1. Environmental Setup

In [1]:
```
# ============================================================================
# 1. Load Libraries
# ============================================================================
import os
import rasterio
import pandas as pd
import numpy as np
import matplotlib.pyplot as plt
import matplotlib as mpl
import matplotlib.patches as mpatches
import matplotlib.colors as mcolors

from matplotlib.colors import ListedColormap, BoundaryNorm
from matplotlib.ticker import FuncFormatter
from matplotlib_scalebar.scalebar import ScaleBar
from matplotlib_map_utils import north_arrow

from pyproj import Transformer
from rasterio.enums import Resampling
```

In [2]:
```
# ============================================================================
# 2. Set the parameters
# ============================================================================

# Input raster maps:
path_series_x = r"C:\Temp\PIE\8bits\pixelBased"
path_series_y = r"C:\Temp\PIE\8bits\objectBased"
time_points = [2010, 2012, 2014, 2016, 2018, 2021]
class_name = "PIE"

# path_series_x = r"C:\Users\AntFonseca\github\compare-time-series\input\collection6"
# path_series_y = r"C:\Users\AntFonseca\github\compare-time-series\input\collection8"
# time_points = [1990, 1995, 2000, 2005, 2010, 2015, 2020]
# class_name = "savanna"

# path_series_x = r"C:\Users\AntFonseca\github\compare-time-series\input\toydata\x"
# path_series_y = r"C:\Users\AntFonseca\github\compare-time-series\input\toydata\y"
# time_points = [0, 1, 2]
# class_name = "toydata"

# Output folder
output_path = r"C:\Temp\PIE\output"
if not os.path.exists(output_path):
    os.makedirs(output_path)

# NoData values
nodata_value = -1

print("✅ Parameters successfully defined.")
```

```
✅ Parameters successfully defined.
```

2. Metrics

2.1 Presence

Calculate metrics

In [ ]:

```
# ==============================================================================
# 1. Function for calculating Presence metrics
# ==============================================================================

def calculate_presence_metrics(file_x, file_y):
    """
    Calculates presence agreement metrics for a single time point.
    """
    with rasterio.open(file_x) as src_x, rasterio.open(file_y) as src_y:
        array_x = src_x.read(1)
        array_y = src_y.read(1)
        valid_mask = (array_x != nodata_value) & (array_y != nodata_value)
        presence_x = array_x[valid_mask]
        presence_y = array_y[valid_mask]

        hits = np.sum(np.minimum(presence_x, presence_y))
        total_x = np.sum(presence_x)
        total_y = np.sum(presence_y)

        hits = hits.astype(np.int64)
        total_x = total_x.astype(np.int64)
        total_y = total_y.astype(np.int64)

        space_difference = np.minimum(total_x, total_y) - hits
        misses = np.maximum(0, total_x - total_y)
        false_alarms = np.maximum(0, total_y - total_x)

        return {
            "Hit": hits, "Miss": misses, "False Alarm": false_alarms,
            "Space Difference": space_difference, "Total X": total_x, "Total Y": total_y
        }

results_by_time = {}
print("Starting time series processing...")
for year in time_points:
    # Build the file name based on the standardized pattern: {class}{year}.tif
    file_name = f"{class_name}{year}.tif"
    file_x = os.path.join(path_series_x, file_name)
    file_y = os.path.join(path_series_y, file_name)

    # Check that both files exist before processing
    if os.path.exists(file_x) and os.path.exists(file_y):
        print(f"Processing: {file_name}...")
        results_by_time[year] = calculate_presence_metrics(file_x, file_y)
    else:
        print(f"Warning: File '{file_name}' not found in either folder. Skipping.")

sum_results = {
    "Hit": 0, "Space Difference": 0, "Total X": 0, "Total Y": 0
}

# Sum the components of Hit, Space Difference, and Totals for all ytime points.
for year in results_by_time:
    sum_results["Hit"] += results_by_time[year]["Hit"]
    sum_results["Space Difference"] += results_by_time[year]["Space Difference"]
    sum_results["Total X"] += results_by_time[year]["Total X"]
    sum_results["Total Y"] += results_by_time[year]["Total Y"]

# Calculate Time Difference
sum_results["Time Difference"] = (
    np.minimum(sum_results["Total X"], sum_results["Total Y"])
    - sum_results["Hit"]
    - sum_results["Space Difference"]
)
```

```python
# Calculates Miss and False Alarm for the "Sum" bar based on the overall totals.
sum_results["Miss"] = np.maximum(0, sum_results["Total X"] - sum_results["Total Y"])
sum_results["False Alarm"] = np.maximum(0, sum_results["Total Y"] - sum_results["Total X"])

print("\n✅ Calculations for Presence Agreement are complete.")
```

Plot the graphic

In [ ]:
```python
# ============================================================================
# 2. Making the graphic
# ============================================================================
print("\nMaking the graphic...")

mpl.rcParams['font.family'] = 'serif'

labels = [str(tp) for tp in time_points] + ["Sum"]
hits = [results_by_time.get(tp, {}).get("Hit", 0) for tp in time_points] + [sum_results["Hit"
space_diff = [results_by_time.get(tp, {}).get("Space Difference", 0) for tp in time_points] +
time_diff = [0] * len(time_points) + [sum_results["Time Difference"]]
misses = [results_by_time.get(tp, {}).get("Miss", 0) for tp in time_points] + [sum_results["M
false_alarms = [results_by_time.get(tp, {}).get("False Alarm", 0) for tp in time_points] + [s
reference_line = [results_by_time.get(tp, {}).get("Total X", 0) for tp in time_points]
comparison_line = [results_by_time.get(tp, {}).get("Total Y", 0) for tp in time_points]

fig, ax = plt.subplots(figsize=(14, 8))

bottom = np.zeros(len(labels))

ax.axhline(
    0,
    color='black',
    linewidth=0.8
)
ax.bar(labels,
       hits,
       label='Hit',
       color='black',
       bottom=bottom);bottom += np.array(hits)
ax.bar(labels,
       space_diff,
       label='Space Difference',
       color='grey',
       bottom=bottom); bottom += np.array(space_diff)
ax.bar(labels,
       time_diff,
       label='Time Difference',
       color='lightgray',
       bottom=bottom); bottom += np.array(time_diff)
ax.bar(labels,
       misses,
       label='Miss',
       color='white',
       edgecolor='black',
       hatch='\\\\\\',
       bottom=bottom);bottom += np.array(misses)
ax.bar(labels,
       false_alarms,
       label='False Alarm',
       color='white',
       edgecolor='black',
       hatch='///',
       bottom=bottom)
ax.plot(labels[:-1],
        reference_line,
        's-g',
```

```python
        label='Pixel-based',
        linewidth=2,
        markersize=8)
ax.plot(labels[:-1],
        comparison_line,
        'd--y',
        label='Object-based',
        linewidth=2,
        markersize=8)

handles, labels_list = ax.get_legend_handles_labels()
order = ["Pixel-based",
         "Object-based",
         "Miss",
         "False Alarm",
         "Time Difference",
         "Space Difference",
         "Hit"]

legend_dict = dict(zip(labels_list, handles))
ordered_handles = [legend_dict[label] for label in order]
ordered_labels = order
ax.legend(ordered_handles,
          ordered_labels,
          loc='center left',
          bbox_to_anchor=(1, 0.5),
          frameon=False)

ax.set_title('Time Points and Sum',
             fontsize=14)
ax.set_xlabel('Time Point',
              fontsize=12)

# ============================================================================
# --- y-axis scale settings (choose one option) ---
# ============================================================================

# --- Option 1: For 'toy_data' or data with small values ---
# ax.set_ylim(-6, 6)
# ax.set_ylabel(
#     'Presence',
#     fontsize=12
# )

# # --- Option 2: For real data with large values (e.g., MapBiomas) ---
def millions_formatter(y, pos):
    """Formats the y-axis tick by dividing by 1 million."""
    return f'{y / 1_000_000:.0f}'
ax.yaxis.set_major_formatter(FuncFormatter(millions_formatter))
# ax.set_ylim(-25_000_000, 10_000_000) # Optional: uncomment to set manual limits
ax.set_ylabel(
    'Presence (Million pixels)',
    fontsize=12
)

# ============================================================================

plt.tight_layout(rect=[0, 0, 0.85, 1])

output_filename = f'presence_agreement_{class_name}_graphic.png'
final_chart_path = os.path.join(output_path,
                                 output_filename)

plt.savefig(final_chart_path,
            dpi=300)
```

```python
plt.show()

print(f"\n✅Processing complete. Graphic saved as: {final_chart_path}")
```

2.2 Gross Change

Calculate metrics

In [ ]:
```python
# ============================================================================
# 1. Helper Function for Data Reading
# ============================================================================
print("Starting the Calculation of Gains and Losses...")

# Dictionary to store raster arrays and avoid re-reading in this cell
raster_arrays = {}

def get_raster_array(year):
    """
    Reads a pair of raster files (x and y) for a given year or returns it from the
    cache if it has already been read previously in this cell.
    """
    if year in raster_arrays:
        return raster_arrays[year]

    file_name = f"{class_name}{year}.tif"
    path_x = os.path.join(path_series_x,
                          file_name)
    path_y = os.path.join(path_series_y,
                          file_name)

    if not os.path.exists(path_x) or not os.path.exists(path_y):
        print(f"Warning: File '{file_name}' not found in either folder. Skipping.")
        return None, None

    print(f"Lendo do disco: {file_name}...")
    with rasterio.open(path_x) as src_x, rasterio.open(path_y) as src_y:
        array_x = src_x.read(1)
        array_y = src_y.read(1)
        raster_arrays[year] = (array_x, array_y)
        return array_x, array_y

print("\n✅ Calculations for Gains and Losses are complete.")
```

