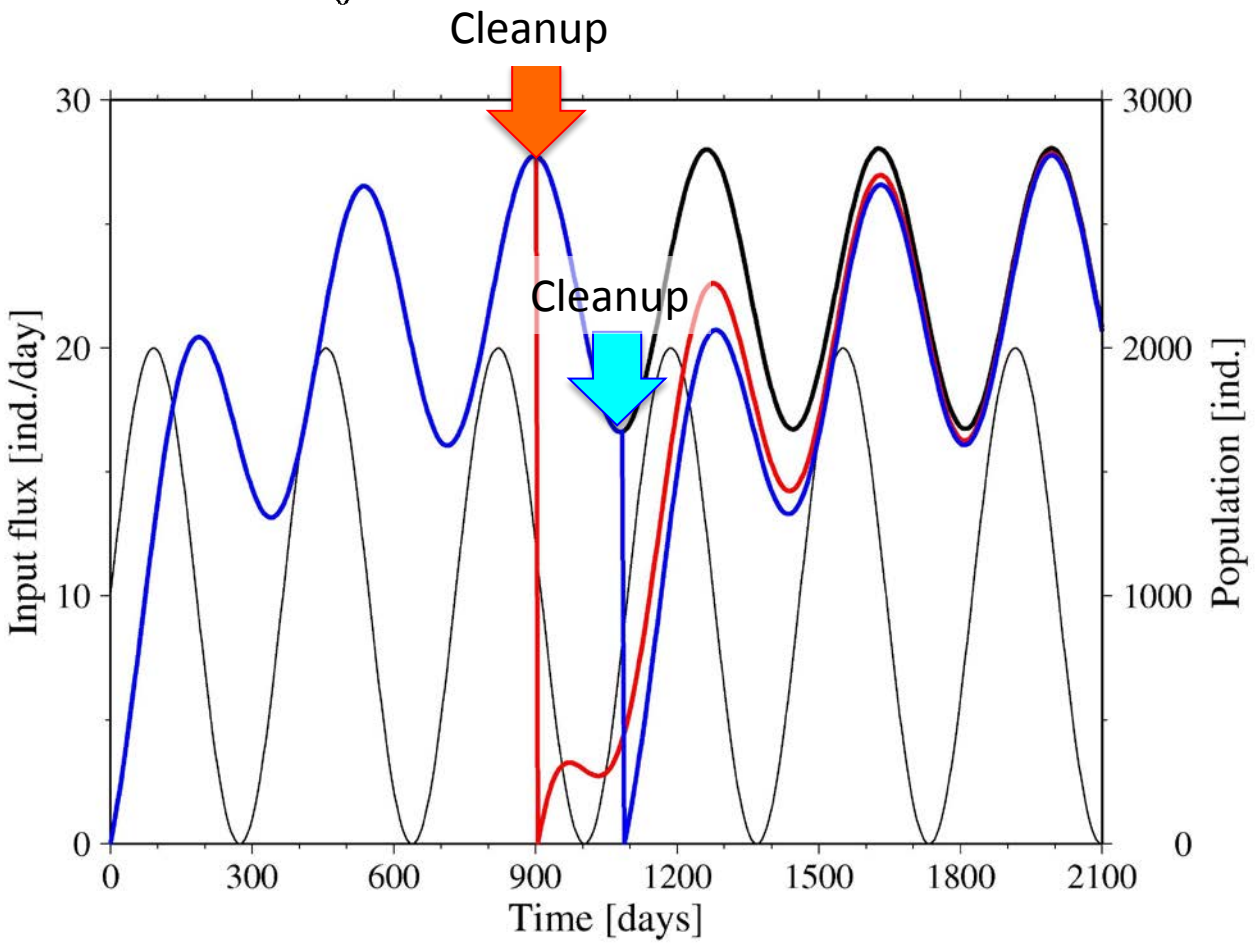
Beach Response to Constant + Sinusoidal Input

