Effects of Hull Coatings & Hull Cleaning Practices on Fouling Organisms
(Southern & South-Central California Ecological Research)

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IACC Marina & AFS Webinar Sep. 18, 2013

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Changes Facing West Coast Boaters

• CA SWRCB requires that copper discharged from AF paints in Shelter Island Yacht Basin of San Diego Bay be reduced by 75% during 2007-2022 (TMDL Regulatory Program)
• RWQCBs are concerned re: elevated Cu in other San Diego Bay locations, in Newport Bay and Marina Del Rey
• Statewide restrictions may or may not be implemented in CA
• WA law restricts Cu antifouling paint to low level
The California Aquatic Invasive Species (AIS) Management Plan

Strategy 2c: Recreation

Calls for limiting new AIS introductions through recreational boating, fishing, diving and other water-based activities.

Transport of AIS

Interfere with boating activities
Potential impacts on natives

Outcompete natives for space and food

Often more copper-tolerant

Transport ‘hitch-hikers’

Threat to kelp beds & Island ecosystems

Encrusting bryozoan
*Watersipora subtorquata*

Sea squirts – *Ciona* spp.

Tube worms – *Hydroides* spp.

Asian kelp
*Undaria pinnatifida*
Transport of AIS

Sargassum horneri

2003: Long Beach Harbor
Now: Santa Cruz Island south to Isla Natividad, Baja California

Research diver, Lindsey Marks, next to S. horneri

S. horneri at Catalina Island

Juvenile, S. horneri

Adult, S. horneri
Balanced Approach

Boat Operations & Ecosystem Health

Performance and Efficiency

Water Quality and Non-native Invasive Species
Managing Hull Fouling

IPM for Boats in Harbors

- Use multiple tactics
- Target multiple life stages
- Adaptively manage

Not a one size fits all!
Strategy adapted to boater’s situation
Chemical Control

Antifouling Paints and Coatings

Toxic Paints
Reduce fouling (not 100%)
- Copper-based
- Zinc-based
- Short-lived organic

Biocide-Free Coatings
Restrict water penetration, not fouling
- Epoxy ceramic (epoxy)
- Siliconized epoxy (slick)
- and others
Research Questions

• How does the **coating type** applied to a boat affect recruitment of fouling organisms, particularly non-native invasive species?

• How effective is **copper**-based AF paint in the **long term**?
Two Study Sites
Santa Barbara Harbor (Blue dot)
4 locations x 4 replicates = 16 stations
San Diego Bay (Pink dot)
3 locations x 4 replicates = 12 stations
Coating Types (n=4) (all black)

Gel (G): Cook’s Composites Polyester Gel
Epoxy (E): CeRam-Kote Biocide-Free Ceramic-Epoxy
Slick (S): Eco-5 Marine Biocide-Free Siliconized Epoxy
Copper (C): Interlux Epoxy Modified AF

Time Period: monthly intervals, one year (April-March)

Recruitment Measurements: Percentage of cover

Counts (non-colonial)
More than 30 spp.; 8 phyla
12 non-native, 11 native, 1 cryptogenic, 11 unresolved

- Non-natives
  - Tube worms
  - Tunicates (colonial and non-colonial)
  - Bryozoans (encrusting, branching)

- Several spp. with unresolved taxonomy
  - Encrusting bryozoans
  - Green algae
  - *Spirorbid* tube worms
Copper-based Antifouling Paint

Fouling extremely low (1-month intervals on new copper paint)

7 organisms:

- *Hydroides elegans, Diplosoma listerianum (NN)*
- Tubes of *Laticorophium baconi (cryptogenic)*
- *Spirorbid* sp., *Cladophora* sp. and *Enteromorpha* sp. (unresolved taxonomy)
- Unidentified sabellid worm (most likely *Pseudopotamilla* sp.)