In [ ]:
```python
# ============================================================================
# 2. Function for calculating change metrics
# ============================================================================

def calculate_change_metrics(year_t, year_t_minus_1):
    """
    Calculates all gross change metrics (gains and losses) for a single time interval.

    This function compares the raster maps from the start and end of an interval
    to compute the components of gross change, such as Gain Hit, Loss Hit,
    Gain Space Difference, etc., according to the article's equations.
    """
    array_x_t, array_y_t = get_raster_array(year_t)
    array_x_t_minus_1, array_y_t_minus_1 = get_raster_array(year_t_minus_1)

    if array_x_t is None or array_x_t_minus_1 is None:
        return None

    valid_mask = (
        (array_x_t != nodata_value) &
```

```python
        (array_y_t != nodata_value) &
        (array_x_t_minus_1 != nodata_value) &
        (array_y_t_minus_1 != nodata_value)
    )

    px_t = array_x_t[valid_mask].astype(np.int64)
    py_t = array_y_t[valid_mask].astype(np.int64)
    px_t_minus_1 = array_x_t_minus_1[valid_mask].astype(np.int64)
    py_t_minus_1 = array_y_t_minus_1[valid_mask].astype(np.int64)

    gain_x = np.maximum(0, px_t - px_t_minus_1)
    gain_y = np.maximum(0, py_t - py_t_minus_1)

    gain_total_x = np.sum(gain_x)
    gain_total_y = np.sum(gain_y)

    gain_hit = np.sum(np.minimum(gain_x, gain_y))
    gain_space_diff = np.minimum(gain_total_x, gain_total_y) - gain_hit
    gain_miss = np.maximum(0, gain_total_x - gain_total_y)
    gain_false_alarm = np.maximum(0, gain_total_y - gain_total_x)

    loss_x = np.minimum(0, px_t - px_t_minus_1)
    loss_y = np.minimum(0, py_t - py_t_minus_1)

    loss_total_x = np.sum(loss_x)
    loss_total_y = np.sum(loss_y)

    loss_hit = np.sum(np.maximum(loss_x, loss_y))
    loss_space_diff = np.maximum(loss_total_x, loss_total_y) - loss_hit
    loss_miss = np.minimum(0, loss_total_x - loss_total_y)
    loss_false_alarm = np.minimum(0, loss_total_y - loss_total_x)

    return {
        "Gain Hit": gain_hit,
        "Gain Miss": gain_miss,
        "Gain False Alarm": gain_false_alarm,
        "Gain Space Difference": gain_space_diff,
        "Loss Hit": loss_hit,
        "Loss Miss": loss_miss,
        "Loss False Alarm": loss_false_alarm,
        "Loss Space Difference": loss_space_diff,
        "Gain Total X": gain_total_x,
        "Gain Total Y": gain_total_y,
        "Loss Total X": loss_total_x,
        "Loss Total Y": loss_total_y
    }

def calculate_extent_metrics(time_points_list):
    """
    Calculates gross change metrics for the entire temporal extent.

    This function compares only the first and last time points of the series,
    ignoring all intermediate steps, to calculate the overall gross change
    components for the 'Extent' bar.
    """
    start_year, end_year = time_points_list[0], time_points_list[-1]

    array_x_start, array_y_start = get_raster_array(start_year)
    array_x_end, array_y_end = get_raster_array(end_year)

    if array_x_start is None or array_x_end is None:
        return None

    valid_mask = (
        (array_x_start != nodata_value) &
        (array_y_start != nodata_value) &
```

```python
        (array_x_end != nodata_value) &
        (array_y_end != nodata_value)
    )

    px_start = array_x_start[valid_mask].astype(np.int64)
    py_start = array_y_start[valid_mask].astype(np.int64)
    px_end = array_x_end[valid_mask].astype(np.int64)
    py_end = array_y_end[valid_mask].astype(np.int64)

    gain_x = np.maximum(0, px_end - px_start)
    gain_y = np.maximum(0, py_end - py_start)

    gain_total_x = np.sum(gain_x)
    gain_total_y = np.sum(gain_y)

    gain_hit = np.sum(np.minimum(gain_x, gain_y))
    gain_space_diff = np.minimum(gain_total_x, gain_total_y) - gain_hit
    gain_miss = np.maximum(0, gain_total_x - gain_total_y)
    gain_false_alarm = np.maximum(0, gain_total_y - gain_total_x)

    loss_x = np.minimum(0, px_end - px_start)
    loss_y = np.minimum(0, py_end - py_start)

    loss_total_x = np.sum(loss_x)
    loss_total_y = np.sum(loss_y)

    loss_hit = np.sum(np.maximum(loss_x, loss_y))
    loss_space_diff = np.maximum(loss_total_x, loss_total_y) - loss_hit
    loss_miss = np.minimum(0, loss_total_x - loss_total_y)
    loss_false_alarm = np.minimum(0, loss_total_y - loss_total_x)

    return {
        "Gain Hit": gain_hit,
        "Gain Miss": gain_miss,
        "Gain False Alarm": gain_false_alarm,
        "Gain Space Difference": gain_space_diff,
        "Loss Hit": loss_hit,
        "Loss Miss": loss_miss,
        "Loss False Alarm": loss_false_alarm,
        "Loss Space Difference": loss_space_diff
    }
```

In [ ]:

```python
# ==============================================================================
# 3. Calculating Metrics for Intervals and Extent
# ==============================================================================
change_results_by_interval = {}
time_intervals = []
print("Calculating change metrics for each interval...")
for i in range(1, len(time_points)):
    year_t, year_t_minus_1 = time_points[i], time_points[i-1]
    interval_label = f"{year_t_minus_1}-{year_t}"
    time_intervals.append(interval_label)
    print(f"Processing interval: {interval_label}...")
    change_results_by_interval[interval_label] = calculate_change_metrics(year_t, year_t_minu

print("Calculating metrics for temporal extension...")
extent_results = calculate_extent_metrics(time_points)

print("\n✅ Calculations for each time interval and temporal extension are complete.")
```

In [ ]:

```python
# ==============================================================================
# 4. Aggregating Results for the 'Sum' Bar
# ==============================================================================
sum_change_results = {
    "Gain Hit": 0,
```

```
    "Gain Space Difference": 0,
    "Gain Total X": 0,
    "Gain Total Y": 0,
    "Gain Time Difference": 0,
    "Loss Hit": 0,
    "Loss Space Difference": 0,
    "Loss Total X": 0,
    "Loss Total Y": 0,
    "Loss Time Difference": 0,
}

for interval in time_intervals:
    results = change_results_by_interval[interval]
    if results:
        for key in [
            "Gain Hit", "Gain Space Difference", "Gain Total X", "Gain Total Y",
            "Loss Hit", "Loss Space Difference", "Loss Total X", "Loss Total Y"
        ]:
            sum_change_results[key] += results[key]

sum_change_results["Gain Time Difference"] = (
    np.minimum(sum_change_results["Gain Total X"], sum_change_results["Gain Total Y"])
    - sum_change_results["Gain Hit"]
    - sum_change_results["Gain Space Difference"]
)

sum_change_results["Gain Miss"] = np.maximum(
    0, sum_change_results["Gain Total X"] - sum_change_results["Gain Total Y"]
)

sum_change_results["Gain False Alarm"] = np.maximum(
    0, sum_change_results["Gain Total Y"] - sum_change_results["Gain Total X"]
)

sum_change_results["Loss Time Difference"] = (
    np.maximum(sum_change_results["Loss Total X"], sum_change_results["Loss Total Y"])
    - sum_change_results["Loss Hit"]
    - sum_change_results["Loss Space Difference"]
)

sum_change_results["Loss Miss"] = np.minimum(
    0, sum_change_results["Loss Total X"] - sum_change_results["Loss Total Y"]
)

sum_change_results["Loss False Alarm"] = np.minimum(
    0, sum_change_results["Loss Total Y"] - sum_change_results["Loss Total X"]
)
```

Plot the graphic

In [ ]:

```
# ==============================================================================
# 5. making the graphic
# ==============================================================================
print("\nGenerating the Gains and Losses graphic...")

# --- prepare data for plotting ---
plot_data_list = []
for interval in time_intervals:
    row_data = change_results_by_interval.get(interval, {})
    row_data['Interval'] = interval
    plot_data_list.append(row_data)

sum_row_gross = sum_change_results.copy()
sum_row_gross['Interval'] = 'Sum'
plot_data_list.append(sum_row_gross)
```

```python
extent_row_gross = extent_results.copy()
extent_row_gross['Interval'] = 'Extent'
plot_data_list.append(extent_row_gross)

df_plot = pd.DataFrame(plot_data_list).set_index('Interval')
df_plot = df_plot.fillna(0)

# --- setup for the plot ---
labels = df_plot.index.tolist()

gain_colors = {
    'Hit': '#0070C0',
    'Space Difference': '#00B0F0',
    'Time Difference': '#BDD7EE',
    'Miss': 'white',
    'False Alarm': 'white'
}
loss_colors = {
    'Hit': '#C00000',
    'Space Difference': '#FF0000',
    'Time Difference': '#FF9696',
    'Miss': 'white',
    'False Alarm': 'white'
}
gain_hatch_color = '#0070C0'
loss_hatch_color = '#FF0000'

fig, ax = plt.subplots(
    figsize=(14, 8)
)
mpl.rcParams['font.family'] = 'serif'

# --- plotting gains ---
bottom_gain = np.zeros(len(labels))
for comp in [
    "Hit",
    "Space Difference",
    "Time Difference",
    "Miss",
    "False Alarm"
]:
    # Get original data with zeros for stacking calculations
    data = df_plot[f"Gain {comp}"].values

    if comp in ["Miss", "False Alarm"]:
        # Create a copy for plotting, replacing 0 with NaN
        plot_data = data.copy().astype(float)
        plot_data[plot_data == 0] = np.nan

        hatch = '///' if comp == 'False Alarm' else '\\\\\\'
        ax.bar(
            labels,
            plot_data,
            label=f'Gain {comp}',
            color='white',
            bottom=bottom_gain,
            edgecolor='black'
        )
        ax.bar(
            labels,
            plot_data,
            color='none',
            bottom=bottom_gain,
            edgecolor=gain_hatch_color,
            hatch=hatch
```

```
        )
    else:
        ax.bar(
            labels,
            data,
            label=f'Gain {comp}',
            color=gain_colors[comp],
            bottom=bottom_gain,
            edgecolor='none'
        )
    # Always update the bottom with the original data (containing zeros)
    bottom_gain += data

# --- plotting losses ---
bottom_loss = np.zeros(len(labels))
for comp in [
    "Hit",
    "Space Difference",
    "Time Difference",
    "Miss",
    "False Alarm"
]:
    # Get original data with zeros for stacking calculations
    data = df_plot[f"Loss {comp}"].values

    if comp in ["Miss", "False Alarm"]:
        # Create a copy for plotting, replacing 0 with NaN
        plot_data = data.copy().astype(float)
        plot_data[plot_data == 0] = np.nan

        hatch = '///' if comp == 'False Alarm' else '\\\\\\'
        ax.bar(
            labels,
            plot_data,
            label=f'Loss {comp}',
            color='white',
            bottom=bottom_loss,
            edgecolor='black'
        )
        ax.bar(
            labels,
            plot_data,
            color='none',
            bottom=bottom_loss,
            edgecolor=loss_hatch_color,
            hatch=hatch
        )
    else:
        ax.bar(
            labels,
            data,
            label=f'Loss {comp}',
            color=loss_colors[comp],
            bottom=bottom_loss,
            edgecolor='none'
        )
    # Always update the bottom with the original data (containing zeros)
    bottom_loss += data

# --- final graphic settings ---
ax.axhline(
    0,
    color='black',
    linewidth=0.8
)
ax.set_title(
```

```python
    'Gross Loss and Gain During Time Intervals',
    fontsize=14
)
ax.set_xlabel(
    'Time Interval',
    fontsize=12
)

# =============================================================================
# --- y-axis scale settings (choose one option) ---
# =============================================================================

# --- Option 1: For 'toy_data' or data with small values ---
# ax.set_ylim(-6, 6)
# ax.set_ylabel(
#     'Gross Loss and Gross Gain',
#     fontsize=12
# )

# # --- Option 2: For real data with large values (e.g., MapBiomas) ---
def millions_formatter(y, pos):
    """Formats the y-axis tick by dividing by 1 million."""
    return f'{y / 1_000_000:.0f}'
ax.yaxis.set_major_formatter(FuncFormatter(millions_formatter))
ax.set_ylim(-60_000_000, 60_000_000) # Optional: uncomment to set manual limits
ax.set_ylabel(
    'Gross Loss and Gross Gain (Million pixels)',
    fontsize=12
)

# =============================================================================

# --- logic to order the legend ---
handles, labels_list = ax.get_legend_handles_labels()
legend_dict = dict(zip(labels_list, handles))

legend_dict['Gain Miss'] = (
    mpatches.Patch(facecolor='white', edgecolor='black'),
    mpatches.Patch(facecolor='none', edgecolor=gain_hatch_color, hatch='\\\\\\')
)
legend_dict['Gain False Alarm'] = (
    mpatches.Patch(facecolor='white', edgecolor='black'),
    mpatches.Patch(facecolor='none', edgecolor=gain_hatch_color, hatch='///')
)
legend_dict['Loss Miss'] = (
    mpatches.Patch(facecolor='white', edgecolor='black'),
    mpatches.Patch(facecolor='none', edgecolor=loss_hatch_color, hatch='\\\\\\')
)
legend_dict['Loss False Alarm'] = (
    mpatches.Patch(facecolor='white', edgecolor='black'),
    mpatches.Patch(facecolor='none', edgecolor=loss_hatch_color, hatch='///')
)

order = [
    'Gain Miss', 'Gain False Alarm', 'Gain Time Difference',
    'Gain Space Difference', 'Gain Hit', 'Loss Miss', 'Loss False Alarm',
    'Loss Time Difference', 'Loss Space Difference', 'Loss Hit'
]

ordered_handles = [legend_dict.get(label) for label in order if label in legend_dict]
ordered_labels = [label for label in order if label in legend_dict]

legend = ax.legend(
    handles=ordered_handles,
    labels=ordered_labels,
    loc='center left',
```

```
    bbox_to_anchor=(1, 0.5),
    frameon=False,
    alignment='left'
)
legend.get_title().set_ha('left')
for text in legend.get_texts():
    text.set_ha('left')

# --- save the graphic ---
output_filename = f'gross_change_{class_name}_graphic.png'
final_path = os.path.join(
    output_path,
    output_filename
)

plt.savefig(
    final_path,
    dpi=300,
    bbox_inches='tight'
)

plt.show()

print(f"\n✅ Processing complete. Graphic saved as: {final_path}")
```