$$y(t) = \int_0^t \{10 + 10\sin(2\pi t/365)\} e^{-(t-\tau)/\tau_r} d\tau$$



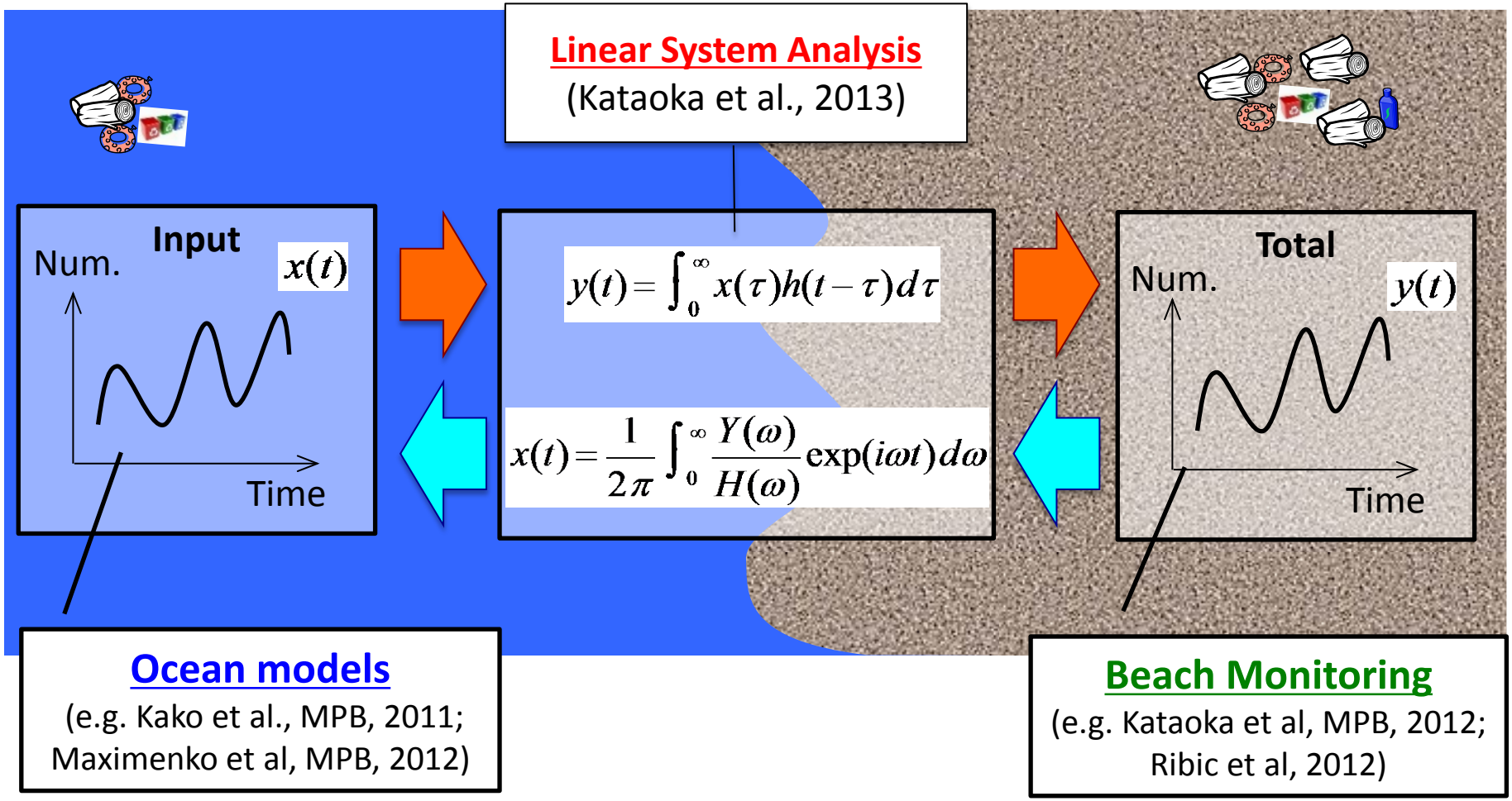
Beach Response to Cleanups

$$y(t) = \int_0^t \{10 + 10\sin(2\pi t/365)\} e^{-(t-\tau)/\tau_r} d\tau$$



Linear System Analysis

➔Mediator between Ocean Models and Beach Monitoring



Future work

It is not realistic to conduct long-term MR experiments of all beaches involving human effort.

➔ We are developing a mathematical model of residence time as a function of hydro statistics, so that we will be able to produce a residence time map for a region of interest with much less effort.

➔The map would allow us to assess the impacts of marine litter caused by natural disasters and/or loss of flow accidents on beaches and to take measures to minimize the overall damage in the region.

Characteristics of Wadahama Beach System

Frequency Response (FR)

$$H(\omega) = \int_0^{\infty} h(t)\exp(-i\omega t)dt.$$

Amplification Characteristics

$$A(\omega) = \left|H(\omega)\right|$$

Phase Characteristics

$$\theta(\omega) = \tan^{-1}\frac{im\left(H(\omega)\right)}{re\left(H(\omega)\right)}$$