Copper panels dropped from analyses
### Results

**Biocide-Free Coatings**

<table>
<thead>
<tr>
<th>Location</th>
<th>Effect</th>
<th>Wilks’ value</th>
<th>F</th>
<th>P</th>
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</thead>
<tbody>
<tr>
<td>Santa Barbara</td>
<td>Hull Coating</td>
<td>0.684</td>
<td>1.06</td>
<td>0.395</td>
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<tr>
<td>San Diego</td>
<td>Hull Coating</td>
<td>0.327</td>
<td>2.68</td>
<td>&lt;0.001</td>
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</table>

### San Diego

<table>
<thead>
<tr>
<th>Dependent Variable</th>
<th>Coating</th>
<th>F</th>
<th>P</th>
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<tr>
<td><em>Cladophora</em> sp.</td>
<td>0.51</td>
<td>0.602</td>
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<td><em>Botryllloides violaceus</em></td>
<td>1.78</td>
<td>0.178</td>
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<tr>
<td><em>Botryllus schlosseri</em></td>
<td>2.46</td>
<td>0.095</td>
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<td><em>Diplosoma listerianum</em></td>
<td>0.87</td>
<td>0.425</td>
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<tr>
<td><em>Ciona</em> spp.</td>
<td>0.11</td>
<td>0.900</td>
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<tr>
<td>Bugula neritina</td>
<td>1.52</td>
<td>0.229</td>
<td></td>
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<tr>
<td><em>Watersipora subtorquata</em></td>
<td>9.22</td>
<td>&lt;0.001</td>
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<tr>
<td><em>Cryptosula pallasiana</em></td>
<td>1.91</td>
<td>0.157</td>
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<tr>
<td>Amphipod tube mat</td>
<td>0.58</td>
<td>0.561</td>
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<tr>
<td><em>Hydroides</em> spp.</td>
<td>4.08</td>
<td><strong>0.022</strong></td>
<td></td>
</tr>
<tr>
<td><em>Filograna implexa</em></td>
<td>2.04</td>
<td>0.140</td>
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<tr>
<td>Spirorbid worm</td>
<td>1.66</td>
<td>0.200</td>
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</table>
Results
Biocide-Free Coatings

*Hydroides* spp.: Higher fouling on epoxy tiles as compared to slick

*Watersipora subtorquata*: Higher fouling on slick and epoxy tiles as compared to gel
Long-Term Copper Exposure Experiment

How effective is copper-based AF paint in the long term?

Do non-native species settle sooner than natives?

Do non-native species occupy more space over time than natives?
Long-Term Copper Exposure Experiment

Methods

1 Site, 2 Locations, 8 Stations

San Diego Bay (Pink dot)
Half Moon Anchorage (inner)
Kona Kai Marina (outer)

Dissolved copper levels substantially higher at inner location.
Long-Term Copper Exposure Experiment

Methods

Exposure Times (n=3)
3, 6, 12 months

Time Period
One year (July-June)

Recruitment Measurements
Percentage of cover, counts (non-colonial organisms)

Dock
15 x 15 cm fiberglass panels
1 m
## Long-Term Copper Exposure Experiment Results