2.3 Net Change

Calculate metrics

In [ ]:

```
# ============================================================================
# 1. Function for calculating net change components
# ============================================================================

def calculate_net_change_components(gross_results):
    """
    Calculates the Net Change components from a set of Gross Change results.

    This function implements the two-step process described in the article
    (Equations 41-48) to convert gross change metrics into net change
    (or quantity change) metrics.

    Args:
        gross_results (dict): A dictionary containing the gross change
                              components for a single time interval or extent.

    Returns:
        dict or None: A dictionary with the calculated Net Change components.
                      Returns None if the input is invalid.
    """
    if not gross_results:
        return None

    # Unpack gross results for clarity
    Ght = gross_results["Gain Hit"]
    Gut = gross_results["Gain Space Difference"]
    Gmt = gross_results["Gain Miss"]
    Gft = gross_results["Gain False Alarm"]
    Lht = gross_results["Loss Hit"]
    Lut = gross_results["Loss Space Difference"]
    Lmt = gross_results["Loss Miss"]
    Lft = gross_results["Loss False Alarm"]

    # Step 1: Calculate Quantity Gain and Quantity Loss (Eqs. 41-44)
    QGxt = np.maximum(0, Ght + Gut + Gmt + Lht + Lut + Lmt)
```

```
    QGyt = np.maximum(0, Ght + Gut + Gft + Lht + Lut + Lft)
    QLxt = np.minimum(0, Ght + Gut + Gmt + Lht + Lut + Lmt)
    QLyt = np.minimum(0, Ght + Gut + Gft + Lht + Lut + Lft)

    # Step 2: Calculate Net Change components
    net_gain_hit = np.minimum(QGxt, QGyt)
    net_gain_miss = np.maximum(0, QGxt - QGyt)
    net_gain_false_alarm = np.maximum(0, QGyt - QGxt)

    net_loss_hit = np.maximum(QLxt, QLyt)
    net_loss_miss = np.minimum(0, QLxt - QLyt)
    net_loss_false_alarm = np.minimum(0, QLyt - QLxt)

    return {
        "Gain Hit": net_gain_hit,
        "Gain Miss": net_gain_miss,
        "Gain False Alarm": net_gain_false_alarm,
        "Loss Hit": net_loss_hit,
        "Loss Miss": net_loss_miss,
        "Loss False Alarm": net_loss_false_alarm,
        "QG_Total_X": QGxt,
        "QG_Total_Y": QGyt,
        "QL_Total_X": QLxt,
        "QL_Total_Y": QLyt
    }
```

In [ ]:

```
# ==============================================================================
# 2. Calculating net change for intervals and extent
# ==============================================================================

# This section iterates through the previously calculated gross change results
# to compute the net change components for each time interval and for the
# overall temporal extent.

net_change_by_interval = {}
print("Calculating Net Change components for each interval...")
for interval_label, gross_results in change_results_by_interval.items():
    net_change_by_interval[interval_label] = calculate_net_change_components(gross_results)

print("Calculating Net Change components for the extent...")
net_extent_results = calculate_net_change_components(extent_results)

print("\n✅ Calculations for each interval and extent are complete.")
```

In [ ]:

```
# ==============================================================================
# 3. Aggregating results for the 'sum' bar
# ==============================================================================

# This section aggregates the per-interval net change results to calculate
# the final components for the 'Sum' bar in the Net Change chart.

print("Calculating Net Change components for the Sum...")

sum_net_results = {
    "QG_Total_X": 0,
    "QG_Total_Y": 0,
    "QL_Total_X": 0,
    "QL_Total_Y": 0,
    "Gain Hit": 0,
    "Loss Hit": 0
}

# First, accumulate the QG/QL totals and the Hits from each interval
for interval, results in net_change_by_interval.items():
    if results:
```

```python
        sum_net_results["QG_Total_X"] += results["QG_Total_X"]
        sum_net_results["QG_Total_Y"] += results["QG_Total_Y"]
        sum_net_results["QL_Total_X"] += results["QL_Total_X"]
        sum_net_results["QL_Total_Y"] += results["QL_Total_Y"]
        sum_net_results["Gain Hit"] += results["Gain Hit"]
        sum_net_results["Loss Hit"] += results["Loss Hit"]

# Now, calculate the final components for the SUM bar
sum_net_results["Gain Miss"] = np.maximum(
    0, sum_net_results["QG_Total_X"] - sum_net_results["QG_Total_Y"]
)
sum_net_results["Gain False Alarm"] = np.maximum(
    0, sum_net_results["QG_Total_Y"] - sum_net_results["QG_Total_X"]
)
sum_net_results["Loss Miss"] = np.minimum(
    0, sum_net_results["QL_Total_X"] - sum_net_results["QL_Total_Y"]
)
sum_net_results["Loss False Alarm"] = np.minimum(
    0, sum_net_results["QL_Total_Y"] - sum_net_results["QL_Total_X"]
)

# Time Difference is the remaining quantity agreement after summing the interval hits
sum_net_results["Gain Time Difference"] = (
    np.minimum(sum_net_results["QG_Total_X"], sum_net_results["QG_Total_Y"])
    - sum_net_results["Gain Hit"]
)
sum_net_results["Loss Time Difference"] = (
    np.maximum(sum_net_results["QL_Total_X"], sum_net_results["QL_Total_Y"])
    - sum_net_results["Loss Hit"]
)

print("\n✅ Calculations for Nect Change for the Sum are complete.")
```

Plot the graphic

```python
# ===========================================================================
# 5. making the net change graphic
# ===========================================================================
print("\nGenerating the Net Change graphic...")

# --- prepare data for plotting ---
net_plot_data_list = []
for interval in time_intervals:
    row_data = net_change_by_interval.get(interval, {})
    row_data['Interval'] = interval
    net_plot_data_list.append(row_data)

sum_row_net = sum_net_results.copy()
sum_row_net['Interval'] = 'Sum'
net_plot_data_list.append(sum_row_net)

extent_row_net = net_extent_results.copy()
extent_row_net['Interval'] = 'Extent'
net_plot_data_list.append(extent_row_net)

df_plot_net = pd.DataFrame(net_plot_data_list).set_index('Interval')
df_plot_net = df_plot_net.fillna(0)


# --- setup for the plot ---
labels = df_plot_net.index.tolist()
gain_colors = {
    'Hit': '#0070C0',
    'Time Difference': '#BDD7EE',
    'Miss': 'white',
```

```
    'False Alarm': 'white'
}
loss_colors = {
    'Hit': '#C00000',
    'Time Difference': '#FF9696',
    'Miss': 'white',
    'False Alarm': 'white'
}
gain_hatch_color, loss_hatch_color = '#0070C0', '#FF0000'

fig, ax = plt.subplots(
    figsize=(14, 8)
)
mpl.rcParams['font.family'] = 'serif'

# --- plotting net gains ---
bottom_gain = np.zeros(len(labels))
for comp in [
    "Hit",
    "Time Difference",
    "Miss",
    "False Alarm"
]:
    # Get the original data with zeros for stacking calculations
    data = df_plot_net[f"Gain {comp}"].values

    # Create a copy for plotting, replacing 0 with NaN
    plot_data = data.copy().astype(float)
    plot_data[plot_data == 0] = np.nan

    if comp in ["Miss", "False Alarm"]:
        hatch = '///' if comp == 'False Alarm' else '\\\\\\'
        ax.bar(
            labels,
            plot_data, # Use data with NaNs for plotting
            label=f'Gain {comp}',
            color='white',
            bottom=bottom_gain,
            edgecolor='black'
        )
        ax.bar(
            labels,
            plot_data, # Use data with NaNs for plotting
            color='none',
            bottom=bottom_gain,
            edgecolor=gain_hatch_color,
            hatch=hatch
        )
    else:
        # Use original data for solid bars as they have no problematic edge
        ax.bar(
            labels,
            data,
            label=f'Gain {comp}',
            color=gain_colors[comp],
            bottom=bottom_gain,
            edgecolor='none'
        )
    # Always update the bottom with the original data (containing zeros)
    bottom_gain += data

# --- plotting net losses ---
bottom_loss = np.zeros(len(labels))
for comp in [
    "Hit",
    "Time Difference",
```

```
    "Miss",
    "False Alarm"
]:
    # Get the original data with zeros for stacking calculations
    data = df_plot_net[f"Loss {comp}"].values

    # Create a copy for plotting, replacing 0 with NaN
    plot_data = data.copy().astype(float)
    plot_data[plot_data == 0] = np.nan

    if comp in ["Miss", "False Alarm"]:
        hatch = '///' if comp == 'False Alarm' else '\\\\\\'
        ax.bar(
            labels,
            plot_data, # Use data with NaNs for plotting
            label=f'Loss {comp}',
            color='white',
            bottom=bottom_loss,
            edgecolor='black'
        )
        ax.bar(
            labels,
            plot_data, # Use data with NaNs for plotting
            color='none',
            bottom=bottom_loss,
            edgecolor=loss_hatch_color,
            hatch=hatch
        )
    else:
        # Use original data for solid bars
        ax.bar(
            labels,
            data,
            label=f'Loss {comp}',
            color=loss_colors[comp],
            bottom=bottom_loss,
            edgecolor='none'
        )
    # Always update the bottom with the original data (containing zeros)
    bottom_loss += data

# --- final graphic settings ---
ax.axhline(
    0,
    color='black',
    linewidth=0.8
)
ax.set_title(
    'Net Loss and Gain During Time Intervals',
    fontsize=14
)
ax.set_xlabel(
    'Time Interval',
    fontsize=12
)

# =============================================================================
# --- Y-AXIS SCALE SETTINGS (CHOOSE ONE OPTION) ---
# =============================================================================

# --- Option 1: For 'toy_data' or data with small values ---
# ax.set_ylim(-6, 6)
# ax.set_ylabel(
#     'Net Loss and Net Gain',
#     fontsize=12
# )
```

```
# # --- Option 2: For real data with large values (e.g., MapBiomas) ---
def millions_formatter(y, pos):
    """Formats the y-axis tick by dividing by 1 million."""
    return f'{y / 1_000_000:.0f}'
ax.yaxis.set_major_formatter(FuncFormatter(millions_formatter))
ax.set_ylim(-60_000_000, 60_000_000) # Optional: uncomment to set manual limits
ax.set_ylabel(
    'Net Loss and Net Gain (Million pixels)',
    fontsize=12
)

# =============================================================================

# --- logic to order the legend ---
handles, labels_list = ax.get_legend_handles_labels()
legend_dict = dict(zip(labels_list, handles))

legend_dict['Gain Miss'] = (
    mpatches.Patch(facecolor='white', edgecolor='black'),
    mpatches.Patch(facecolor='none', edgecolor=gain_hatch_color, hatch='\\\\\\')
)
legend_dict['Gain False Alarm'] = (
    mpatches.Patch(facecolor='white', edgecolor='black'),
    mpatches.Patch(facecolor='none', edgecolor=gain_hatch_color, hatch='///')
)
legend_dict['Loss Miss'] = (
    mpatches.Patch(facecolor='white', edgecolor='black'),
    mpatches.Patch(facecolor='none', edgecolor=loss_hatch_color, hatch='\\\\\\')
)
legend_dict['Loss False Alarm'] = (
    mpatches.Patch(facecolor='white', edgecolor='black'),
    mpatches.Patch(facecolor='none', edgecolor=loss_hatch_color, hatch='///')
)

order = [
    'Gain Miss', 'Gain False Alarm', 'Gain Time Difference', 'Gain Hit',
    'Loss Miss', 'Loss False Alarm', 'Loss Time Difference', 'Loss Hit'
]

ordered_handles = [legend_dict.get(label) for label in order if label in legend_dict]
ordered_labels = [label for label in order if label in legend_dict]

legend = ax.legend(
    handles=ordered_handles,
    labels=ordered_labels,
    loc='center left',
    bbox_to_anchor=(1, 0.5),
    frameon=False,
    alignment='left'
)
legend.get_title().set_ha('left')
for text in legend.get_texts():
    text.set_ha('left')

# --- save the graphic ---
output_filename = f'net_change_{class_name}_graphic.png'
final_path = os.path.join(
    output_path,
    output_filename
)

plt.savefig(
    final_path,
    dpi=300,
    bbox_inches='tight'
```

```
)

plt.show()

print(f"\n✅ Processing complete. Graphic saved as: {final_path}")
```

3. Export results

In [ ]:

```
# ==============================================================================
# 1. Export all graphic results to an Excel file
# ==============================================================================
print("Starting the export of results to Excel...")

# Import pandas if it's not already in memory
import pandas as pd

# Define the output Excel filename and path
excel_filename = f'analysis_results_{class_name}.xlsx'
excel_final_path = os.path.join(output_path, excel_filename)

# Use pandas ExcelWriter to save multiple dataframes to one .xlsx file
with pd.ExcelWriter(excel_final_path, engine='xlsxwriter') as writer:

    # --- 1. README SHEET ---
    readme_text = (
        "This excel file summarizes all the results from the Python Notebook.\n\n"
        "Sheet Descriptions:\n\n"
        "- Presence Agreement:\n"
        "  Contains the aggregated values for the Presence Agreement chart, showing Hits, Mis
        "- Gross Change:\n"
        "  Contains the values for the Gross Loss and Gain chart, showing all components of gr
        "- Net Change:\n"
        "  Contains the values for the Net Change chart, showing the quantity-based components
    )
    df_readme = pd.DataFrame({'File Description': [readme_text]})
    df_readme.to_excel(writer, sheet_name='ReadMe', index=False)

    # --- 2. PRESENCE AGREEMENT SHEET ---
    presence_data_list = []
    for tp in time_points:
        row_data = results_by_time.get(tp, {})
        row_data['Time Point'] = tp
        presence_data_list.append(row_data)
    sum_row_presence = sum_results.copy()
    sum_row_presence['Time Point'] = 'Sum'
    presence_data_list.append(sum_row_presence)

    df_presence = pd.DataFrame(presence_data_list)
    presence_cols_order = ['Time Point', 'Hit', 'Space Difference', 'Time Difference', 'Miss'
    df_presence = df_presence[presence_cols_order]
    df_presence = df_presence.fillna(0)
    df_presence.to_excel(writer, sheet_name='Presence Agreement', index=False)

    # --- 3. GROSS CHANGE SHEET ---
    gross_change_data_list = []
    for interval in time_intervals:
        row_data = change_results_by_interval.get(interval, {})
        row_data['Interval'] = interval
        gross_change_data_list.append(row_data)
    sum_row_gross = sum_change_results.copy()
    sum_row_gross['Interval'] = 'Sum'
    gross_change_data_list.append(sum_row_gross)
    extent_row_gross = extent_results.copy()
    extent_row_gross['Interval'] = 'Extent'
```

```
    gross_change_data_list.append(extent_row_gross)

    df_gross = pd.DataFrame(gross_change_data_list)
    gross_cols_order = [
        'Interval', 'Gain Hit', 'Gain Space Difference', 'Gain Time Difference', 'Gain Miss',
        'Loss Hit', 'Loss Space Difference', 'Loss Time Difference', 'Loss Miss', 'Loss False
    ]
    df_gross = df_gross[gross_cols_order]
    df_gross = df_gross.fillna(0) # <-- CORREÇÃO AQUI
    df_gross.to_excel(writer, sheet_name='Gross Change', index=False)

    # --- 4. NET CHANGE SHEET ---
    net_change_data_list = []
    for interval in time_intervals:
        row_data = net_change_by_interval.get(interval, {})
        row_data['Interval'] = interval
        net_change_data_list.append(row_data)
    sum_row_net = sum_net_results.copy()
    sum_row_net['Interval'] = 'Sum'
    net_change_data_list.append(sum_row_net)
    extent_row_net = net_extent_results.copy()
    extent_row_net['Interval'] = 'Extent'
    net_change_data_list.append(extent_row_net)

    df_net = pd.DataFrame(net_change_data_list)
    net_cols_order = [
        'Interval', 'Gain Hit', 'Gain Time Difference', 'Gain Miss', 'Gain False Alarm',
        'Loss Hit', 'Loss Time Difference', 'Loss Miss', 'Loss False Alarm'
    ]
    df_net = df_net[net_cols_order]
    df_net = df_net.fillna(0) # <-- CORREÇÃO AQUI
    df_net.to_excel(writer, sheet_name='Net Change', index=False)

    # --- Auto-adjust column widths ---
    workbook = writer.book
    for sheet_name in writer.sheets:
        worksheet = writer.sheets[sheet_name]
        if sheet_name == 'ReadMe':
            worksheet.set_column('A:A', 80) # Set a fixed width for the description
            # Enable text wrapping
            cell_format = workbook.add_format({'valign': 'top', 'text_wrap': True})
            worksheet.set_row(1, 150, cell_format) # Set row height and format
        else:
            for idx, col in enumerate(df_net.columns if 'Net' in sheet_name else df_gross.col
                series = (df_net if 'Net' in sheet_name else df_gross if 'Gross' in sheet_nam
                max_len = max((series.astype(str).map(len).max(), len(str(series.name)))) + 2
                worksheet.set_column(idx, idx, max_len)

print(f"\n✅ All results successfully exported to: {excel_final_path}")
```