Many more organisms (22 spp.; 6 phyla) than on new copper exposed for 1 month

**Common:** 5 non-native (O), 2 native (G), 1 cryptogenic (Y), 1 unr (P)

<table>
<thead>
<tr>
<th>Taxa</th>
<th>Species</th>
<th>Origin</th>
<th>1 mo</th>
<th>3 mo</th>
<th>6 mo</th>
<th>12 mo</th>
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<tr>
<td><strong>Algae</strong></td>
<td><em>Cladophora sp.</em></td>
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<tr>
<td></td>
<td><em>Colpomenia sp.</em></td>
<td>Unr</td>
<td></td>
<td>x</td>
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<tr>
<td></td>
<td><em>Enteromorpha sp.</em></td>
<td>Unr</td>
<td>x</td>
<td></td>
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<tr>
<td></td>
<td><em>Green monofilament</em></td>
<td>UnID</td>
<td></td>
<td></td>
<td>x</td>
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<tr>
<td></td>
<td>Rhodymenia californica</td>
<td>N</td>
<td></td>
<td>x</td>
<td>x</td>
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<tr>
<td><strong>Polychaeta</strong></td>
<td>Filograna implexa</td>
<td>NN</td>
<td></td>
<td></td>
<td>x</td>
<td>x</td>
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<tr>
<td></td>
<td>Hydroides spp. complex</td>
<td>NN/N</td>
<td></td>
<td>x</td>
<td>x</td>
<td>x</td>
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<tr>
<td></td>
<td>H. elegans, H. gracilis</td>
<td></td>
<td>X</td>
<td>x</td>
<td>x</td>
<td>x</td>
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<tr>
<td></td>
<td>Sabellid</td>
<td>Unr</td>
<td>x</td>
<td></td>
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<tr>
<td></td>
<td>Spirorbis sp.</td>
<td>Unr</td>
<td></td>
<td>x</td>
<td>x</td>
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<tr>
<td><strong>Chordata</strong></td>
<td>Aplidium californicum</td>
<td>N</td>
<td></td>
<td></td>
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<td>x</td>
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<td></td>
<td><em>Botrylloides diegensis</em></td>
<td>N</td>
<td></td>
<td></td>
<td></td>
<td>x</td>
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<tr>
<td></td>
<td><em>Botrylloides violaceus</em></td>
<td>NN</td>
<td></td>
<td></td>
<td></td>
<td>x</td>
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<tr>
<td></td>
<td><em>Ciona sp.</em></td>
<td>NN</td>
<td></td>
<td></td>
<td></td>
<td>x</td>
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<tr>
<td></td>
<td>C. intestinalis or C. savignyi</td>
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<td></td>
<td>Diplosoma listerianum</td>
<td>NN</td>
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<td>x</td>
<td>x</td>
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<tr>
<td><strong>Crustacea</strong></td>
<td>Laticorophium baconi (tubes)</td>
<td>C</td>
<td></td>
<td>x</td>
<td>x</td>
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<tr>
<td><strong>Ectoprocta</strong></td>
<td>Bowerbankia sp.</td>
<td>Unr</td>
<td></td>
<td>x</td>
<td>x</td>
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<td></td>
<td>Bugula californica</td>
<td>N</td>
<td></td>
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<tr>
<td></td>
<td>Bugula neritina</td>
<td>NN</td>
<td></td>
<td></td>
<td>x</td>
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<td></td>
<td><em>Celleporaria brunnea</em></td>
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<td>x</td>
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<td></td>
<td><em>Crisulipora occidentalis</em></td>
<td>N</td>
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<td>x</td>
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<td></td>
<td><em>Cryptosula pallasiana</em></td>
<td>NN</td>
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<td></td>
<td></td>
<td>x</td>
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<td></td>
<td><em>Thalamoporella californica</em></td>
<td>N</td>
<td></td>
<td></td>
<td></td>
<td>x</td>
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<tr>
<td></td>
<td>Watersipora subtorquata</td>
<td>NN</td>
<td></td>
<td></td>
<td>x</td>
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<tr>
<td><strong>Porifera</strong></td>
<td><em>Sponge</em></td>
<td>UniID</td>
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</table>
Non-native tube worms showed up early but not detected with percentage of cover, only with counts.
Increased fouling at longer exposures (6, 12 months)

- Non-natives appear sooner
- Non-natives occupy more space

Panel with copper antifouling paint after 12 months in San Diego Bay
Copper-Tolerant Species

- Selectivity of non-native species
  Attach directly to copper antifouling paint
- Provide biocide-free refuge for sensitive species
  Facilitate transport of other species

Other supporting evidence in the scientific literature
Conclusions

• There are risks of transporting AIS via boats with copper-based paints, particularly w/ increased time (selectivity, persistence)

• Higher risk of transporting AIS on boats with biocide-free coatings

• Higher risk for transporting certain AIS on boats with certain biocide-free coatings (e.g., *Hydroides* tube worms)
NIS Risks from Recreational Boat Traffic: CA and Baja CA Peninsula*

Overnight Visitors

- Races, tournaments, holidays, vacation
- 3,000 mi (5,000 km) coast
- Heaviest boat traffic
  - So. Cal ↔ Baja Cal Peninsula, SF Bay
  - Central Coast → SF Bay
  - Delta → SF Bay (salinity change, less risk)
  - North Coast → Central Coast, Delta, So. Cal

Resident Boats

- Yet, 48% of boats rarely leave marina

**Recommendations**

For boats **often** used that travel **far** from home port

- Consider copper-based or alternative toxic paints, especially for hard to clean areas
- Keep boat in well flushed area of harbor

For boats **seldom** used that stay **near** home port

- Consider biocide-free coatings
- Exception: travel to nearby islands!