Maps

Presence Agreement

In [ ]:

```
# ==============================================================================
# 1. Initialize accumulator map
# ==============================================================================
print("Starting calculation for Presence Agreement raster map...")

# Use the first time point to get the spatial profile (dimensions, CRS, etc.)
# This ensures the output map has the same spatial properties as the inputs.
first_year = time_points[0]
```

```python
first_file_name = f"{class_name}{first_year}.tif"
path_to_first_file = os.path.join(
    path_series_x,
    first_file_name
)

try:
    with rasterio.open(path_to_first_file) as src:
        # Copy the profile from the source raster to use when saving the output
        profile = src.profile
        height = src.height
        width = src.width

        # Initialize the accumulator map with zeros
        # float32 is used to safely handle sums that might exceed the range of uint8
        An_map = np.zeros((height, width), dtype=np.float32)

        print(f"Accumulator map initialized with dimensions: {height}x{width}.")

except FileNotFoundError:
    print(f"ERROR: Could not find the reference file '{path_to_first_file}' to initialize the
    An_map = None

# ============================================================================
# 2. Calculate and accumulate presence hits
# ============================================================================

if An_map is not None:
    print("\nStarting pixel-wise calculation for each time point...")

    # This mask will track pixels that are never valid across the entire series
    final_nodata_mask = np.ones_like(An_map, dtype=bool)

    for year in time_points:
        file_name = f"{class_name}{year}.tif"
        path_x = os.path.join(path_series_x, file_name)
        path_y = os.path.join(path_series_y, file_name)

        if os.path.exists(path_x) and os.path.exists(path_y):
            print(f"Processing: {file_name}...")
            with rasterio.open(path_x) as src_x, rasterio.open(path_y) as src_y:
                array_x = src_x.read(1)
                array_y = src_y.read(1)

                # Calculate presence hits for the current year (Equation 1)
                Phtn_map = np.minimum(array_x, array_y)

                # Create a mask to handle NoData values
                valid_mask = (array_x != nodata_value) & (array_y != nodata_value)

                # Add the current year's hits to the accumulator map, only on valid pixels
                np.add(
                    An_map,
                    Phtn_map,
                    out=An_map,
                    where=valid_mask
                )

                # Update the final mask
                final_nodata_mask &= ~valid_mask
        else:
            print(f"Warning: Files for year {year} not found. Skipping.")

    # Apply the NoData value to pixels that were never valid
    An_map[final_nodata_mask] = nodata_value
```

```python
    print("\nPixel-wise calculations complete.")

# ==============================================================================
# 3. Save the final raster map
# ==============================================================================

if An_map is not None:
    # Update the profile for the output data type and add compression
    profile.update(
        dtype=rasterio.float32,
        nodata=nodata_value,
        compress='lzw'
    )

    # Define the output filename and path
    output_filename_map = f'presence_agreement_{class_name}.tif'
    final_map_path = os.path.join(
        output_path,
        output_filename_map
    )

    print(f"\nSaving final map to: {final_map_path}")

    with rasterio.open(final_map_path, 'w', **profile) as dst:
        dst.write(An_map, 1)

    print("✅ Successfully saved the Presence Agreement raster map.")
```

In [ ]:

```python
# # ==============================================================================
# # 1. Making the Presence Agreement map
# # ==============================================================================
# print("Generating the Presence Agreement map visualization...")

# # ==============================================================================
# # 2. Prepare data and metadata for plotting
# # ==============================================================================

# # Define the path to the raster file created in the previous cell
# input_map_filename = f'presence_agreement_{class_name}.tif'
# input_map_path = os.path.join(
#     output_path,
#     input_map_filename
# )

# # Define a scale factor to downsample the raster for efficient plotting
# scale_factor = 0.15

# with rasterio.open(input_map_path) as src:
#     # Get spatial metadata from the source file
#     bounds = src.bounds
#     src_crs = src.crs
#     transform = src.transform
#     transformer = Transformer.from_crs(src_crs, "EPSG:4326", always_xy=True)

#     # Read the data, downsampling it for visualization
#     data = src.read(
#         1,
#         out_shape=(
#             int(src.height * scale_factor),
#             int(src.width * scale_factor)
#         ),
#         resampling=Resampling.nearest
#     )

#     # Mask the NoData values
```

```
#     masked_map = np.ma.masked_equal(data, nodata_value)

# # ============================================================================
# # 3. Setup colormap and legend
# # ============================================================================

# # Define a discrete colormap: gray for 0, and viridis for 1 to N
# num_time_points = len(time_points)
# viridis_colors = plt.get_cmap('viridis', num_time_points)
# colors = ['gray'] + [viridis_colors(i / (num_time_points - 1)) for i in range(num_time_poin
# boundaries = list(range(num_time_points + 2))
# cmap = ListedColormap(colors)
# cmap.set_bad(color='white')
# norm = BoundaryNorm(boundaries, cmap.N)

# # ============================================================================
# # 4. Generate the plot
# # ============================================================================

# # --- Tick formatting functions (Degrees, Minutes, Seconds) ---
# def format_x_ticks(x, pos):
#     lon, _ = transformer.transform(x, bounds.bottom)
#     deg = int(abs(lon))
#     min_val = int((abs(lon) - deg) * 60)
#     sec = ((abs(lon) - deg) * 60 - min_val) * 60
#     return f"{deg}° {min_val}' {sec:.2f}\"" + ("E" if lon >= 0 else "W")

# def format_y_ticks(y, pos):
#     _, lat = transformer.transform(bounds.left, y)
#     deg = int(abs(lat))
#     min_val = int((abs(lat) - deg) * 60)
#     sec = ((abs(lat) - deg) * 60 - min_val) * 60
#     return f"{deg}° {min_val}' {sec:.2f}\"" + ("N" if lat >= 0 else "S")

# # --- Create the figure ---
# fig, ax = plt.subplots(
#     figsize=(14, 12)
# )
# mpl.rcParams['font.family'] = 'serif'

# # --- Plot the raster image ---
# im = ax.imshow(
#     masked_map,
#     cmap=cmap,
#     norm=norm,
#     extent=[bounds.left, bounds.right, bounds.bottom, bounds.top]
# )

# # --- Format axes and ticks ---
# ax.xaxis.set_major_formatter(FuncFormatter(format_x_ticks))
# ax.yaxis.set_major_formatter(FuncFormatter(format_y_ticks))
# ax.xaxis.set_major_locator(plt.MaxNLocator(3))
# ax.yaxis.set_major_locator(plt.MaxNLocator(6))
# ax.tick_params(
#     axis='x', which='major', labelsize=10, pad=4
# )
# ax.tick_params(
#     axis='y', which='major', labelsize=10, pad=4
# )
# plt.setp(
#     ax.get_yticklabels(),
#     rotation=90,
#     va='center'
# )

# # --- Add cartographic elements ---
```

```
# north_arrow(
#     ax,
#     location="upper right",
#     rotation={"degrees": 0},
#     shadow=False
# )

# # scalebar = ScaleBar(
# #     1/1000,
# #     units='km',
# #     length_fraction=0.4,
# #     location='lower right',
# #     scale_formatter=lambda value, _: f"{int(value)} km"
# # )
# # ax.add_artist(scalebar)

# # --- Create the discrete legend ---
# labels_legenda = [
#     '0 Years',
#     '1 Year'
# ] + [f'{i} Years' for i in range(2, num_time_points + 1)]
# patches = [mpatches.Patch(color=colors[i], label=labels_legenda[i]) for i in range(len(labe
# legend = ax.legend(
#     handles=patches,
#     title='Number of Time Points in Agreement',
#     loc='center left',
#     bbox_to_anchor=(1.05, 0.5),
#     frameon=False,
#     fontsize=12,
#     alignment='left',
# )

# legend.get_title().set_ha('left')

# for text in legend.get_texts():
#     text.set_ha('left')

# # --- Final styling and saving ---
# ax.set_aspect('equal')
# ax.set_title(
#     f'Presence Agreement Map - {class_name.capitalize()}',
#     fontsize=18,
#     pad=20
# )
# ax.set_xlabel(
#     'Longitude',
#     fontsize=12
# )
# ax.set_ylabel(
#     'Latitude',
#     fontsize=12
# )

# output_plot_filename = f'presence_agreement_{class_name}_map.png'
# final_plot_path = os.path.join(output_path, output_plot_filename)

# plt.savefig(
#     final_plot_path,
#     dpi=300,
#     bbox_inches='tight'
# )

# plt.show()

# print(f"\n✅Map visualization saved to: {final_plot_path}")
```

Presence Difference

In [ ]:

```
# ============================================================================
# 1. Initialize accumulator map
# ============================================================================
print("Starting calculation for Presence Difference raster map...")

# Use the first time point to get the spatial profile (dimensions, CRS, etc.)
# This ensures the output map has the same spatial properties as the inputs.
first_year = time_points[0]
first_file_name = f"{class_name}{first_year}.tif"
path_to_first_file = os.path.join(
    path_series_x,
    first_file_name
)

try:
    with rasterio.open(path_to_first_file) as src:
        # Copy the profile from the source raster to use when saving the output
        profile = src.profile
        height = src.height
        width = src.width

        # Initialize the accumulator map with zeros
        # float32 is used to safely handle positive and negative sums
        Dn_map = np.zeros((height, width), dtype=np.float32)

        print(f"Accumulator map initialized with dimensions: {height}x{width}.")

except FileNotFoundError:
    print(f"ERROR: Could not find the reference file '{path_to_first_file}' to initialize the
    Dn_map = None

# ============================================================================
# 2. Calculate and accumulate presence differences
# ============================================================================

if Dn_map is not None:
    print("\nStarting pixel-wise calculation for each time point...")

    # This mask will track pixels that are never valid across the entire series
    final_nodata_mask = np.ones_like(Dn_map, dtype=bool)

    for year in time_points:
        file_name = f"{class_name}{year}.tif"
        path_x = os.path.join(path_series_x, file_name)
        path_y = os.path.join(path_series_y, file_name)

        if os.path.exists(path_x) and os.path.exists(path_y):
            print(f"Processing: {file_name}...")
            with rasterio.open(path_x) as src_x, rasterio.open(path_y) as src_y:
                # Cast to a signed integer type before subtraction to prevent overflow errors
                array_x = src_x.read(1).astype(np.int64)
                array_y = src_y.read(1).astype(np.int64)

                # Calculate presence difference for the current year (from Equation 50)
                difference_map = array_y - array_x

                # Create a mask to handle NoData values (using the original uint8 arrays)
                valid_mask = (src_x.read(1) != nodata_value) & (src_y.read(1) != nodata_value

                # Add the current year's difference to the accumulator map
                np.add(
```

```python
                    Dn_map,
                    difference_map,
                    out=Dn_map,
                    where=valid_mask
                )

                # Update the final mask
                final_nodata_mask &= ~valid_mask
        else:
            print(f"Warning: Files for year {year} not found. Skipping.")

    # Apply the NoData value to pixels that were never valid
    Dn_map[final_nodata_mask] = nodata_value

    print("\n✅ Pixel-wise calculations complete.")

# ==============================================================================
# 3. Save the final raster map
# ==============================================================================

if Dn_map is not None:
    # Update the profile for the output data type and add compression
    profile.update(
        dtype=rasterio.float32,
        nodata=nodata_value,
        compress='lzw'
    )

    # Define the output filename and path
    output_filename_map = f'presence_difference_{class_name}.tif'
    final_map_path = os.path.join(
        output_path,
        output_filename_map
    )

    print(f"\nSaving final map to: {final_map_path}")

    with rasterio.open(final_map_path, 'w', **profile) as dst:
        dst.write(Dn_map, 1)

    print("✅ Successfully saved the Presence Difference raster map.")
```

In [ ]:

```python
# # ==============================================================================
# # 1. Prepare data and metadata for plotting
# # ==============================================================================
# print("Generating the Presence Difference map visualization...")

# # Define the path to the raster file created in the previous cell
# input_map_filename = f'presence_difference_{class_name}.tif'
# input_map_path = os.path.join(
#     output_path,
#     input_map_filename
# )

# # Define a scale factor to downsample the raster for efficient plotting
# scale_factor = 0.15

# with rasterio.open(input_map_path) as src:
#     # Get spatial metadata from the source file
#     bounds = src.bounds
#     src_crs = src.crs
#     transform = src.transform
#     transformer = Transformer.from_crs(src_crs, "EPSG:4326", always_xy=True)

#     # Read the data, downsampling it for visualization
```

```
#     data = src.read(
#         1,
#         out_shape=(
#             int(src.height * scale_factor),
#             int(src.width * scale_factor)
#         ),
#         resampling=Resampling.nearest
#     )

#     # Mask the NoData values
#     masked_map = np.ma.masked_equal(data, nodata_value)

# # ==============================================================================
# # 2. Setup custom diverging colormap
# # ==============================================================================

# # Create a custom diverging colormap
# colors = [
#     "#b2182b",
#     "gray",
#     "#2166ac"]
# cmap = mcolors.LinearSegmentedColormap.from_list("custom_div_cmap", colors)

# # Set the color for NoData (masked values) to white
# cmap.set_bad(color='white')

# # Find the maximum absolute value to center the colormap on zero
# max_abs_val = np.ma.max(np.abs(masked_map))
# norm = mcolors.Normalize(vmin=-max_abs_val, vmax=max_abs_val)

# # ==============================================================================
# # 3. Generate the plot
# # ==============================================================================

# # --- Tick formatting functions (Degrees, Minutes, Seconds) ---
# def format_x_ticks(x, pos):
#     lon, _ = transformer.transform(x, bounds.bottom)
#     deg = int(abs(lon))
#     min_val = int((abs(lon) - deg) * 60)
#     sec = ((abs(lon) - deg) * 60 - min_val) * 60
#     return f"{deg}° {min_val}' {sec:.2f}\"" + ("E" if lon >= 0 else "W")

# def format_y_ticks(y, pos):
#     _, lat = transformer.transform(bounds.left, y)
#     deg = int(abs(lat))
#     min_val = int((abs(lat) - deg) * 60)
#     sec = ((abs(lat) - deg) * 60 - min_val) * 60
#     return f"{deg}° {min_val}' {sec:.2f}\"" + ("N" if lat >= 0 else "S")

# # --- Create the figure ---
# fig, ax = plt.subplots(
#     figsize=(14, 12)
# )
# mpl.rcParams['font.family'] = 'serif'

# # --- Plot the raster image ---
# im = ax.imshow(
#     masked_map,
#     cmap=cmap,
#     norm=norm,
#     extent=[bounds.left, bounds.right, bounds.bottom, bounds.top]
# )

# # --- Format axes and ticks ---
# ax.xaxis.set_major_formatter(FuncFormatter(format_x_ticks))
# ax.yaxis.set_major_formatter(FuncFormatter(format_y_ticks))
```

```
# ax.xaxis.set_major_locator(plt.MaxNLocator(3))
# ax.yaxis.set_major_locator(plt.MaxNLocator(6))
# ax.tick_params(
#     axis='x', which='major', labelsize=10, pad=4
# )
# ax.tick_params(
#     axis='y', which='major', labelsize=10, pad=4
# )
# plt.setp(
#     ax.get_yticklabels(),
#     rotation=90,
#     va='center'
# )

# # --- Add cartographic elements ---
# north_arrow(
#     ax,
#     location="upper right",
#     rotation={"degrees": 0},
#     shadow=False
# )

# # scalebar = ScaleBar(
# #     1/1000,
# #     units='km',
# #     length_fraction=0.4,
# #     location='lower right',
# #     scale_formatter=lambda value, _: f"{int(value)} km"
# # )
# # ax.add_artist(scalebar)

# # --- Create the continuous color bar ---
# cbar = fig.colorbar(
#     im,
#     ax=ax,
#     orientation='vertical',
#     fraction=0.046,
#     pad=0.08,
#     shrink=0.5
# )

# cbar.set_label(
#     'Accumulated Difference',
#     fontsize=12,
#     rotation=0,
#     y=1.08,
#     labelpad=0
# )

# vmin = norm.vmin
# vmax = norm.vmax
# ticks = np.arange(int(np.ceil(vmin)), int(np.floor(vmax)) + 1)
# cbar.set_ticks(ticks)

# # --- Final styling and saving ---
# ax.set_aspect('equal')
# ax.set_title(
#     f'Presence Difference Map - {class_name.capitalize()}',
#     fontsize=18,
#     pad=20
# )
# ax.set_xlabel(
#     'Longitude',
#     fontsize=12
# )
# ax.set_ylabel(
```

```
#     'Latitude',
#     fontsize=12
# )

# output_plot_filename = f'presence_difference_{class_name}_map.png'
# final_plot_path = os.path.join(output_path, output_plot_filename)

# plt.savefig(
#     final_plot_path,
#     dpi=300,
#     bbox_inches='tight'
# )

# plt.show()

# print(f"\n✅ Map visualization saved to: {final_plot_path}")
```

Change Agreement

In [25]:
```
# ============================================================================
# 1. Initialize accumulator map
# ============================================================================
print("Starting calculation for Change Agreement raster map...")

try:
    with rasterio.open(path_to_first_file) as src:
        # Copy the profile from the source raster to use when saving the output
        profile = src.profile
        height = src.height
        width = src.width

        # Initialize the accumulator map with zeros
        Bn_map = np.zeros((height, width), dtype=np.float32)

        print(f"Accumulator map initialized with dimensions: {height}x{width}.")

except NameError:
    print("ERROR: The first map cell must be run to define variables.")
    Bn_map = None

# ============================================================================
# 2. calculate and accumulate change agreement
# ============================================================================

if Bn_map is not None:
    print("\nStarting pixel-wise calculation for each time interval...")

    # This mask will track pixels that are never valid across the entire series
    final_nodata_mask = np.ones_like(Bn_map, dtype=bool)

    # Iterate over TIME INTERVALS
    for i in range(1, len(time_points)):
        year_t = time_points[i]
        year_t_minus_1 = time_points[i-1]

        print(f"Processing interval: {year_t_minus_1}-{year_t}...")

        # Get the four required raster arrays for the interval
        array_x_t, array_y_t = get_raster_array(year_t)
        array_x_t_minus_1, array_y_t_minus_1 = get_raster_array(year_t_minus_1)

        if array_x_t is None or array_x_t_minus_1 is None:
            print(f"Warning: Data not found for interval {year_t_minus_1}-{year_t}. Skipping.
            continue
```

```python
        # Create a mask for valid data across all four arrays
        valid_mask = (
            (array_x_t != nodata_value) &
            (array_y_t != nodata_value) &
            (array_x_t_minus_1 != nodata_value) &
            (array_y_t_minus_1 != nodata_value)
        )

        # --- Memory-Efficient Calculation ---
        # Calculate change directly into int16 arrays to save memory
        change_x = np.subtract(array_x_t, array_x_t_minus_1, dtype=np.int16)
        change_y = np.subtract(array_y_t, array_y_t_minus_1, dtype=np.int16)

        # Calculate gains and losses from the change arrays
        gain_x = np.maximum(0, change_x)
        gain_y = np.maximum(0, change_y)
        loss_x = np.minimum(0, change_x)
        loss_y = np.minimum(0, change_y)

        # Calculate gain hits (Ghtn) and loss hits (Lhtn) for the interval
        Ghtn_map = np.minimum(gain_x, gain_y)
        Lhtn_map = np.maximum(loss_x, loss_y)

        # Accumulate the result (Ghtn - Lhtn) in-place for memory efficiency
        np.add(Bn_map, Ghtn_map, out=Bn_map, where=valid_mask)
        np.subtract(Bn_map, Lhtn_map, out=Bn_map, where=valid_mask)
        # --- End of Memory-Efficient Calculation ---

        final_nodata_mask &= ~valid_mask

    # Apply the NoData value to pixels that were never valid
    Bn_map[final_nodata_mask] = nodata_value

    print("\n✅ Pixel-wise calculations complete.")

# =============================================================================
# 3. save the final raster map
# =============================================================================

if Bn_map is not None:
    # Update the profile for the output data type and add compression
    profile.update(
        dtype=rasterio.float32,
        nodata=nodata_value,
        compress='lzw'
    )

    # Define the output filename and path
    output_filename_map = f'change_agreement_{class_name}.tif'
    final_map_path = os.path.join(
        output_path,
        output_filename_map
    )

    print(f"\nSaving final map to: {final_map_path}")

    with rasterio.open(final_map_path, 'w', **profile) as dst:
        dst.write(Bn_map, 1)

    print("✅ Successfully saved the Change Agreement raster map.")
```

```
Starting calculation for Change Agreement raster map...
Accumulator map initialized with dimensions: 22568x21911.

Starting pixel-wise calculation for each time interval...
Processing interval: 2010-2012...
Processing interval: 2012-2014...
Processing interval: 2014-2016...
Processing interval: 2016-2018...
Processing interval: 2018-2021...

✅ Pixel-wise calculations complete.

Saving final map to: C:\Temp\PIE\output\change_agreement_PIE.tif
✅ Successfully saved the Change Agreement raster map.
```