**For ALL Boats**

Need to use **additional tactics** (e.g., hull cleaning) to improve boat operations and to reduce potential spread of non-native invasive species
“Beyond Paint” – **Other Tactics for Fouling IPM**

- **Physical**:
  - Trailer: OK for small boats
  - Boat “barn”: rare CA coast – waterfront space $$$$
  - Boat lift: OK in 45% CA & 38% Baja CA marinas*
  - Slip liner: OK in 47% CA & 88% Baja CA marinas*

- **Mechanical**
  - In-water hull cleaning

- **Cultural**
  - Timing & frequency of cleaning re: fouling recruitment

Part II: The Role of Hull CLEANING
GOAL: Balanced Approach

**Ecosystem Health** & **Boat Operations**

*Water quality & Aquatic invasive species (AIS)*

**Fouling control & Cost effectiveness**

Research-based information is needed to support:

Sound decisions
Sustainable policies
“Beyond Paint” – Other Tactics for Fouling IPM

- **Physical:**
  - Trailer: OK for small boats
  - Boat “barn”: rare CA coast – waterfront space $$$$
  - Boat lift: OK in 45% CA & 38% Baja CA marinas*
  - Slip liner: OK in 47% CA & 88% Baja CA marinas*

- **Mechanical**
  - In-water hull cleaning

- **Cultural**
  - Timing & frequency of cleaning re: fouling recruitment

Research Questions

① Does in-water hull cleaning, using California Best Management Practices (BMPs), stimulate fouling growth?

② Do fouling organisms, particularly non-native invasive species have recruitment peaks that could be useful in scheduling control tactics?
Hull Cleaning Experiment

Australian research:¹,²
In-water hull cleaning increases the susceptibility of vessel hulls to fouling
- Disturbance Hypothesis (space)
- Settlement Cues

Methods:
- Fouled 7 months
- Cleaned with a paint scraper
- Some sterilized, some not
- Returned to water for 2 and 6.5 wks
  - (visiting boat residence times)

California Hull Cleaning BMPs

California Professional Divers Association (CPDA):
Clean frequently with least abrasive tool possible

- **San Diego Bay** – CPDA-recommended hull cleaning frequencies
  - *Copper*-based paints – 13 times/year
  - *Biocide-Free* hull coatings – 26 times/year

- Mean **regional** hull cleaning frequencies for *Copper*-based paints:*
  - 4 times/year in northern CA
  - 12 times/year in southern CA
  - 16 times/year in Baja CA

Soft-bristled, powered brushes

Hand-held pads

Green 3M™ pad - Level 2

White 3M™ pad - Level 1

Shag Carpet - Level 1

Gentle Hull Cleaning Tools
Study Locations

Three Sites:
Santa Barbara Harbor (4 stations)
San Diego Bay (8 stations)
Half Moon Anchorage and Kona Kai Marina
In-Water Hull Cleaning Experiment - Methods

3 panel types:
- Biocide-Free epoxy coating
- Biocide-Free slick coating
- Copper antifouling (AF) paint

3 cleaning treatments:
First 3 months:
- Frequently cleaned (BMPs)
  - Biocide-Free coatings – every 2 weeks
  - Copper AF paint – every 3 weeks
- Not cleaned in first 3 months

4th month:
- All cleaned and returned to water
- New (never cleaned) added

Tools: Carpet; White or Green hand-held pads

Time Period:
Peak “recruitment” period (July-Oct)
Fouling Biomass:

✓ Coating type & geography matter
✓ Cleaning does not matter

ANOVA

<table>
<thead>
<tr>
<th>Variable</th>
<th>F Value</th>
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<tr>
<td>*Location</td>
<td>28.51</td>
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<tr>
<td>*Panel type</td>
<td>50.84</td>
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<tr>
<td>Cleaning treatment</td>
<td>2.56</td>
<td>0.0829</td>
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*statistically significant results
Frame #34 - Kona Kai Marina, San Diego, CA

Multiple cleanings for 3 mos.  Single cleaning after 3 mos.  Never cleaned/new for mo. 4
All Locations

**Epoxy** - Multiple Cleanings

Kona Kai Marina, San Diego

Half Moon Anchorage
San Diego

Santa Barbara Harbor
Frequent cleanings:

- Less effort (fewer, smaller organisms)
- Less abrasive tool → Longer life of coatings
- Fewer deep scratches and chipping; left over ‘parts’
- Fouling growth less developed, so less risk of transporting reproductive individuals:
Recruitment Patterns - Pulse

Filograna implexa
Note Scale

San Diego Bay

Santa Barbara Harbor

Month

Number of individuals

Recruitment Patterns - Pulse

Filograna implexa
Note Scale

San Diego Bay

Santa Barbara Harbor

Month

Number of individuals
Recruitment Patterns – Year-Round

**Spirorbid sp.**

Shelter Island Yacht Basin

Santa Barbara Harbor

**Note Scale**

- Gel
- Epoxy
- Slick
- Copper

Number of individuals vs. Month
Other Factors to Consider in Integrated Approach

- Time of the Year (Season)
- Harbor Location (geography)
- Slip Location
  - Water flow
  - Sunny vs shady
  - Nearby sources of fouling species
Summary of Coating & Cleaning Results

- Paint/coating type and age important
- Location important
- California hull cleaning BMPs (frequent and gentle) do not stimulate new fouling
- Fouling recruitment peaks matter when scheduling toxic hull coating applications and cleaning
Create Integrated Pest Management (IPM) strategy via a suite of fouling control tactics

Choose hull coating to suit boat’s travel pattern

- **Biocide-Free** hull coatings for boats that rarely leave home (50%)
- **Toxic** hull coatings for boats that go far or often

Locate boat according to hull coating

- **Toxic** hull coatings in well-flushed areas
Recommendations

Clean before you leave/Clean before you return!

- Clean hull **before departing** to other region, island, or event

- Clean hull **again before moving on** or returning home
  - Consider location, exposure time, season

- If boat is kept in or visits a **major port**, be especially diligent about cleaning the hull before departing

- Upon arrival, **haul and clean heavily fouled hulls**
  - Contain and dispose removed fouling **on land**

- In other words........
Coastal Resources website [http://ucanr.edu/sites/coast](http://ucanr.edu/sites/coast)

- **IPM for Boats: Integrated Pest Management for Hull Fouling in Southern California Coastal Marinas** (28p)
  (IPM strategies & tactics + ecological, coatings & cleaning research)

- **Crossing Boundaries: Managing Invasive Species and Water Quality Risks for Coastal Boat Hulls in California and Baja California** (16p)
  (supplies/services; costs/availability; boater behavior)

- **Hull Fouling and Copper Tolerance – 2011 Scientific Review** (4p)
  (English y Español)

- And many short publications in English y en Español

Boating Environmental Forum blogsite [http://ucanr.edu/blogs/BoatingEnvironmentalForum/](http://ucanr.edu/blogs/BoatingEnvironmentalForum/)

Leigh Johnson  ltjohnson@ucanr.edu
Focus: QZM (broadly applicable to AIS eradication & control)

Workshop materials
- Agenda
- Extended abstracts

Information Sheets
- Individual strategies & other info
- Combined in Technical Report
- References & Weblinks

Carolynn Culver  cculver@ucsd.edu
http://ca-sgep.ucsd.edu/quaggazebra_mussel_control
Acknowledgments

CA Department of Boating and Waterways
University of California Cooperative Extension
California Sea Grant Extension Program
Counties of San Diego, Ventura, Santa Barbara
Santa Barbara Harbor * Half Moon Anchorage
Kona Kai Marina * Southwestern Yacht Club

Field & Laboratory Assistants and Volunteers
San Diego: Scott Parker, Gary Tanizaki, Debbie McAdams
Santa Barbara: Nick Schooler, Suzanne Iwanicki, Kara Ohlinger,
Alena Kahn and more…

Thank You!

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