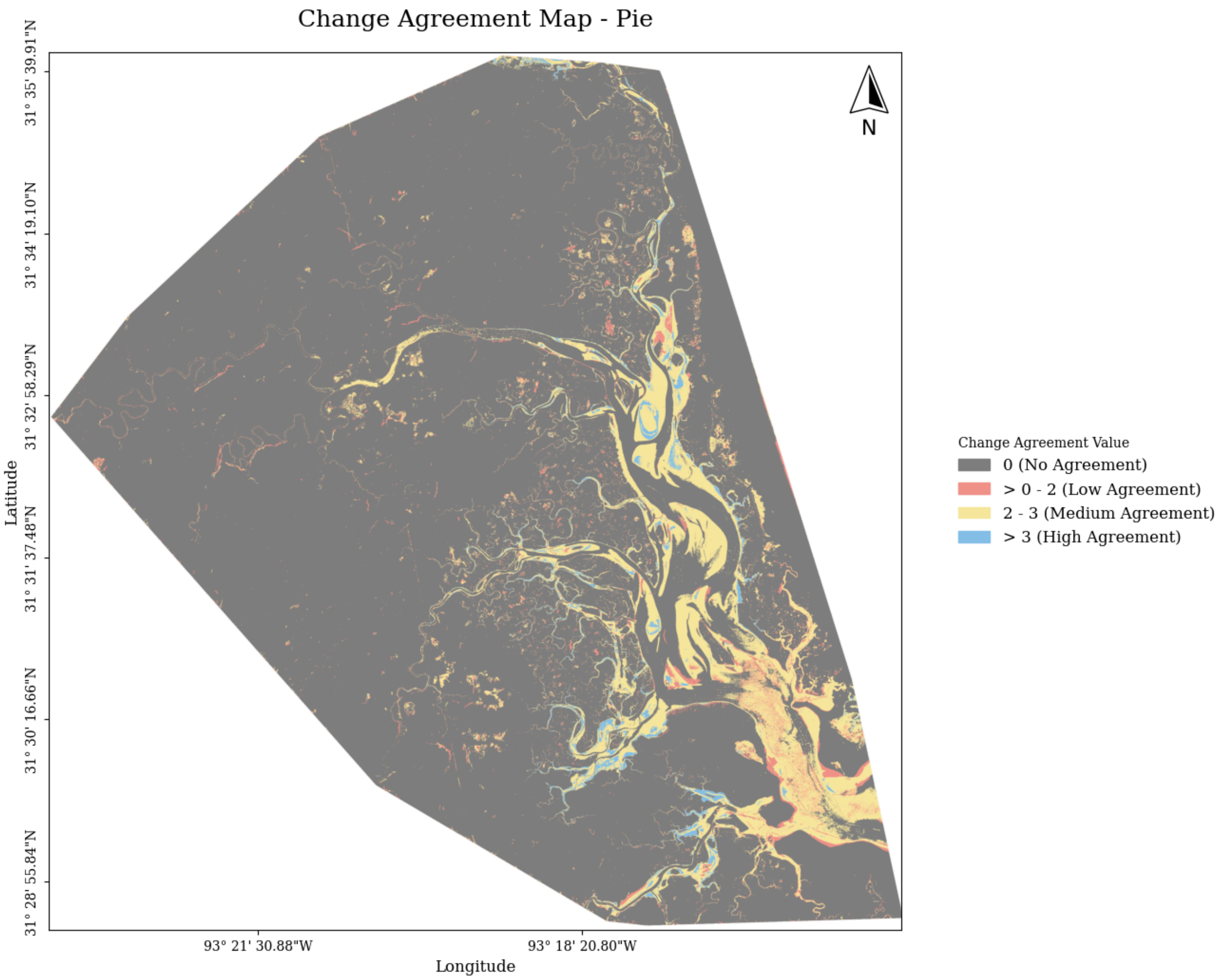
In [5]:

```python
# ==============================================================================
# 1. Prepare data and metadata for plotting
# ==============================================================================
print("Generating the Change Agreement map visualization...")

# Define the path to the raster file created in the previous cell
input_map_filename = f'change_agreement_{class_name}.tif'
input_map_path = os.path.join(
    output_path,
    input_map_filename
)

# Define a scale factor to downsample the raster for efficient plotting
scale_factor = 0.15

with rasterio.open(input_map_path) as src:
    # Get spatial metadata from the source file
    bounds = src.bounds
    src_crs = src.crs
    transform = src.transform
    transformer = Transformer.from_crs(src_crs, "EPSG:4326", always_xy=True)

    # Read the data, downsampling it for visualization
    data = src.read(
        1,
        out_shape=(
            int(src.height * scale_factor),
            int(src.width * scale_factor)
        ),
        resampling=Resampling.nearest
    )

    # Mask the NoData values
    masked_map = np.ma.masked_equal(data, nodata_value)

# ==============================================================================
# 2. Setup colormap and Legend
# ==============================================================================

# Classify the continuous data into discrete bins for the legend
# Find the maximum value to create the class boundaries, ignoring zeros
max_val = np.ma.max(masked_map[masked_map > 0]) if np.ma.count(masked_map[masked_map > 0]) > 0

# Define the boundaries for 3 levels (terciles) plus the zero class
b1, b2 = max_val / 3, 2 * max_val / 3
boundaries = [0, 1e-9, b1, b2, max_val + 1] # Add a small value to isolate 0

#
colors_categories = [
    '#F1948A',  # Low agreement
    '#F9E79F',  # Medium agreement
```

```python
    '#85C1E9'   # High agreement
]
colors = ['gray'] + colors_categories

cmap = ListedColormap(colors)
cmap.set_bad(color='white')
norm = BoundaryNorm(boundaries, cmap.N)

# ==============================================================================
# 4. Generate the plot
# ==============================================================================

# --- Tick formatting functions (Degrees, Minutes, Seconds) ---
def format_x_ticks(x, pos):
    lon, _ = transformer.transform(x, bounds.bottom)
    deg = int(abs(lon))
    min_val = int((abs(lon) - deg) * 60)
    sec = ((abs(lon) - deg) * 60 - min_val) * 60
    return f"{deg}° {min_val}' {sec:.2f}\"" + ("E" if lon >= 0 else "W")

def format_y_ticks(y, pos):
    _, lat = transformer.transform(bounds.left, y)
    deg = int(abs(lat))
    min_val = int((abs(lat) - deg) * 60)
    sec = ((abs(lat) - deg) * 60 - min_val) * 60
    return f"{deg}° {min_val}' {sec:.2f}\"" + ("N" if lat >= 0 else "S")

# --- Create the figure ---
fig, ax = plt.subplots(
    figsize=(14, 12)
)
mpl.rcParams['font.family'] = 'serif'

# --- Plot the raster image ---
im = ax.imshow(
    masked_map,
    cmap=cmap,
    norm=norm,
    extent=[bounds.left, bounds.right, bounds.bottom, bounds.top]
)

# --- Format axes and ticks ---
ax.xaxis.set_major_formatter(FuncFormatter(format_x_ticks))
ax.yaxis.set_major_formatter(FuncFormatter(format_y_ticks))
ax.xaxis.set_major_locator(plt.MaxNLocator(3))
ax.yaxis.set_major_locator(plt.MaxNLocator(6))
ax.tick_params(
    axis='x', which='major', labelsize=10, pad=4
)
ax.tick_params(
    axis='y', which='major', labelsize=10, pad=4
)
plt.setp(
    ax.get_yticklabels(),
    rotation=90,
    va='center'
)

# --- Add cartographic elements ---
north_arrow(
    ax,
    location="upper right",
    rotation={"degrees": 0},
    shadow=False
)
```

```
# scalebar = ScaleBar(
#     1/1000,
#     units='km',
#     length_fraction=0.4,
#     location='lower right',
#     scale_formatter=lambda value, _: f"{int(value)} km"
# )
# ax.add_artist(scalebar)

# --- Create the discrete legend with objective value ranges ---
labels_legenda = [
    '0 (No Agreement)',
    f'> 0 - {b1:.0f} (Low Agreement)',
    f'{b1:.0f} - {b2:.0f} (Medium Agreement)',
    f'> {b2:.0f} (High Agreement)'
]
patches = [mpatches.Patch(color=colors[i], label=labels_legenda[i]) for i in range(len(labels_

legend = ax.legend(
    handles=patches,
    title='Change Agreement Value',
    loc='center left',
    bbox_to_anchor=(1.05, 0.5),
    frameon=False,
    fontsize=12,
    alignment='left'
)
legend.get_title().set_ha('left')
for text in legend.get_texts():
    text.set_ha('left')

# --- Final styling and saving ---
ax.set_aspect('equal')
ax.set_title(
    f'Change Agreement Map - {class_name.capitalize()}',
    fontsize=18,
    pad=20
)
ax.set_xlabel(
    'Longitude',
    fontsize=12
)
ax.set_ylabel(
    'Latitude',
    fontsize=12
)

output_plot_filename = f'change_agreement_{class_name}_map.png'
final_plot_path = os.path.join(output_path, output_plot_filename)

plt.savefig(
    final_plot_path,
    dpi=300,
    bbox_inches='tight'
)

plt.show()

print(f"\n✅ Map visualization saved to: {final_plot_path}")
```

```
Generating the Change Agreement map visualization...
```



✅ Map visualization saved to: C:\Temp\PIE\output\change_agreement_PIE_map.png

Change Difference

In [26]:

```
# ==============================================================================
# 1. Initialize accumulator map
# ==============================================================================
print("Starting calculation for Change Difference Map...")

try:
    with rasterio.open(path_to_first_file) as src:
        # Copy the profile from the source raster to use when saving the output
        profile = src.profile
        height = src.height
        width = src.width

        # Initialize the accumulator map with zeros
        En_map = np.zeros((height, width), dtype=np.float32)

        print(f"Accumulator map initialized with dimensions: {height}x{width}.")

except NameError:
    print("ERROR: The first map cell must be run to define variables.")
    En_map = None

# ==============================================================================
# 2. Calculate and accumulate change differences
# ==============================================================================

if En_map is not None:
    print("\nStarting pixel-wise calculation for each time interval...")
```

```python
    # This mask will track pixels that are never valid across the entire series
    final_nodata_mask = np.ones_like(En_map, dtype=bool)

    # Iterate over TIME INTERVALS
    for i in range(1, len(time_points)):
        year_t = time_points[i]
        year_t_minus_1 = time_points[i-1]

        print(f"Processing interval: {year_t_minus_1}-{year_t}...")

        # Get the four required raster arrays for the interval
        array_x_t, array_y_t = get_raster_array(year_t)
        array_x_t_minus_1, array_y_t_minus_1 = get_raster_array(year_t_minus_1)

        if array_x_t is None or array_x_t_minus_1 is None:
            print(f"Warning: Data not found for interval {year_t_minus_1}-{year_t}. Skipping.
            continue

        # Create a mask for valid data across all four arrays
        valid_mask = (
            (array_x_t != nodata_value) &
            (array_y_t != nodata_value) &
            (array_x_t_minus_1 != nodata_value) &
            (array_y_t_minus_1 != nodata_value)
        )

        # --- Memory-Efficient Calculation ---
        # Calculate change in each series directly into int16 arrays
        change_x = np.subtract(array_x_t, array_x_t_minus_1, dtype=np.int16)
        change_y = np.subtract(array_y_t, array_y_t_minus_1, dtype=np.int16)

        # Calculate the difference between the changes for the interval
        difference_of_changes = np.subtract(change_y, change_x, dtype=np.int16)

        # Accumulate the result in-place for memory efficiency
        np.add(
            En_map,
            difference_of_changes,
            out=En_map,
            where=valid_mask
        )
        # --- End of Memory-Efficient Calculation ---

        final_nodata_mask &= ~valid_mask

    # Apply the NoData value to pixels that were never valid
    En_map[final_nodata_mask] = nodata_value

    print("\n ✅Pixel-wise calculations complete.")

# ==============================================================================
# 3. Save the final raster map
# ==============================================================================

if En_map is not None:
    # Update the profile for the output data type and add compression
    profile.update(
        dtype=rasterio.float32,
        nodata=nodata_value,
        compress='lzw'
    )

    # Define the output filename and path
    output_filename_map = f'change_difference_{class_name}.tif'
    final_map_path = os.path.join(
        output_path,
```

```python
        output_filename_map
    )

    print(f"\nSaving final map to: {final_map_path}")

    with rasterio.open(final_map_path, 'w', **profile) as dst:
        dst.write(En_map, 1)

    print("✅ Successfully saved the Change Difference map.")
```

```
Starting calculation for Change Difference Map...
Accumulator map initialized with dimensions: 22568x21911.

Starting pixel-wise calculation for each time interval...
Processing interval: 2010-2012...
Processing interval: 2012-2014...
Processing interval: 2014-2016...
Processing interval: 2016-2018...
Processing interval: 2018-2021...

 ✅Pixel-wise calculations complete.

Saving final map to: C:\Temp\PIE\output\change_difference_PIE.tif
✅ Successfully saved the Change Difference map.
```

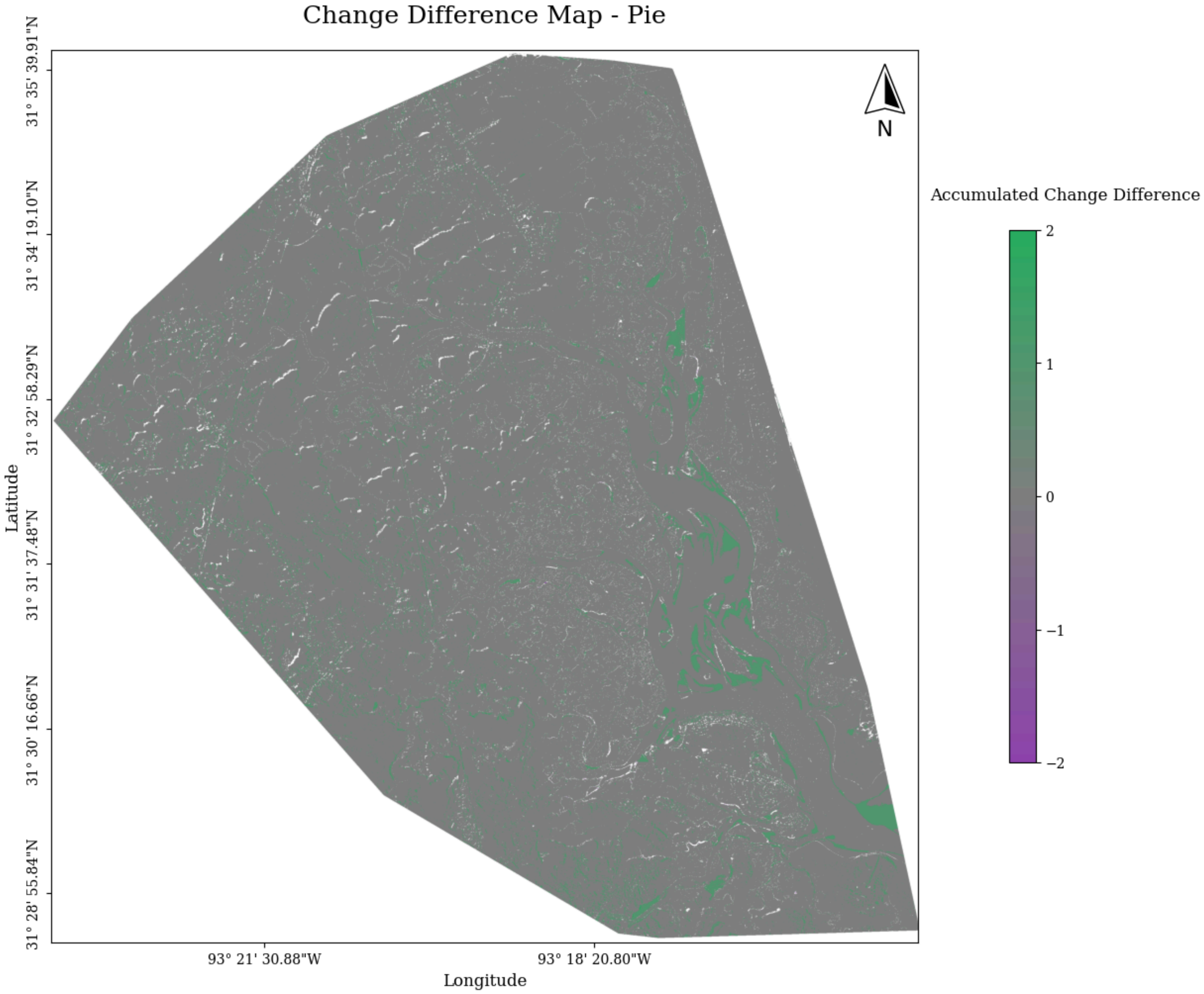
In [6]:

```python
# ==============================================================================
# 1. Prepare data and metadata for plotting
# ==============================================================================
print("Generating the Change Difference map visualization...")

# Define the path to the raster file created in the previous cell
input_map_filename = f'change_difference_{class_name}.tif'
input_map_path = os.path.join(
    output_path,
    input_map_filename
)

# Define a scale factor to downsample the raster for efficient plotting
scale_factor = 0.15

with rasterio.open(input_map_path) as src:
    # Get spatial metadata from the source file
    bounds = src.bounds
    src_crs = src.crs
    transform = src.transform
    transformer = Transformer.from_crs(src_crs, "EPSG:4326", always_xy=True)

    # Read the data, downsampling it for visualization
    data = src.read(
        1,
        out_shape=(
            int(src.height * scale_factor),
            int(src.width * scale_factor)
        ),
        resampling=Resampling.nearest
    )

    # Mask the NoData values
    masked_map = np.ma.masked_equal(data, nodata_value)

# ==============================================================================
# 2. Setup custom diverging colormap
# ==============================================================================

# Create a custom diverging colormap: Purple -> Gray -> Green
colors = [
```

```python
    "#8e44ad",
    "gray",
    "#27ae60"
    ]
cmap = mcolors.LinearSegmentedColormap.from_list("custom_div_cmap", colors)

# Set the color for NoData (masked values) to white
cmap.set_bad(color='white')

# Find the maximum absolute value to center the colormap on zero
max_abs_val = np.ma.max(np.abs(masked_map))
norm = mcolors.Normalize(vmin=-max_abs_val, vmax=max_abs_val)

# ============================================================================
# 3. generate the plot
# ============================================================================

# --- Tick formatting functions (Degrees, Minutes, Seconds) ---
def format_x_ticks(x, pos):
    lon, _ = transformer.transform(x, bounds.bottom)
    deg = int(abs(lon))
    min_val = int((abs(lon) - deg) * 60)
    sec = ((abs(lon) - deg) * 60 - min_val) * 60
    return f"{deg}° {min_val}' {sec:.2f}\"" + ("E" if lon >= 0 else "W")

def format_y_ticks(y, pos):
    _, lat = transformer.transform(bounds.left, y)
    deg = int(abs(lat))
    min_val = int((abs(lat) - deg) * 60)
    sec = ((abs(lat) - deg) * 60 - min_val) * 60
    return f"{deg}° {min_val}' {sec:.2f}\"" + ("N" if lat >= 0 else "S")

# --- Create the figure ---
fig, ax = plt.subplots(
    figsize=(14, 12)
)
mpl.rcParams['font.family'] = 'serif'

# --- Plot the raster image ---
im = ax.imshow(
    masked_map,
    cmap=cmap,
    norm=norm,
    extent=[bounds.left, bounds.right, bounds.bottom, bounds.top]
)

# --- Format axes and ticks ---
ax.xaxis.set_major_formatter(FuncFormatter(format_x_ticks))
ax.yaxis.set_major_formatter(FuncFormatter(format_y_ticks))
ax.xaxis.set_major_locator(plt.MaxNLocator(3))
ax.yaxis.set_major_locator(plt.MaxNLocator(6))
ax.tick_params(
    axis='x', which='major', labelsize=10, pad=4
)
ax.tick_params(
    axis='y', which='major', labelsize=10, pad=4
)
plt.setp(
    ax.get_yticklabels(),
    rotation=90,
    va='center'
)

# --- Add cartographic elements ---
north_arrow(
    ax,
```

```
    location="upper right",
    rotation={"degrees": 0},
    shadow=False
)

# scalebar = ScaleBar(
#     1/1000,
#     units='km',
#     length_fraction=0.4,
#     location='lower right',
#     scale_formatter=lambda value, _: f"{int(value)} km"
# )
# ax.add_artist(scalebar)

# --- Create the continuous color bar ---
cbar = fig.colorbar(
    im,
    ax=ax,
    orientation='vertical',
    fraction=0.046,
    pad=0.09, # Increased padding to avoid overlap
    shrink=0.5
)
cbar.set_label(
    'Accumulated Change Difference',
    fontsize=12,
    rotation=0,
    y=1.08,
    labelpad=0
)
vmin = norm.vmin
vmax = norm.vmax
ticks = np.arange(int(np.ceil(vmin)), int(np.floor(vmax)) + 1)
cbar.set_ticks(ticks)

# --- Final styling and saving ---
ax.set_aspect('equal')
ax.set_title(
    f'Change Difference Map - {class_name.capitalize()}',
    fontsize=18,
    pad=20
)
ax.set_xlabel(
    'Longitude',
    fontsize=12
)
ax.set_ylabel(
    'Latitude',
    fontsize=12
)

plt.tight_layout(rect=[0, 0, 0.85, 1])

output_plot_filename = f'change_difference_{class_name}_map.png'
final_plot_path = os.path.join(output_path, output_plot_filename)

plt.savefig(
    final_plot_path,
    dpi=300,
    bbox_inches='tight'
)

plt.show()

print(f"\n✅ Map visualization saved to: {final_plot_path}")
```

```
Generating the Change Difference map visualization...
```




```
✅ Map visualization saved to: C:\Temp\PIE\output\change_difference_PIE_map.png
```